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ECOSYSTEM-BASED ADAPTATION PRACTICES FOR SMALLHOLDER FARMERS' CLIMATE RESILIENCE IN MABALANE DISTRICT

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A Dissertation Submitted to the Department of Economics and Agrarian Development in Partial Fulfilment of the Requirements for the Award of the Master's Degree in Climate Change in Agrarian Systems

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DECLARATION OF ORIGINALITY

I do here by declaring that, this dissertation titled ''Ecosystem-based Adaptation Practices for Smallholder Farmers' Climate Resilience in Mabalane District'' is my own original work. It has not been submitted for the purpose of obtaining any degree or examination at any other university. All sources of information used in this research work have been duly acknowledged.

Signature: __________________ Date: ______________________

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APPROVAL

I, the undersigned, confirm that the dissertation entitled: ‘‘Ecosystem-based Adaptation Practices for Smallholder Farmers’ Climate Resilience in Mabalane District’’, submitted by Claudius Patrick Taban Waran, is the original research work of the candidate and was carried out under my supervision. I approve it for submission to the post graduate office in partial fulfilment of the requirements for the award of Master’s Degree in Climate Change in Agrarian Systems.

Supervisor

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ABSTRACT

Ecosystem-based adaptation practices emerged as a sustainable strategy for enhancing smallholder farmers' climate resilience, particularly in drought-prone areas where declining crop yields threaten livelihoods and food security. However, limited research has examined smallholder farmers' perceptions of the effectiveness and co-benefits of ecosystem-based adaptation practices. This study investigated the perceived effectiveness of ecosystem-based adaptation practices, co-benefits smallholder farmers derived at farm-level, and their influence on adoption decisions among smallholder farmers. A mixed method approach was employed, combining a one-time household survey of 360 farm household heads conducted between 11 September and 11 October 2025 with focus group discussions and key informant interviews in the Mabalane district. The findings identified mixed cropping (83.9%), integrated crop-livestock management (57.2%), and mulch tillage (51.1%) as the most widely adopted ecosystem-based adaptation practices. Smallholder farmers perceived these practices as effective primarily because of their visible contributions to improved soil fertility, soil moisture content, crop productivity, and food security. Additionally, multiple ecological and socio-economic co-benefits, including erosion control, pest regulation, enhanced agrobiodiversity, and income diversification were reported. Although the study revealed statistically significant relationships between ecosystem-based adaptation practices and the perceived co-benefits, these co-benefits were not statistically significant associated with an increase in the number of adopted practices. The results suggest that while perceived effectiveness and co-benefits reinforce the value of ecosystem-based adaptation practices, adoption decisions among smallholder farmers were not driven by the perceived axillary benefits derived from ecosystem-based adaptation practices alone, but a broader set of factors, including enabling conditions and resource endowments.

Therefore, it is concluded that, the predominance of three main ecosystem-based adaptation practices in the study area reflects their compatibility with traditional farming systems and their direct contributions in strengthening local climate resilience.

Keywords: climate change, ecosystem-based adaptation, effectiveness, resilience

RESUMO

As práticas de adaptação baseadas nos ecossistemas têm emergido como uma estratégia sustentável para aumentar a resiliência climática dos pequenos agricultores, particularmente em áreas propensas à seca, onde o declíneo da produtividade agrícola ameaça os meios de subsistência e a segurança alimentar. No entanto, poucas pesquisas examinaram as perceções dos pequenos agricultores sobre a eficácia e os benefícios colaterais das práticas de adaptação baseadas nos ecossistemas. Este estudo investigou a eficácia destas práticas percebidapelos pequenos produtores, os benefícios colaterais obtidos nas suas parcelas (machambas) e a sua influência nas decisões de adopção. Foi empregue uma abordagem mista, combinando um inquérito a 360 agregados familiares , com enfoque para os chefes de famílias agrícolas, realizado entre 11 de Setembro e 11 de Outubro de 2025, com discussões em grupos focais e entrevistas com informantes-chave no distrito de Mabalane. Os resultados identificaram o cultivo consorciado (83,9%), o maneio integrado das culturas e da pecuária (57,2%) e o cultivo com cobertura morta (51,1%) como as práticas de adaptação baseadas nos ecossistemas mais amplamente adoptadas. Os pequenos agricultores percebem estas práticas como eficazes principalmente devido às suas contribuições visíveis para a melhoria da fertilidade do solo, do teor de humidade do solo, da produtividade agrícola e da segurança alimentar. Além disso, foram relatados múltiplos benefícios ecológicos e socioeconómicos, incluindo o controlo da erosão, a regulação de pragas, o aumento da agrobiodiversidade e a diversificação do rendimento. Embora o estudo tenha revelado relações estatisticamente significativas entre as práticas de adaptação baseadas nos ecossistemas e os benefícios percebidos, estes benefícios não apresentaram uma associação estatisticamente significativa com o aumento do número de práticas adoptadas. Os resultados sugerem que, embora a eficácia e os benefícios percebidos reforcem o valor das práticas de adaptação baseadas nos ecossistemas, as decisões de adopção entre os pequenos agricultores não foram apenas impulsionadas pelos benefícios indiretos percebidos derivados destas práticas, mas por um conjunto mais vasto de factores, incluindo condições favoráveis e recursos disponíveis.

Assim sendo, conclui-se que a predominância de três principais práticas de adaptação baseadas nos ecossistemas na área de estudo reflecte a sua compatibilidade com os sistemas agrícolas tradicionais e as suas contribuições directas para o reforço da resiliência climática local.

Palavras-chave: mudanças climáticas, adaptação baseada nos ecossistemas, eficácia, resiliência

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LIST OF ABBREVIATIONS

CBD	Convention on Biological Diversity
CE-AFSN	Centre of Excellence 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
PhD	Docter of Philosophy
RII	Relative Important Index
SCBD	Secretariate of the Convention on Biological Diversity
SDAE	Serviço Distrital de Actividades Económicas
WAI	Weighted Average Index

CHAPTER ONE

INTRODUCTION

1.1 Background

Climate change is a global growing threat that significantly impact agriculture and food security (Wiebe et al., 2018). The earth's average temperature has risen by 1.09°C between 2011 and 2020, surpassing the levels observed during the pre-industrial era (Zhang, 2023). The rise in temperature has contributed to climate change that negatively affect agriculture, an important sector in developed and developing economies (Nath & Behera, 2011). Agriculture contributes significantly to global Gross Domestic Product (GDP) varying from 4.18% in 2012 to 4.31% in 2021 in developed countries and above 25% in many least developed countries (Nugroho et al., 2023). Especially, in the region of sub-Sahara Africa, a country like Mozambique with estimated 32 million people rely heavily on agriculture as the basis of its economy, contributing to about 27.5% of the total Gross Domestic Product (GDP) where 4.3 million farmers operates in small scale level (Mondlhane et al., 2025). Small scale farmers manage the productive areas by practicing slash-and-burn, followed by 3 to 5 years of planting crops in the same area before shifting to a new area to allow the cultivated areas fallow due to low yield resulting from soil fertility depletion (Nhantumbo et al., 2009).

Due to the total dependency of the agricultural systems on rainfall as the only main source of water to produce crops in rural communities, changes in the rainfall patterns during growing seasons lead to agricultural water deficit that arises from both insufficient rainfall and soil water to sustain a high crop yield (Sanchi et al., 2021). Additionally, small-scale farmers cultivate marginal lands such as steep hillsides, poor soil and areas that are prone to flooding, landslides and droughts (Chapagain & Raizada, 2017). During the growing seasons, the daily amount of rainfall required for crops growth may not be consistent for number of days or weeks leading to dry spell events (Mohamed et al., 2023). A dry spell in the context of agriculture is defined as a sequence of dry days including days with rainfall less than 1 mm as threshold value during growing season (Chimimba et al., 2023). Whereas a drought is defined as a period of time experiencing significant reduction in precipitation below normal recorded levels, that result in hydrological imbalances causing severe impacts on land resource production systems (Haile et al., 2020). Dry spell is different from drought in terms of duration, intensity and impact on crops. A dry spell can evolve into a drought if it persists long enough to cause significant water shortages and impacts (Sanchi et al., 2021). All droughts begin with a dry spell; however, not all dry spells escalate into droughts. This means that when rainfall deficits persist for weeks or months, they initiate a cascade of hydrological and socio-economic impacts. Initially, reduced precipitation lowers soil moisture availability, limiting water accessibility to crops and natural vegetation. As the deficit continues, river discharge decreases, groundwater recharge weakens, and reservoir storage declines, eventually leading to hydrological drought (Araneda-cabrera, 2021).

Hydrological drought develops more slowly than meteorological or agricultural drought because rivers, reservoirs, aquifers respond gradually to prolonged precipitation deficits. The delay response reflects the time required for reduced rainfall to affect surface and subsurface water resources. Consequently, prolonged dry condition can substantially diminish water availability for domestic use, livestock, irrigation and ecosystems functions. If hydrological drought persists, its impacts extend beyond the physical environment and begin to affect human livelihoods and economic activities, resulting in socio-economic drought (Jason, 2020). In southern Mozambique, where most rural households depend on rain-fed agriculture and livestock production, prolonged dry spells and subsequent drought can reduce crop yield, increase food insecurity, lower household income, and intensify poverty. These impacts are particularly severe in arid and semi-arid districts such as Mabalane where community already experienced chronic water stress and have limited adaptive capacity (Milgroom & Giller, 2013).

Therefore, the progression from a simple dry spell to a socio-economic drought depends on the duration, severity, and spatial extent of rainfall deficits, as well as the vulnerability and resilience of affected communities (Arndt & Strzepeck, 2011).

In southern Mozambique, drought development follows a cascading process: a dry spell caused by rainfall interruption may evolve into a meteorological drought characterized by a persistent precipitation deficit. Continued rainfall shortages then lead to agricultural drought through soil moisture depletion and crop water stress. As water deficits accumulate, hydrological drought emerges through reduced river flows, reservoir levels, and groundwater availability. Ultimately, when these water shortages disrupt food production, water supply, livelihoods, and economic impact activities, socio-economic drought occurs (Araneda-cabrera, 2021).

This cascading sequence explains why all major droughts originate from dry spell necessarily develops into severe hydrological or socio-economic drought. If rainfall resumes sufficiently early, soil moisture can recover, crops may survive critical growth stages, and hydrological systems can replenish before significant hydrological and socio-economic impacts occur (Odete et al., 2016).

The severity of the impacts of dry spells and droughts on crop growth largely depend on agroecological condition particularly the antecedent soil moisture content and the growth stage (Barron et al., 2003). In this context, understanding the agroecological characteristics of the country is very crucial.

Mozambique is divided into three agroecological characteristics such as the sub-humid north, sub-humid centre including humid highlands, and the southern semi-arid region (Mondlhane et al., 2025). The southern region is characterized by the Miombo woodland ecosystem on the coast transitioning to arid-eutrophic savannah in inland areas (Mondlhane et al., 2025). The southern region is the driest with soils predominantly composed of sand material and semi-arid areas receive rainfall from 616 mm to 766 mm per annum. The rainfall pattern shows a strong seasonal distribution with more than 80% falling in the warm and wet season (Araneda-Cabrera et al., 2021). Additionally, potential evapotranspiration in the southern region ranges from 1000 to 1300 mm per year largely exceeds precipitation level (de Sousa et al., 2017). Frequent drought is also a critical issue with occurrences in seven out of ten years (Baez et al., 2020). The recurrent droughts, high evapotranspiration and the fragile soils heighten the vulnerability of agricultural systems under rainfed conditions in the country. Such climatic imbalances represents a very high risk of crop failure more than 50% under rainfed cropping systems in the semi-arid areas across the southern region (Nhantumbo et al., 2021).

Therefore, amidst the many constraints, smallholder farmers try out various actions and innovations to enhance their resilience and adaptation. Adaptation is defined as an initiative and measure aimed at reducing the vulnerability of nature and human systems against actual or expected effects of climate change (IPCC, 2014). The smallholder farmers may therefore opt for adaptation strategies such as irrigation, the use of early-maturing and drought resistance crop varieties, shift planting dates, use of inorganic fertilizers among others (Nelson et al., 2022). However, such adaptation strategies are limited in terms of costs and sustainable ecosystem management (Nanfuka et al., 2020).

Research studies conducted in various countries across Latin America, sub-Sahara Africa and Asia revealed that, one effective method to 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 (Mburu et al., 2016). Ecosystem-based adaptation in the context of agriculture is defined 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 variabilities (Vignola et al., 2015). In this study, the concepts of climate change and climate variabilities are treated as distinct phenomena and are therefore not used interchangeably although they are closely related concepts. Climate change refers to a long-term and alterations persistent in average weather patterns, typically occurring over a period of 30 years or more. These changes may manifest through shifts in temperature, precipitation and the frequency or intensity of extreme weather events. In contrast, climate variability refers to short-term fluctuations in climatic conditions that occur around the long-term average climate. Such fluctuations including events such as dry spells, droughts, floods and El Nino episode, which may occur over seasonal, annual, or interannual timescales (IPCC, 2023).

A review and strategies proposal by Mondlhane et al. (2025) on sustainable agricultural alternatives to cope with drought effects in semi-arid areas of southern Mozambique pointed out conservation agriculture as one of the best and most promising solution for smallholder farmers in the southern region of the country under three principles (1) minimal soil disturbance, (2) crop residue retention, and (3) crop diversification via crop rotation or intercropping. The above principle can ultimately result in the reduction of soil erosion, the improvement of water use efficiency, and regulation of the upper soil temperature among other beneficial effects. For instance, maize is the most cultivated crop in the southern region of Mozambique, the use of maize stover to cover the soil surface can be an advantage due to its availability, and it can be used as mulching. Another common practices used also include diversification of crops by rotation with cereals and legumes such as cowpea and peanut or cereals-legume intercropping, as these strategies provide insurance against environmental fluctuations, since the different species occupy different niches and respond in different manners to change (Zakir et al., 2023).

As such, ecosystem-based adaptation practices are well-suited for smallholder farmers in sub-Sahara Africa due to their cost-effectiveness, alignment with traditional knowledge and capacity to enhance resilience against climatic variabilities (Nagabhooshanam et al., 2024).

1.2 Problem statement

Smallholder farmers who rely on rainfed subsistence agriculture face deleterious effects of changes in rainfall patterns during growing seasons (Cooper et al., 2008). Dry spells caused by late onset (delayed November rains) and early cessation (lack of February – March rains) is a critical issue that heightened droughts impacts on crop yields among the rainfed farming communities in Mozambique (Baez et al., 2020). The 2001/2002 main season was characterized by irregular and insufficient rains in the southern and central regions, rains started in October, then stopped briefly and resumed in November-December and then ceased completely in January (Takele et al., 2023). There was virtually no rain in the southern region from January to March, resulting to poor grain-filling in maize, with around 60,000 hectors yielding less than 10% of typical output (FAO, 2014). Additionally, during the 2015 – 2016 El-Nino event across southern Africa, the southern and central regions of Mozambique also experienced severe drought conditions that caused significant reduction in maize yields by 20%-30% affecting the staple crop for the majority of the population. The large proportion of maize failure was due to the irregular rainfall patterns that resulted in a delayed onset and early cessation of rains during the growing season (Rembold et al., 2016). Consequently, smallholder farmers got poor harvest that negatively affected their households' livelihood and food security.

To mitigate the negative effects of dry spells and droughts on crop yield, diversified agro-ecological approaches such as the use of local tree species as crop cover, agroforestry, inclusion of perennial crops in agriculture field can exhibit higher and more stable crop yields compared to conventional monoculture systems (Borsari, 2020). A study conducted by Kuyah et al. (2016) in Kenya found that, maize yields on farms using integrated soil fertility management and agroforestry were 20-30% higher than on nearby conventional farms during a severe drought. The maize yield increases due to improved microclimate, nutrient cycle and soil fertility under different ecosystem-based adaptation practices. Favourable alteration of microclimatic conditions results in increased growth and yield of crops due to reduced temperature and evapotranspiration (Kuyah et al., 2021).

Although EbA practices have been widely recognized in studies across Latin America, Sub-Saharan Africa, Asia as effective strategies for climate change adaptation, limited research has examined their effectiveness at farm-level from the perspective of smallholder farmers. As a result, existing knowledge is largely based on scientific and policy-oriented assessments, with insufficient attention given to smallholder farmers' lived experiences and perceptions. This limitation creates a potential gap that may hinder a comprehensive understanding of the practical effectiveness, benefits and challenges of EbA practices interventions, thereby creating a disconnect between scientific evidence and the realities faced by smallholder farming communities.

Therefore, this study aims to evaluate the effectiveness of locally implemented ecosystem-based adaptation practices in enhancing smallholder farmers' resilience to dry spells within their farming systems.

1.3 Study objectives

1.3.1 General objective

The general objective was to evaluate the perceived effectiveness of the ecosystem-based adaptation practices in mitigating the negative effects of dry spells on crop yields.

1.3.2 Specific objectives

1. To identify the ecosystem-based practices used by smallholder farmers as adaptation strategy at farm level.
2. To assess the perceived effectiveness of roles of the ecosystem-based practices in mitigating the negative effects of dry spells on crop yield.
3. To examine the relationship between the perceived co-benefits and the adopted ecosystem-based adaptation practices.
4. To determine how perceived co-benefits influence adoption intensity of EbA practices among smallholder farmers.

1.4 Significance of the study

The findings of this study broaden our understanding of how locally adopted ecosystem-based adaptation practices enhance smallholder farmers' resilience and adaptive capacity to dry spells in their farming systems. Furthermore, the study provides a comprehensive perspective on the effectiveness of locally adopted ecosystem-based adaptation practices in sustaining and optimizing production within rainfed farming systems, while also offering insights into the perceived co-benefits that influence the adoption of ecosystem-based adaptation practices at farm level. These findings provide policymakers and development actors with evidence-based information grounded in smallholder farmers' local knowledge and lived experiences. This evidence can serve as a framework for designing context-specific and farmers' centred strategies aimed at strengthening climate resilience through the promotion of sustainable, low cost, and locally tailored solutions drawn from smallholder farmers' practical realities.

1.5 Brief methodological overview

The study adopted a mixed-methods approach combining quantitative and qualitative techniques to examine local ecosystem-based adaptation strategies among smallholder farmers. A cross-sectional research design was employed, targeting a sample size of 360 smallholder farmers derived from Cochran's formula for sample size of finite population. Data were collected using structured questionnaires, that allow participants to provide additional information where necessary, as well as through key informant interviews, and gender-specific focus group discussions. Quantitative data were analysed using Descriptive Statistics, Correspondence Factorial Analysis, Principal Axis Factoring, and Negative Binomial regression in SPSS, while qualitative data were analysed using thematic analysis to identify key patterns and narratives regarding climate adaptation strategies. The quantitative and qualitative datasets were analysed separately and subsequently integrated during interpretation stage. This process involved comparing and synthesizing findings from both datasets to identify areas of convergence, complementarity, and divergence. The integrated interpretation enabled the development of meta-inferences providing a more comprehensive understanding of the research phenomenon by combining statistical evidence with participants' experiences and perspectives.

1.6 Structure of the dissertation

This dissertation is structured into six chapters. Chapter one introduces the study by presenting the background, problem statement, research objectives, the significance of the study, brief methodological overview and the structure of the dissertation. Chapter two defines the key concept and reviews relevant literature and theoretical perspectives related to smallholder farming, climate resilience and adaptive strategies in mitigating the negative effects of dry spells on crop yields. Chapter three outlines the research methodology which includes the study area, sample design, data collection methods, data analysis procedures, ethical considerations and the limitations of the study. Chapter four presents a summary of the findings drawn from the two published articles that constitute this dissertation and are included as appendices IV and V of the dissertation. The first article addressed specific objective one and two by identifying the ecosystem-based adaptation practices adopted by smallholder farmers at farm level as adaptation strategies to mitigate the negative effects of dry spells on crop yields. The first article further evaluated the perceived effectiveness of the identified practices and assessed the importance of their associated co-benefits in the farming system. The second article corresponds to specific objective three and four and explored the relationship between the perceived co-benefits and the adopted EbA practices. In addition, it examined the extent to which the perceived co-benefits influence the adoption intensity of these practices among smallholder farmers. Chapter five provides an integrative discussion of the overall research findings in relation to the study objectives and existing literature. Chapter six synthesizes the key findings of the study, draws relevant conclusions and proposes recommendations for policy development and future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of the concept of ecosystem-based adaptation (EbA): Origin, evolution and adaptation

The concept of ecosystem-based adaptation was derived from the concept of ecosystem that evolved from the field of ecology into one of the most fundamental ideas used to manage environmental problems (Dong-Uuro & Peprah, 2024). The concept of ecosystem-based adaptation is focused on the premise that ecosystem services are crucial to help people adapt to climate change (Secretariat of the Convention on Biological Diversity, 2009). Ecosystem services is recognized for its adaptation benefits, where well-managed ecosystems have greater potentials to adopt, resist and recover more easily from extreme weather events, and also provide a range of benefits on which people depend (Uy & Shaw, 2012).

The concept of ecosystem-based adaptation was defined in several ways, in 2009, the concept 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" (Secretariat of the Convention on Biological Diversity, 2009). This definition was revised by the Convention on Biological Diversity in 2010 to make it more holistic by referring to the concept of ecosystem-based adaptation as a sustainable management, conservation and restoration of ecosystems as part of an overall adaptation strategy that takes into account multiple social, economic and cultural co-benefits for local communities (Ladekjær & Funder, 2021).

The above altered definition was based on three adaptation approaches focusing on "human well-being"; "ecosystem management, conservation, restoration"; and "climate change adaptation" that include the restoration of mangroves to shield them against storm and sea-level rises, the management of water sheds against droughts and flooding, the management of range lands to inhibit desertification and land degradation and more sustainably managed fisheries and forestry to address food insecurity (Chong, 2014). These three adaptation approaches distinguish ecosystem-based adaptation from some forms of community-based adaptation that has specific goal, for example, introducing improved crop varieties to the rural farming communities focuses on immediate community needs such as increasing yields while taking limited consideration on the potential long-term impacts on the ecosystem.

However, for this study, we adopt Vignola et al. (2015) definition of the concept of ecosystem-based adaptation in the context of 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 variabilities. The definition according to Vignola et al. (2015) expanded the revised definition by the Convention on biological Diversity in 2010 to encompass both human and natural systems to incorporate managed ecosystems such as plot, farm, landscape and integrating social, economic, and institutional dimensions for a more holistic approach to reduce vulnerability. Vignola et al. (2015) definition agrees with the concept that ecosystem-based management practice is beneficial for farmers at both landscape and on-farm level (Dong-Uuro & Peprah, 2024).

Most drought mitigation strategies that are traditionally implemented by smallholder farmers are ecosystem-based (Dorren & Schwarz, 2016). Sustainable agricultural practices that are locally adopted strengthen ecosystem functioning to address challenges such as land degradation, food insecurity and lack of access to agricultural inputs (Mabhaudhi et al., 2022).

The potentials in the local adaptation reduce agro-ecosystem (croplands, rangelands, agro-forests etc..) susceptibility to droughts risks and increase preparedness through diversification of agricultural production. Through these sustainable ecosystem services, the nature's capacity is being utilized to buffer farming communities from the adverse impacts of climate change and natural hazards (Dinesh, 2016).

There are more similarities between the two concepts of Eco-Disaster Risk Reduction (Eco-DDR) and Ecosystem-based Adaptation (EbA) than divergence in addressing climate-related hazards (Whelchel & Beck, 2016). The benefits both approaches provide are beyond disaster risk reduction and climate change adaptation functions. Both concepts emphasize on sustainable use of biodiversity and ecosystem services to restore degraded/transformed agro-systems. Importantly, Eco-DRR and EbA when compared to other conventional disaster risk reduction strategies such as dams and dikes, they stress the generation of economic, social and environmental benefits (Dong-Uuro & Peprah, 2024). Landscape is very important for ecosystem-based disaster risk reduction and climate change adaptation. Decisions on land use changes need to be informed by the flow of ecosystem services at the landscape scale (Vignola et al., 2017). The multifunctional approach supports the idea that ecosystem services flow needs to be managed at multiple scales and integrate ecological principles at field, farm and landscape scale (McGranahan, 2014). Ecosystem-based approaches do not necessarily focus on measures themselves, but also on how to best combine them at the field, farm and landscape levels to maximize disaster risk reduction, climate change adaptation and development objectives. Some approaches target the landscape level, while others are farm or field level, but can be of landscape level approaches (Dong-Uuro & Peprah, 2024).

Depending on the type of hazards to be addressed, the two concepts vary in terms of their scope and methodology. Ecosystem-based disaster risk reduction deals with immediate risk and disaster for instance earthquake, and ecosystem-based adaptation addresses natural hazards associated to climate change. The timeline for the underlying analysis is a more nuanced distinction that will affect the kind of approach metric used. Therefore, it is necessary to consider long-term changes in the frequency and intensity of anticipated future effects of climate change such as slow-onset events for a successful planning of ecosystem-based adaptation.

Table 1: Definitions of the concept of EbA according to various authors

S/N	Source	Definition	Strength	Limitation
1	CBD (2010)	The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change.	Clear, concise and widely accepted internationally. Strong emphasis on biodiversity and ecosystem services. Aligns well with conservation goals.	Narrow focus on helping people adopt, less attention to ecosystem resilience. Limited integration of social, economic or institutional aspects.
2	Locatelli et al., (2011)	An approach that integrates the use of ecosystem services into an overall adaptation strategy recognizing the multifunctional role of ecosystems for both people and the environment.	Recognizes dual benefits for people and ecosystems. Emphasises integration into broader adaptation strategies. Acknowledges multifunctionality of ecosystems.	More conceptual, less guidance on implementation. May be harder to apply without further operational farming.
3	IUCN (2012)	The use of biodiversity and ecosystem services to help people adapt to the adverse effects of climate change which includes the sustainable management, conservation and restoration ecosystems to provide services that help people adapt.	Emphasizes sustainable ecosystem management. Links adaptation with ecosystem restoration and conservation. Operational focus for project implementation.	Largely human centred Less explicit inclusion of broader socio-economic or institutional systems.
4	Vignola et al., (2015)	The use of natural or managed ecosystems to enhance resilience and reduce vulnerability of human and natural ecosystems to the impacts of climate change, integrating social, economic and institutional dimensions.	Holistic and inclusive. Recognises managed ecosystems (e.g farms). Explicitly integrates social, economic and institutional factors.	Broader scope may reduce ecological focus. Less direct guidance on operational implementation.

2.2 The effects of droughts on agro-ecosystems

In sub-Sahara Africa, the timing of agricultural activities in relation to rainfall pattern is crucial since the region is known for its seasonal rainfall patterns and rainfed agriculture systems. Dry spells which are predicted to intensify in the eastern and southern region of Africa in the future differ from droughts. Dry spells are defined as rainfall deficiencies over a period of several weeks during the growing season (Hettiarachchi et al., 2022). According to Haile et al. (2020), drought is defined as a period of time when precipitation considerably below average level, resulting in a major hydrological imbalance that negatively impact land resource production systems. Generally, droughts are categorized according to how they develop and the type of impacts they cause (Sanchi et al., 2021).

Meteorological drought occurs due to prolong period of lower precipitation than normal causing large swath of parched and cracked earth. Agricultural dry spells are occasioned by agricultural tendencies when available water supplies are insufficient for crops or livestock at a particular time. This type of drought can stem from meteorological droughts, reduced access to water supplies or supply poor timing. Hydrological drought happens when a prolonged absence of precipitation causes a severe, long-term depletion of surface and ground water supplies which is manifested by a critically low flow in rivers and diminished storage in reservoirs (Van Loon, 2015). Socio-economic drought is characterized by reduced precipitation and water availability affecting human activities. Human activities are associated to this form of drought where elements of meteorological, agricultural and hydrological drought become evidence when drought affects health, the well-being and the community quality of life (Wilhite & Glantz, 1985). The impact of any type of drought or dry spells is very much dependent on its length, timing and frequency in addition to its severity, intensity, magnitude and areal extend (Dorren & Schwarz, 2016) and simultaneously on the vulnerability of exposed system. Hence, drought can impact a range of ecosystem services and reduce the capacity of agro-ecosystems to provide the benefits on which people depend. Provisioning services are negatively impacted, resulting in reduced productivity of agro-ecosystems, services such as fresh water quality and quantity regulation, soil and cultural services. Biodiversity can negatively be impacted to increase the likelihood of other potentially hazardous events such as wild fires. For agricultural droughts, the distribution of rainfall in relation to crop requirements matters more than total seasonal rainfall. The impacts of agricultural dry spells depend very much on critical plant growth stages. Plants which have already been impacted by previous water shortages show a reduced capacity to take up water in the root zone (Falkenmark & Rockström, 2008). Soil condition such as water holding capacity and water infiltration, have an impact on the manifestation of an agricultural dry spells, as they directly affect soil moisture content. Plants conditions in particular water uptake capacity, further determine the degree of plant water stress and eventually yield reductions. In order to mitigate the impacts of agricultural dry spells, the most direct entry point is an integrated agricultural management of water, soils and crops. According to Falkenmark & Rockström, (2008) agricultural dry spells can be strongly influenced by existing management practices related to water soils and crops. Building resilience to droughts therefore depends on increasing the ability to implement these management practices optimally for drought risk reduction (Rockström, 2003). This is a crucial angle of ecosystem-based approaches to address. Approaches that strengthen resilience to droughts need to reduce the susceptibility of social ecological system to drought impacts, for instance, through improving the water holding capacity of soil, or through crop diversification to balance crop water requirements. Such measures can simultaneously improve the resilience and sustainability of rural livelihoods, for example through increased yields, income and food stocks.

2.3. The effects of dry spells on crop yield and performance

Climate change manifest itself through recurrent dry spells that often co-occur with heat waves and longer-term agricultural drought. The effects are manifested by existing drought, aridity and heat waves. Co-stressor such as longer-term water stress and heat waves may influence the effects of dry spells on crop production (Jarrett et al., 2023). Extreme heat can be detrimental to crops whether occurring for a single day or several in a raw during a heat wave (Schmitt et al., 2022). Plant ecophysiology suggests that dry spells and extreme heat could have a compounding effect, whether they coincide or one precedes the other (Lesk et al., 2022). The effects of an additional day in a dry spell at least 28 days long have a significant negative effects of extended dry spells days, the minimum duration of dry spells is shorter (7, 14 or 21 days) or longer (35days) have a negative effect on crop yield (Chimimba et al., 2023). Extended dry spell days are more damaging when they occur in locations that are experiencing annual water deficits or are arid compare to when they occur in aggregate crop production where they exhibit a modest average direct effect and the effects vary with the presence of other stressors (Dorren & Schwarz, 2016). According to Malvern et al. (2012), dry spells lengths of 7 days can stress shallow rooted crops, 10 days to medium rooted crops, 15 days to deep rooted crops and for 20 or more days almost all crops are affected. Shiferaw et al. (2014), stated that, the effects of dry spells lasting 2-4 weeks on sorghum and millet during the critical flowering stage can reduce yield by 30-50% and longer dry spells of 4-8 weeks can significantly reduce yield up to 80%. Similarly, a study conducted by Adebayo et al. (2018) in semi-arid area in northern Nigeria under two dry spell parameters (10 days dry spells in August and total dry spells during the growing season) that were identified as being critical to the yield of crops examined the impact of pentad dry spells on yield of maize, millet, sorghum, groundnuts and cowpea. The study revealed that, the recurrent pentad dry spells in all the months and total dry spells have significantly affected the yields of sorghum, groundnuts, and maize. Maize showed more sensitivity to dry spells than the other crops, while millet showed more tolerant to dry spells than the other crops. The two factors jointly accounted for about 74.1%, 21.5%, 52.9%, 51.4%, and 40.1% reduction in yields for the crops respectively.

2.4 Adaptation strategies to mitigate the negative effects of dry spells on crop yield

In dryland areas which cover more than half of sub-Sahara Africa, smallholder farmers have various copying and adaptive strategies to address the negative effects of droughts and dry spells on farming systems. Several scientific approaches have been employed to efficiently use water for agricultural productivity and the reduction of land degradation. In this case, ecosystem-based approaches are directly linked to agricultural activities and in the context of agricultural drought, ecosystem-based adaptation is referred to agricultural practices that maintain vegetative, shelter belts and green bells (Huettmann, 2018).

Taking into account the broader classes of approaches, resource-conserving agriculture and sustainable intensification have commonalities (Dorren & Schwarz, 2016) that aim to make the best use of natural resources and ecosystem services in a sustainable manner and to simultaneously promote social, environmental and health objectives while increasing productivities. Resource-conserving agriculture and sustainable intensification include measures such as , eco-agriculture, conservation agriculture, water harvesting, organic agriculture, integrated pest management amongst other that draw on, the capabilities of smallholder farmers to be innovative and manage land conservation through participatory methods of decision-making, implementation and capacity building (Kaimowitz et al., 2005).

A study conducted by Pretty et al. (2011) compiled evidence of many farmers in sub-Sahara Africa apply a wider range of approaches for sustainable intensification and found evidence of reduced soil erosion, increased resilient to climate-related shock such as droughts, increased soil carbon content, improved water productivity, reduced debt and production costs, livelihood diversification, and improved-food security at household level and income. These approaches fit into the criteria detailed in the framework developed by Vignola et al. (2015).

2.4.1 Organic agriculture practices

In order to sustain livelihoods in the context of sustainable development and vulnerability reduction, organic agriculture is often recognized as an effective approach (Illukpitiya & Khanal, 2016). The key strategies for organic agriculture include crop diversification and increasing organic soil matter (Seufert et al., 2018). Crop diversification contributes to a more efficient use of nutrients and water with multiple sowing dates for different crops, which could decrease the risk of crop failures due to dry spells and increase livelihood resilience by providing different crops at different point in time and fostering biodiversity (Dorren & Schwarz, 2016). On the other hand, organic cotton production directly enhanced climatic risk that households faced and contribute to reducing economic risk and women empowerment in the rural communities. However, the major obstacles remain the availability of sufficient organic material and the need for transport to the disposed fields which limits the adaptation potential (Kloos & Renaud, 2014).

The soil nutrients level is enhanced by improved organic matter and thus maintains and increases soil productivity. The water holding capacity of soil is also improved by the content of its organic matter such that water in the plant root zone is increased (Leenaars et al., 2015). Increased soil fertility and moisture content increases yield and net income as well other additional benefits which include improved food security, investments to improve housing conditions, school attendance of children and reduced migration (Eyhorn, Frank, 2007). Therefore, organic agriculture is tolerant to extreme weather events caused by climatic changes (G. Ravindra Chary*, K.P.R. Vittal, B. Venkateswarlu, P.K. Mishra, G.G.S.N. Rao, G. Pratibha, K.V. Rao, 2007).

2.4.2 Conservation agriculture practices

Conservation agriculture is an agro-ecological approach that aims to achieve sustainable and profitable intensification of agricultural system through the application of three interlinked principles, based on locally formulated practices such as minimal soil disturbance and permanent soil cover and crop rotation (Shrestha et al., 2020). The practice of conservation agriculture is increasingly promoted as a measure to address land degradation, mitigation of droughts and increase economic gross margin (Kassam et al., 2014). The permanent organic cover benefits the water balance and biological activity and contributes to the in-situ build-up of soil organic matter (Rana, 2009). Conservation agriculture helps the soil to retain its moisture content due to the permanent organic soil cover and over the recent decades it has gained recognition as an effective technology to mitigate the negative effects of irregular rainfall or dry spells and it includes approaches such as agroforestry, farmer-managed natural tree regeneration, conservation tillage, contouring, terracing and mulching (Jew et al., 2020). Therefore, conservation agriculture provides a viable means for strengthening resilience in agro-ecosystems and livelihoods that also advance adaptation goals.

2.4.3 Evergreen agriculture practices

Farmers practice evergreen agriculture in the face of climate change where conservation agriculture and agroforestry practices are combined in the same field. Such approach involves the integration of trees into cropping systems. Green vegetation cover is maintained throughout the year through the inter-cropped trees (Garrity et al., 2010). Integrating nitrogen-fixing trees increase nitrogen supply in the soil and organic matter that improves water infiltration and soil moisture retention capacity to enhance drought resistance. Garrity et al. (2010) reviewed four national cases where farmers are observed to be applying the principle of evergreen agriculture on a major scale. The first case was the experience in Zambia where conservation farming programs included the cultivation of food crops within an agroforest of the fertilizer tree *Faidherbia albida* and the second case was the Malawi agroforestry food security program which integrated the production of fertilizer tree, fruit, fuelwood and production of timber tree with food crops on small farms on a national scale. The third case included the dramatic expansion of *Faidherbia albida* agroforests in millet and sorghum production systems throughout Niger via assisted natural regeneration, and the fourth case was the development of a unique type of planting pit technology known as Zai along with farmer-managed regeneration of trees on a substantial scale in Burkina Faso. The conclusion drawn from the reviewed articles of the four case studies revealed that, the intercropped trees sustained a green cover on the land throughout the year to maintain vegetative soil cover bolster nutrients supply through nitrogen fixation and nutrient cycling. Additionally, the intercropped trees generated great quantities of organic matter on soil surface that improved soil structure and water infiltration, and also enhance carbon storage both above and below ground biodiversity. On the other hand, the practice also increased food productivity, fodder, fuel, fibre and income.

2.4.4 Agroforestry practices

Agroforestry systems encompass agrosilvicultural which include trees and crops, silvopostoral integrating trees and livestock, and agrosilvopastoral where trees, crops and livestock are all combine in one farming system. These approaches enable farmers to better withstand the adverse effects of climate change, enhance biodiversity, reduces erosion, and contributes to water and nutrient cycling (Bayala et al., 2019). Trees in the agroforestry system can provide a safety net during shocks by providing non-timber forest products when other resources are affected by the climatic impacts. Trees are recognised by multifunctional value they provide and the provisioning services such as food, fuel, fodder, medicines, wood and building materials for farmers and local population (Sinare et al., 2016). Additionally, regulating services such as microclimate regulation and ground water charging and supporting services are provided. In particular, soil carbon sequestration, nutrient cycling and reduced greenhouse gas emissions are supplied and the services are also recognised to contribute to soil fertility improvements and water conservation (Bayala et al., 2019). Farmers managed natural regeneration techniques can address the loss of traditional agroforestry to increase tree cover that help reduce the risk of food shortage in villages due to droughts or other climatic factors. When dealing with such complex agroforestry system, it is important to note the trade-off where trees are shown to yield multiple benefits in terms of micro-climate and soil fertility improvements, some questions remain about their effects on crop yields through competition for resources, depending on the crop-tree combinations (Bayala et al., 2019).

2.4.5 Integrated crop-livestock practices

In rainfed farming systems across sub-Sahara, integrated crop-livestock is one of the most common farming systems. The productivity and management of croplands, rangelands and livestock are closely linked via nutrient cycling, (for example grazing, fodder, manure) and income (availability, investment and storage) and labour (animal power) (Thornton & Herrero, 2015). Grazing livestock on crop residues in the farms transforms poor quality, bulky vegetation into products of high economic and nutritive value. The interdependency of crops and livestock provides opportunities for improving soil fertility by strengthening the complementary and reducing the competition to promote the sustainable intensification of agriculture. In this respect, efficient nutrient management, including the use of ruminant livestock, recycling, and the appropriate use of mineral fertilizers, possibly incorporating rotation with legumes are important options and the contributions of ruminant livestock are essential component of such a strategy.

A major contribution of livestock is their role as vectors in the transfer of nutrients across the landscape from rangeland to cropland (Powell et al., 1996; de Wit et al., 1997). Livestock contribute to soil organic matter and nutrients is in form of manure and urine which may be voided directly onto cropland, or collected from stall-fed animals. The transfer of nutrients from rangelands to cultivated fields by livestock provides the means for a redistribution of nutrients in time and space. The contribution of livestock to soil organic matter and nutrients is especially important to farmers in the dry savannas, where crop production is limited by the availability of nutrients particularly P and N, to the extent that at current levels, vegetative growth may actually utilize less than 15% of the available moisture (Bationo et al., 1998).

By leveraging the synergies between crop and livestock components, farmers can improve soil health, resource efficacy and farm productivity. Approaches to maintain and enhance the productivity of mixed crop-livestock systems require a thorough understanding of the socio-economic and biophysical components and interactions (Muzari, 2016). A balance of approach is needed to incorporate minimization of the risks associated with rainfall variability and dry spells through improved water productivity.

2.4.6 Rainwater harvesting practices

Rainwater harvesting is a technique of collecting runoff from rain for agricultural production purposes. The technique is categorized into macro-catchment systems and micro-catchment systems, and in-situ systems (Dile et al., 2013). Ex-situ harvesting systems have been shown to mitigate intra-seasonal dry spells and increase water availability that improved yields, while in-situ technique prevents soil erosion, increase nutrients deposition and organic matter there by improving soil fertility. According to Barron et al., (2010), these techniques are proved to increase soil water content in the plant root zone helping bridge dry spells. Water harvesting systems sustain ecosystems in agricultural landscape. These mechanisms strengthened social and agro-ecological resilience to address impacts of climate change and improve food insecurity. This can stabilize agro-ecosystems while providing additional benefits to people (Biazin et al., 2023). Additionally, some traditional water harvesting techniques such as Zai and Half-moon techniques are very effective where by runoff water and organic matter are concentrated and conserved in the small pits (Barry et al., 2008). These traditional-based practices have been extensively promoted and well adapted by rainfed smallholders in some parts of sub-Sahara Africa. Under these local-based methods, crops get directly nutrients and water concentrated in the planting pits that improves the buffering capacity of crops to long-term dry spells during critical growth stage. Trees and shrubs are also productive under this traditional technique, using Zai for reforestation, farmers are able to establish agro-forestry systems (Reij, 2015).

However, the major problem associated with this traditional technique is waterlogging which may occur during wet season. The combination of Zai technique with techniques such as stone bunds, agroforestry system is proven to be beneficial for degraded areas (Bado et al., 2016). This a very successful ecosystem-based adaptation that has improved food security by increasing food availability for number of months, enable vegetation growth with additional benefits.

Other techniques for rainwater harvesting include the combination of the traditional knowledge and scientific knowledge such as terracing systems in steep zones or stone lines which are commonly used by smallholder farmers. Contour stone/rock bunds or vegetative barriers slow down and filter runoff which facilitates infiltration and capture sediments thereby increasing soil water and reducing erosion (Doswald et al., 2014). In east Africa, farmers build *"Fanya juu"* along the contour of a sloping terrain together with a ditch. Small scale irrigation together with rainwater harvesting and catching runoff in small dams or water holes is also practiced across sub-Sahara Africa. Traditional water harvesting techniques is gaining interest among smallholder farmers in the Sahelian zone of west Africa (Tamagnone et al., 2020).

Therefore, these strategies integrate land and water management, contribute to build-up of soil organic matter and use varieties well adapted to changing climatic conditions which directly addresses the principles of ecosystem-based adaptation/Eco-disaster Risk Reduction and supports climate change adaptation and disaster risk reduction (Dorren & Schwarz, 2016).

2.5 The perceived effectiveness of EbA practices in mitigating the negative effects of dry spells on crop yield

Effective ecosystem-based adaptation is defined as "an intervention that has restored, maintained, or enhanced the capacity of ecosystems to produce services. These services in turn enhance the well-being, adaptive capacity or resilience of humans, and reduce their vulnerability. The intervention also helps the ecosystem to withstand climate change impacts and other pressures" (Reid & Alam, 2016). Ecosystem-based adaptation is capable to enhance the climate resilience of farming where smallholder farmers are highly vulnerable to droughts, floods, and other extreme weather events. From the agricultural context, ecosystem-based adaptation involves integrating biodiversity and ecosystem services into farming systems to improve productivity, reduce climate-related risks, and strengthen adaptive capacity. Such management of the agroecosystems help in increasing crop yield, farmers' income and food security while preserving and enhancing resource base and environment (Shah et al., 2019).

Approaches such as agroforestry, water management through natural infrastructure, and soil conservation techniques contribute significantly to enhancing farm productivity and resilience (Chaudhary et al., 2021). For instance, agroforestry systems not only increase biodiversity but also improve soil fertility and water retention, buffering farms against extreme weather events like droughts and floods (Muriuki et al., 2013).

The efficacy of ecosystem-based adaptation practices in reducing climate vulnerability for smallholder farmers was highlighted under the systematic review by Doswald et al., 2014 analysed 12 case studies of ecosystem-based adaptation implementation in developing countries. The review revealed that ecosystem-based adaptation practices such as agroforestry, sustainable land management, and ecosystem restoration helped to stabilize crop yields. Integration of trees and shrubs with crops, create biodiversity-rich environments that can provide natural pest control, reduce diseases, and enhance soil fertility through nitrogen fixation and nutrient cycling (Garrity et al., 2010). The result of such adaptation is a more resilient ecosystem less prone to crop failures due to pests or nutrient depletion. Additionally, cover cropping, crop rotation, and minimal tillage help maintain soil structure, increase organic matter content, and enhance nutrient availability. This improves soil fertility and water retention capacity, leading to more stable and higher crop yields over time and diversify income sources (Higashi et al., 2014). Trees and restored ecosystems can moderate microclimates, reducing temperature extremes and wind impacts on crops (Espeland & Kettenring, 2018). The microclimate moderation helps crops cope with climate variability and extreme weather events, thereby stabilizing yields (Rukhsana et al., 2021).

Furthermore, indigenous and local knowledge has been found to be very important when incorporated into the design and implementation of ecosystem-based adaptation initiatives. A study by Nyong et al. (2007) in the Sahel region found that blending scientific climate information with traditional ecological knowledge enhanced the uptake and effectiveness of ecosystem-based adaptation practices like water harvesting and indigenous crop varieties. Community-based approaches that built on local knowledge and institutions are more sustainable and equitable compared to top-down, expert-driven initiatives (Mattern et al., 2018).

2.6 Perceived co-benefits of ecosystem-based adaptation practices and their influence on adoption decision

The most obvious benefits of ecosystem-based adaptation practices are that they help ensure the continued provision of key ecosystem services such as soil fertility and quality improvement, water regulation, pest control and pollination on which farming depends (Lavorel et al., 2015). The adoption of ecosystem-based practices by smallholder farmers at farm-level provide multiple co-benefits beyond just climate adaptation.

The term co-benefits in adaptation refers to the positive outcomes beyond the primary climate adaptation objective that arise from implementing ecosystem-based adaptation practices (Mayrhofer & Gupta, 2016). Co-benefits from ecosystem-based adaptation arise from enhanced ecosystem services, improved agricultural productivity, increased livelihood and food security. These co-benefits occur in addition to the primary benefits of ecosystem-based adaptation practices to reduce climate risk such as buffering the impacts of extreme weather events (Vignola et al., 2015). Vignola et al. (2015) described adoption of ecosystem-based practices by smallholder farmers as a process in which farmers assess the benefits, constrains, and opportunities of ecosystem-based adaptation practices and integrate them into their farming systems when perceived as valuable and feasible. The adoption of the ecosystem-based practices depends on farmers' perceptions of co-benefits. Some studies suggest that smallholder farmers may prioritize short-term productivity and income over longer-term environmental outcomes (B Buhr, Murinde V, Donovan C, Pullin N, Kling G, Volz U, 2018). For instance, small-scale coffee farmers in Uganda recognized benefits such as improved soil fertility and increased biodiversity from adopting agroforestry practices. Primarily, the farmers were motivated to adopt the agroforestry practices by the direct economic returns from selling coffee and timber products (Bongers et al., 2015). Similarly, a case study conducted in Malawi by Nyasimi et al. (2017) looked at how smallholder farmers integrated leguminous plants like pigeon peas and groundnuts into their cropping systems as an ecosystem-based adaptation practice. The study found that the key co-benefits perceived by farmers were the direct livelihood benefits from integrating leguminous plants into the cropping systems. The study affirmed that the addition of leguminous plants into the cropping systems improved food security and dietary diversity, diversified income sources from legume sales and reduced reliance on purchasing fertilizers since the practice enhanced soil fertility from biological nitrogen fixation. As such, the adoption decision among smallholder farmers was influenced by both perceived utility and tangible co-benefits of the adaptation practices. Smallholder farmers adopt ecosystem-based adaptation practices when they perceive clear benefits that outweigh costs, labour requirements, knowledge barriers, market risks and institutional constrains (Vignola et al., 2015).

These co-benefits are central to both smallholder farmers adoption decisions and the three-dimensional framework used to evaluate ecosystem-based adaptation practices in agricultural systems. According to Vignola et al. (2015), ecosystem-based adaptation practices are assessed across three interlinked dimensions: 1- Ecosystem Service Provision (enhancement of ecosystem services). 2- Adaptation Benefits (reduced climate vulnerability) and 3- Livelihood and Food Security Improvement (socioeconomic gains). Co-benefits gain from adoption of ecosystem-based adaptation practices map onto these three dimensions.

2.6.1 Ecosystem services provision

One of the most consistently reported co-benefits of ecosystem-based adaptation practices relate to the enhancement of ecosystem services that are fundamental to agricultural productivity. In the study of ecosystem-based adaptation for smallholder farmers in Togo by Abbey et al,. (2023), farmers ranked soil fertility improvement, water infiltration and erosion control, and runoff regulation as key benefits of adopting ecosystem-based adaptation practices such as agroforestry, grass hedges and crop rotation. These ecosystem services strengthen the environmental conditions necessary to support crop growth and enhance resilience to climate extremes. When smallholder farmers perceived that these practices strengthen ecosystem function, their willingness to adopt and maintain such practices increases. For instant, soil fertility improvements are often directly connected to enhanced crop yields and reduced dependence on purchased inputs a benefit that many smallholder farmers explicitly seek when making management decisions. A review by Vignola et al. (2015) of scientific documents based on field experiments in Latin America showed strong evidence of multiple benefits that same ecosystem-based practices such as tree-based practices for coffee and no tillage for maize can provide to support the adaptation of climate extremes of smallholder farming systems and enhance a farm's natural assets such as biodiversity, water and soil. However, the review also found that most studies on ecosystem-based adaptation practices in the region focused on socioeconomic dimension instead of the capacity of the practices to improve the natural assets of a smallholder farmers or reduce the impact of climate extremes. There were gaps in evidence showing that many ecosystem-based adaptation practices can consistently reduce the impacts of extreme climatic events such as droughts, heatwaves, or flooding. In many studies conducted on several farming practices such as mulching, alloy cropping, biological control, live organic fertilization showed little or no strong evidence of their contribution to buffering hydro-climatic extremes or producing measurable adaptation benefits despite their ecosystem service roles in normal conditions. This implies that in many contexts, these practices do not reliably deliver resilience outcomes under extreme stress without complementary measures or strong contextual support.

2.6.2 Adaptation benefits

Beyond ecosystem function, smallholder farmers often associate ecosystem-based adaptation practices with direct adaptation outcomes notably improved crop productivity and reduced risks associated with climate variability. Evidence from a study conducted in Togo by Abbey et al. (2023) indicated that smallholder farmers perceived crop productivity enhancement and reduced climate-related production risks as significant co-benefits of adopting ecosystem-based adaptation practices such as agroforestry, water management techniques. Similarly, a review study conducted by Vignola et al., (2015) in Latin America on the benefits of ecosystem-based adaptation practices and knowledge gaps found that many ecosystem-based adaptation approaches contributed to yield increase, reduced production cost, diversified income sources, and reduced dependency on external inputs. These socioeconomic benefits are especially salient because they address the immediate livelihood needs of smallholder farmers alongside longer-term adaptation goals. However, the result of the systematic review conducted by Vignola et al. (2015) in Latin America revealed that many widely promoted ecosystem-based practices showed little or no strong evidence of effectively reduced climate extremes, impacts or provided multiple adaptation benefits. Only a few practices like shaded trees or no tillage had robust evidence across multiple benefit dimensions and even evidence sometimes showed negative or inconsistent yield effect under certain conditions meaning that productivity outcomes under climate stress are not guaranteed.

2.6.3 Livelihood and food security improvement

Livelihood improvement increases household income and enhanced food security highlighted as perceived benefits influencing adoption decisions among smallholder farmers. Smallholder farmers rank income and food security improvement as critical advantages linked to the uptake of ecosystem-based adaptation practices, suggesting that livelihood consideration often weigh heavily in farmers' cost-benefit analysis. Furthermore, evidence from a study conducted in Latin America showed that smallholder farmers implement ecosystem-based adaptation practices like shed trees, live fence, and home gardens partly because they perceived these measures provide multiple livelihood benefits such as diversified production, reduced risk exposure, and supplemental streams of agricultural products. Although these practices may require labour or initial investment, their multi-functional outputs (e.g timber, fodder, food crop) elevate their value proposition. Even though many ecosystem-based adaptation practices such as agroforestry, live fence, home garden and water conservation are being perceived to enhance livelihoods and food security, yet under intense droughts, prolonged heatwaves, or extreme floods, the ecosystem services may be insufficient to sustain household livelihoods when the ecological capacity of ecosystem-based adaptation practices is overwhelmed by the severe climate shocks reducing crop yield, fodder availability, or tree productivity there by limiting income and food security gains. A study conducted by Asfaw et al. (2012) in the semi-arid areas of Ethiopia where interventions such as agroforestry, and soil water conservation have been promoted found that during severe drought years, household still experienced significant reductions in crop yield and livestock productivity, which weakens the expected livelihood and food security benefits of these practices.

Therefore, considering together all the findings, suggest that while perceived co-benefits are central to adoption of ecosystem-based adaptation practices, they are neither uniform nor guaranteed across contexts, particularly under intensifying climate extremes. This underscores the importance of conducting similar studies across geographical conditions to capture variability in agro-ecological conditions, climate risk and socioeconomic settings to clarify where ecosystem-based adaptation practices deliver synergetic benefits and where its limits lie. Expanding empirical evidence across regions is critical not only for resolving the existing contradictions in the literature but also for informing context specific policy and programme design that ensures the effective integration of ecosystem-based adaptation practices with broader adaptation measures such as social safety nets and climate-smart technologies to safeguard livelihoods and food security under increasingly extreme climatic conditions.

2.7 Sustainability of ecosystem-based practices in maintaining farm productivity

The economic viability of ecosystem-based adaptation practices remains a critical factor in their sustainability (Shah et al., 2019). While initial investments may be higher compared to conventional practices, the long-term benefits in terms of increased yields, reduced input costs, and resilience to climate extremes often outweigh the costs (Costanza et al., 2017). Social acceptance and local knowledge integration are also crucial for the successful implementation and continuation of ecosystem-based adaptation initiatives (Adger et al., 2005). Without sustainable adaptation strategies, the long- term negative consequences of climate change on the livelihood of smallholder farmers could be severe (Khanal et al., 2021).

In the Savannah region of Togo, a study conducted on climate change adaptation by Abbey, (2023) emphasized the importance of sustainable agriculture management practices to improve agricultural land resilience and boost crop productivity in the climate change context. By reducing reliance on synthetic inputs like pesticides and chemical fertilizers, ecosystem-based adaptation practices can lower production costs and mitigate environmental risks associated with intensive agriculture. This ensures long-term viability of farming systems and stable yields without causing environmental degradation compared to conventional adaptation measures (e.g., engineered solutions), often prove more cost-effective over the long term (Sarkar et al., 2020). Thus, leveraging natural processes and local knowledge, reduces dependency on external inputs and infrastructure. However, the dynamic nature of climate change poses challenges to long-term planning and adaptation. Ecosystem-based adaptation practices must be flexible and adaptive to evolving climate conditions to remain effective (Hoppit et al., 2022). Adequate funding, access to resources (e.g., seeds, tools), and technical assistance enable the scaling up and maintenance of ecosystem-based approaches. Innovative financing mechanisms and partnerships can mobilize resources for sustainable adaptation.

2.8 Theoretical framework

The theoretical framework is drawn on interdisciplinary synthesis of ecological science, resilience theory and development studies that reflect the inherently complex, dynamic and adaptive characteristics of coupled human-environment systems (Folke, 2006). This integrative foundation provides a rigorous basis for evaluating the extent to which ecosystem-based intervention can sustainably enhance climate resilient livelihood, with particular emphasis on the vulnerability and adaptive capacities of smallholder farmers (Reid, 2016). Different theoretical frameworks have been developed with key elements and criteria to evaluate the effectiveness of ecosystem-based adaptation and to select agricultural practices that fit to be considered as ecosystem-based adaptation practices.

Munroe et al. (2012) and Doswald et al. (2014) assessed the state of the evidence-based effectiveness of ecosystem-based adaptation initiatives through a framework developed by the stakeholders. Though the authors concluded that effective ecosystem-based adaptation would reduce people's environmental, social and economic vulnerability and provide benefits. Such an assessment was limited to systematically map ecosystem-based adaptation relevant peer-reviewed literature and a sample of grey literature that provided a methodological overview of ecosystem-based adaptation effectiveness.

Additionally, Reid and Alam (2016) conducted an ecosystem-based adaptation assessment in two action research sites for community adaptation in Bangladesh. They evaluated how effective ecosystem-based adaptation supports adaptive capacity and resilience in the community. However, the effectiveness was viewed only through an ecosystem health lens and the authors argued that effective ecosystem-based adaptation should have two key components: (1) the maintenance of ecosystem services and (2) ecosystem resilience.

Furthermore, Bertram et al. (2017) developed an assessment framework that sets out qualifications and quality standards for evaluating the effectiveness and robustness of an ecosystem-based adaptation intervention. The framework provides a baseline for identifying areas where the intervention can be enhanced. Three key elements were featured to measure the effectiveness of ecosystem-based adaptation projects at national and local levels: (1). Ecosystem-based adaptation helps people adapt to climate change, (2). Ecosystem-based adaptation actively uses biodiversity and ecosystem services, and (3). Ecosystem-based adaptation is part of an overall adaptation strategy. Each featured element contains one or two criteria with various indicators that must be met. The assessment framework was provided to help decision makers design high quality ecosystem-based adaptation measures during planning phase of a project and improve the quality of measures during the implementation phase.

The frameworks (Munroe et al. 2012, Doswald et al. 2014, Reid and Alam 2017, Bertom et al. 2017) share similarities such as ecosystem-based adaptation measures that improve ecosystem's capacity to provide services, improve humans' well-being, adaptive capacity or resilience and reduce their vulnerability , However, these frameworks were not used specifically (Abbey, 2023).

For the purpose of this study, Vignola et al. (2015) framework is used to identify and assess the effectiveness of ecosystem-based adaptation practices for smallholder farmers. Vignola et al. (2015) framework is relevant for use in the context of smallholder farmers and is valuable in simulating 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 (Kissi et al., 2023). Vignola et al. (2015) framework is based on applied interdisciplinary theories that are drawn from various disciplines such as ecology, sociology and economics to develop practical strategies for climate change adaptation in the agricultural communities.

The key theories and concepts upon which Vignola et al. (2015) framework is linked include: Firstly, the ecosystem services theory, that points ecosystem services such as water regulation, soil fertility, and pollination as crucial for human well-being and agricultural productivity (Smith et al., 2013). Ecosystem-based adaptation aims to conserve and sustainably manage these services to support climate adaptation. Secondly, the Socio-ecological systems theory that views human and ecological systems as interconnected and co-evolving. The socio-ecological theory expresses the fundamental of understanding the interactions between social and ecological components to develop effective adaptation strategies (Anderies et al., 2004). Thirdly, the sustainable livelihood theory that focuses on the assets and capabilities that individuals and communities utilize to achieve well-being. Ecosystem-based approach aims to enhance these assets such as nature, social and financial to improve resilience to the negative impacts of climate change (Silva & Matyas, 2014). Fourthly, the institutional theory that expresses the arrangement and governance structures that play a critical role in the implementation of ecosystem-based strategies where effective policies and institutions are necessary to support the adoption and scaling of ecosystem-based practices (Iza, 2021). As such, (Vignola et al., 2015) framework has been applied to the wide variety of agricultural systems that exist globally, for instant, the successful application of (Vignola et al., 2015) framework include the smallholder coffee farmers in Mesoamerica (Vignola et al., 2015), smallholder farmers in the Otti basin, Togo (Abbey, 2023), and in contrast, (Nanfuka et al., 2020) use the same framework for characterizing ecosystem-based adaptation practices for drought for smallholder cattle farmers in the central Uganda.

Therefore, (Vignola et al., 2015) framework is being adopted in this study to select agricultural practices that fit to be considered ecosystem-based practice that is appropriate for smallholder farmers and also to provide indicators that assess the effectiveness of the identified ecosystem-based practices at farm level.

A given agricultural practice that meets at least one criterion in each of the "ecosystem service provision" and "adaptive benefits" dimensions is considered ecosystem-based adaptation practice. Practices that fulfil at least one criterion in all the three dimensions ("ecosystem service provision, "adaptive benefits", "livelihood and food security") are ecosystem-based practices appropriate for smallholder farmers (Vignola et al., 2015). The underlying criteria for each dimension are presented in the figure below.

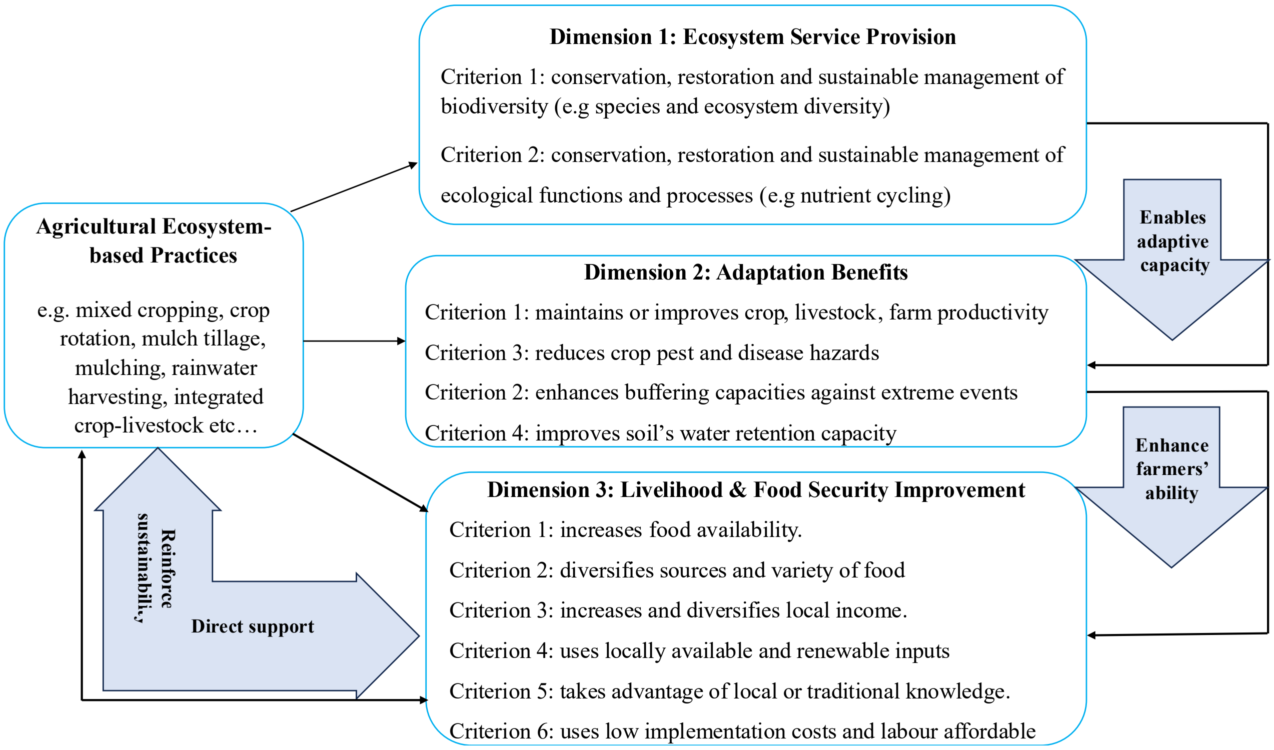

Figure 1: Theoretical Framework

Source: Adopted and modified from Vignola et al. (2015)

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Description of the study area

Mabalane District is located at the centre of Gaza Province (23.849°S 32.62°E). The province is South-East Mozambique, stretching from the coast to the border with South Africa and Zimbabwe. The province is characterized by a very dry, arid climate. Outside the narrow coastal strip centered around Xai-Xai, farming that relies on rainfall is specifically confined to the river valleys of Limpopo, Changane, and Elephant rivers (FAO, 2003).

Mabalane District is approximately 314 Km North of the capital Maputo, and it covers an area of 8929 Km^2 of which 75% is ASALs (arid and semi-arid lands) with a population of 38,644 inhabitants, and the population density of 4.3 people per Km^2 (*Estatísticas Do Distrito de Mabalane*, 2023). The District share part of the Great Limpopo Transfrontier Park about 1600 Km^2 and it belongs to the drainage basin of the Limpopo which includes Limpopo River which is perennial and Chigombe, Sungutane and Chichakuarre which are seasonal rivers respectively (Ministério de Administração Estatal, 2005).

The climate is tropical arid with average temperature of 24°C, rainfall is low and variable between 616 and 766 mm/year falling mostly from November to March, evapotranspiration is very high at 1000 to 1300 mm/year more than the rainfall (de Sousa et al., 2017). The forest ecosystems consist of woodland that occupies more than 80% of the land dominated by Mopane woodlands. Mopane (*Colophospermun mopane*) is one of the proffered indigenous hardwood species for charcoal production as the dense wood produces slow-burning charcoal (Baumert et al., 2016).

The topography is gradually flat to undulating; the soils consist of marine deposits overlain in certain areas by more recent colluvial and alluvial deposits. Soil 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) (Woollen et al., 2016). These latter areas are disconnected by large shallow depression of clay soils that forms watercourses for few weeks in a year (Ng'ang'a et al., 2011).

The major economic activity is charcoal production and commercialization (the district with the highest number of licenses for charcoal production in Gaza province), with households' livelihoods depend traditionally on rainfed agriculture and livestock keeping (Baumert et al., 2016). The communities raise livestock mainly cattle, goats, pigs and chicken, and their farms have an average 4.1 hectors with the main agricultural products including maize, cowpea, pumpkins, water melon, groundnuts and sweet potato. Both livestock and farms are threaten by the negative effects of climate change (World Bank, 2017).

Mabalane district serves as a microcosm of Mozambique's high vulnerability to climate change, being a hotspot for drought and environmental degradation. 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 (Muleia et al., 2024).

The district is a prime, highly representative case study for semi-arid agriculture in Mozambique. It encapsulates the worse-case scenario of climate change impacts on rural livelihoods, making it a crucial representative site for developing and evaluating adaptation strategies.

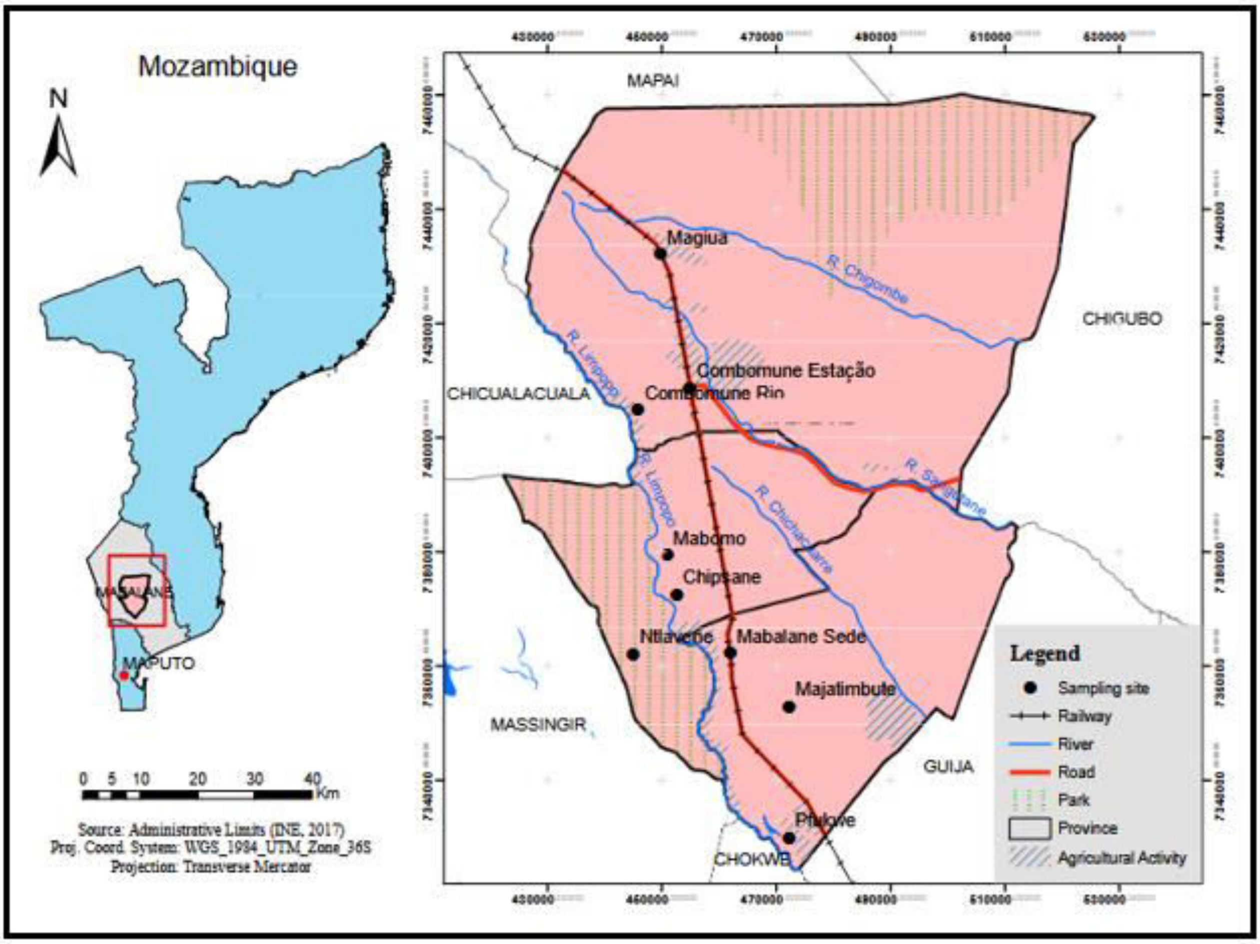

Figure 2: The geographical location of the study area

3.2 Sampling and data collection

3.2.1 Definition of target population

The target population for this study was formally defined as rainfed smallholder farmers operating within the administrative boundaries of 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 sector of agriculture, fisheries and climate resilience at district level. In the year 2025, 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 of 226 male and 528 female.

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

$$S = \frac{Z^2 PQ}{E^2}$$

Where: S = sample size; Z^2 = deviation set at 1.96 corresponding to 95% confident level; P = population proportion usually taken at 0.5 (50%) for maximum variability in the population; 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:

$$n = \frac{S}{1 + \frac{S-1}{N}}$$

Therefore, substituting the values, $n \approx 359.05$

3.2.2 Sampling framework and stratification

Due to the absence of detailed statistics on number of smallholder farmers in each locality and the administrative posts of the district, a stratified random sampling with equal allocation was adopted. The study area was first stratified into three administrative posts of the district, and the total sample size was distributed equally among them (approximately 120 farmers per administrative post). Each administrative post was further divided into three localities resulting into equal allocation of approximately 40 farmers per locality. This approach ensured that all administrative posts and locality were adequately represented in the sample despite the lack of population data required for proportional allocation. The localities were selected to capture the diverse agroecological conditions within the district, including areas located near River Limpopo where farming activities are concentrated due to the fertile soils and water availability and as well as drier areas situated farther from the river. 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 (Maduekwe & de Vries, 2019). 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.

3.2.3 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 locality requiring a minimum of five years to ensure familiarity with local farming conditions and practices. The threshold set at five-years residency was because smallholder farmers shift from one cultivated area to new fields after approximately five years of continuous use of the same land, owing to declining crop yields due to soil nutrients depletion. 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 agriculture enterprises.

3.2.4 Data collection methods

The procedures for data collection were carried out using a mixed-method approach that includes structured questionnaires, key informant interviews, and gendered specific focus group discussions to allow free sharing of information. The questionnaires' items were developed based on the comprehensive review of the relevant literatures. 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 carried out 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 Likert-Scale Levels. The internal consistency of the survey instrument was assessed using Cronbach's alpha to evaluate the reliability of the test items. The scale showed acceptable internal consistency (alpha = 0.81) indicating that the questionnaires' items are sufficiently correlated to measure the intended construct (Tavakol & Dennick, 2011). The 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 capture adequately 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 questionnaires 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 challenges face in adoption.

Considering language barrier as the study was conducted in English language and the official language is Portuguese; majority of the farmers speak their local language Changana. As such guided interviews using questionnaire was conducted to allow establishment of trustworthiness with the respondents hence providing validation of the responses (Nanfuka et al., 2020). The questionnaire provided 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 homestead or farms to avoid interruption of their work.

To complement the quantitative data, enhance the consistency of findings through triangulation, two gender-specific focus group discussions (FGDs) were conducted in both Portuguese and Changana language in each of the three administrative posts: Mabalane Sede, Ntlavene and Combomune Estação respectively. Each focus group consisted of a maximum 12 participants optimal for facilitating interaction and ensuring diverse perspectives (Nyumba et al., 2018). 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 (Muellmann et al., 2021).

3.2.5 Scope and delimitations

Based on the sampling strategy and the defined population boundaries, the conclusions drawn from this study are specifically 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 farming areas. 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.

3.3 Data analysis

3.3.1 Descriptive statistics

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 followed the underlying criteria for each of the three dimensions in the theoretical framework.

3.3.2 Weighted average index

The perceived effectiveness of the identified ecosystem-based adaptation practices was assessed using Weighted Average Index (WAI) in Excel. Weighted Average is a type of average where each observation in a data set is multiplied by the assigned weight reflecting its important before summing all data into a single average value (Abbey, 2023). The Weighted Average Index is an important approach commonly used in Likert-scale questionnaires or Rating-scale questionnaires where respondents indicate their level of agreement, importance, satisfaction or frequency using a predefined ordinal scale. This approach is effectively applied in survey involving perceptions, attitudes, or prioritization of factors (Joshi et al., 2015). The co-benefits of each identified ecosystem-based adaptation practice were categorized into three dimensions based on the theoretical framework such as: (1) Ecosystem service provision, (2) Adaptation benefits and (3) Livelihood and food security improvement and then rated using a rating scale adopted from (Kissi et al., 2023) to compute five effectiveness levels from Weighted Average Index (WAI) values: Highly effective = (3.49 – 4.28); effective = (2.69 – 3.48); moderately effective = (1.89 – 2.68); less effective = (1.09 – 1.88) and not effective = (1 – 1.08) (Akadiri et al., 2013).

The formula for computing Weighted Average Index is given by:

$$WAI = \sum(WiXi/Wi)$$

Where W_i indicates the respective weights for the items, and X_i indicates the value of each item. Based on the three dimensions of the framework, the results showed which practice has the most effective and suitable role in mitigating the effects of dry spells on crop yield.

3.3.2.1 Relative importance index

Furthermore, Relative Importance Index (RII) analysis was done in Excel to rank the perceived co-benefits of the identified ecosystem-based adaptation practices according to their relative importance. Relative Importance Index (RII) was used to prioritize the indicators in this study. The Relative Importance Index (RII) is one of the most reliable approaches for rating variable using a structured questionnaires on a Likert Scale (Abinaya Ishwarya & Rajkumar, 2020). The Relative Importance Index (RII) approach has been used successfully in similar studies by value (Abbey, 2023, Vignola et al., 2015) and the formula is given below as:

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

W = weighting assigned by each respondent on a scale of 1 to 5, with 1 applying for strongly disagreed and 5 strongly agreed.

A = the highest weight, and N the total number of the sample.

Five important levels was drawn from Relative Important Index (RII) values such as: High (H) = ($0.8 \leq RI \leq 1$), High-Medium (H-M) = ($0.6 \leq RI \leq 0.8$), Medium (M) = ($0.4 \leq RI \leq 0.6$), Medium Low (M-L) = ($0.2 \leq RI \leq 0.4$), and Low (L) = ($0 \leq RI \leq 0.2$) (Abbey, 2023).

3.3.4 Correspondence factor analysis

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 dimension (Ecosystem service provision; Adaptation benefits; Livelihood and food security improvement**)**, with a chi-square independence test setting α (type I error) at 5%. Correspondence factorial analysis is a multivariate statistical method use to analyse and visualize relationships within categorical datasets typically displayed as contingency table (Sourial et al., 2013). 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 (Greenacre, 2010). Such 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 (Kokol & Vošner, 2024).

To assess how perceived co-benefits drive adoption of ecosystem-based adaptation practices among smallholder farmers, a two-stage analytical approach was employed. The first step was to identify latent co-benefits constructs and the second step was to assess how variation in these constructs is associated with differences in the number of ecosystem-based adaptation practices adopted per smallholder farmer. The analysis emphasized on latent factors such as smallholder farmers' perceptions of co-benefits as key determinant driving the sustained adoption (Grothmann & Patt, 2005). Smallholder farmers' perceptions constitutes 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 (Adger et al., 2009). Understanding the latent factor is essential for identifying and addressing behavioural barriers to adoption.

3.3.4 Principal axis factoring

To identify the latent co-benefit constructs, exploratory factor analysis using principal axis factoring was conducted. This approach was employed to reduce a large set of correlated indicators into a smaller number of interpretable latent factors while enhancing analytical parsimony. The suitability of the data for factor analysis was assessed using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity. 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 Hutcheson et al. (1999) a bare minimum KMO value of 0.5 is recommended for factor analysis to be considered acceptable. Factors extracted were based on 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 (MacCallum et al., 1999). 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 (Saralah, Sovey; Kamisah, Osman; Mohd, 2022). 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 (Costello & Osborne, 2005). Retaining nuanced indicators helps identify complex relationships and prevents misinterpreting the underlying structure (Sukserm, 2025). To assess how variation in latent co-benefits constructs is associated with differences in the number of adopted ecosystem-based adaptation practices, 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.

3.3.5 Negative binomial regression

Negative Binomial regression model was employed to assess the association between variation in the latent co-benefits construct and the number of adopted ecosystem-based adaptation practices (adoption intensity). This approach was appropriate as the count of the adopted ecosystem-based adaptation practices (dependent variable) per smallholder farmer exhibited overdispersion (variance 5.25 exceeded the mean 3.73) violating the equidispersion assumption of the Poisson Model. Factor scores derived from principal axis factoring were computed and incorporated into the model as continuous independent variables representing the underlying latent co-benefit constructs. The use of the factor scores enhanced analytical clarity and while reducing potential multicollinearity among explanatory variables. By condensing correlated indicators into orthogonal or weakly correlated factor scores, the approach improved both model stability and interpretability of the regression estimates (Tahtali, 2019).

With factor scores from principal axis factoring, then the model is specified as:

$$Log\ (\mu_i) = \beta_0 + \beta_1 F_{1i} + \beta_2 F_{2i} + \dots\dots + \beta_m F_{mi}$$

Then exponentiate:

$$(\mu_i) = exp\ (\beta_0 + \beta_1 F_{1i} + \beta_2 F_{2i} + \dots\dots + \beta_m F_{mi})$$

Whereas:

μ_i = expected count of EbA practices for observation i.

β_0 = intercept

$F_{1i}, F_{2i}, \dots\dots, F_{mi}$ = continuous factor scores representing underlying latent construct of observation i.

$\beta_1, \beta_2, \dots\dots, \beta_m$ = regression coefficients.

The coefficients β_j represents change in the log of the expected count associated with a one-unite increase in the corresponding factor score. Exponentiating the coefficients, Exp (β_j), yields the incidence rate ratio (IRRs), which indicate multiplicative change in the expected count of EbA practices.

Therefore:

If IRR > 1, means increase in the expected count

If IRR < 1, means decrease in the expected count

If IRR = 1, means no effect

3.4 Ethical considerations

The field survey conducted with smallholder farmers adhered to ethical principles and professional standards established by the approval committee to ensure that the study was both ethically sound and scientifically rigorous. A formal letter of exemption was obtained from the Scientific Council at the Faculty of Agronomy and Forestry Engineering, confirming that the study did not require approval from the Institutional Research Ethics Committee. This determination was based on the assessment that the research did not involve human or animal biophysical samples nor did it pose any foreseeable physical, psychological, or social risk to the participants.

Notwithstanding the exemption, the study was conducted in accordance with fundamental ethical principles and standards guiding the survey which included the following:

1. **Informed consent:**

Prior to data collection, a written authorization was obtained from *Serviço Distrital de Actividades Económicas* (SDAE) in Mabalane district to ensure institutional legitimacy. Given that most respondents do not read and write, verbal informed consent was obtained from individual participant before the interviews were conducted through translation into the local language by the research assistants.

Participants were fully informed on the purpose of the survey; participation of individual was voluntary and consent without undue influence. Clear and understandable information was provided in the local language to explain the objectives of the survey, the use of the data and the importance of the survey. Farmers or participants were allowed to ask questions and give their explicit, informed consent before participation.

2. **Confidentiality and privacy**

Personal information and response were kept confidential. Participants were identified anonymously when reporting data and sensitive information such as income, farm size, household structure, assets were only shared with explicit permission and in anonymously way.

3. **Respect for local knowledge and culture**

Local knowledge, traditions and practices of smallholder farmers were respected and their understanding of the ecosystem-based practices and farming systems was acknowledged. Farmers were approached as experts in their own right with viable knowledge, they were given the opportunity to share insights on how ecosystem-based practices have worked or not worked in their context.

4. **Equity and inclusivity**

The survey was conducted in an inclusive manner open to all groups in the community. A diverse group of farmers such as women, youth, ethnic minorities was reached out to ensure their voices are heard. Barriers such as language, literacy and access to technology was addressed with the support of the district agriculture extension officers.

5. **Environmental safety**

Principles aligned with environmental sustainability and local ecosystems or resources were observed. Natural habited were not disrupted during field activities (e.g site visits, demonstration plots) to minimize environmental impact. Ecosystem-based practices that are ecologically sound and sustainable were encouraged.

6. **Data integrity and accuracy**

Data collection was done using well-tested instruments to ensure the process was rigorous and consistent for accurate, reliable and truthfully representation of the participants experiences.

7. **Post-survey feedback**

Feedback on the results and inputs of the participants in the survey was shared with them and stakeholders and how the results of their inputs was used to highlight how their contributions shape research outcomes. Recommendations or practical actions based on the findings that can immediately be applied to improve crop yield during dry spells.

3.5 Limitations of the study

The study is based on cross-sectional data and is geographically limited. The study focused on the psychological construct of smallholder farmers, specifically examining the perceived effectiveness of EbA practices at farm-level, the relationship between perceived co-benefits and the EbA practices, and how the perceived co-benefits influence adoption intensity. The analysis focused only on the adopters of EbA practices. Adoption intensity was measured solely by the number of practices, without capturing differences in quality, complementarity, or effectiveness. Factors such as socioeconomics, household characteristics, farm and biophysical characteristics, and structural constraints that can influence adoption and non-adoption were not included in the study.

Future research should incorporate these factors to comprehensively understand barriers and enablers of adoption. This will act as a benchmark for policymakers and practitioners to design interventions that address structural constraints and enhance the adoption of ecosystem-based adaptation practices in the study area.

CHAPTER FOUR

SUMMARY OF THE FINDINGS

4.1 Identified ecosystem-based adaptation practices

The descriptive statistics (Appendix IV, Figure 2, p. 7) indicate that smallholder farmers employed several ecosystem-based adaptation practices at the farm-level to cope with the effects of dry spells. The identified practices included mixed cropping, integrated crop-livestock, mulch tillage, crop rotation, agroforestry, mulching and rainwater harvesting. Among these practices, mixed cropping, integrated crop-livestock and mulch tillage were the most widely adopted practices. The distribution of EbA practices varied across the administrative posts within the district (Appendix IV, Table 2, p. 7). Notably, rainwater harvesting was reported only in Mabalane Sede, while other practices were adopted to varying degrees across the study area.

4.2 Perceived effectiveness of the roles of ecosystem-based adaptation practices in mitigating the negative effects of dry spells on crop yield.

The results on the perceived effectiveness of EbA practices (Appendix IV, Table 3, p. 7) revealed variations in respondents' assessment across the three dimensions. Mixed cropping was perceived as highly effective (H-E) in improving dimension 2 and 3 and effective (E) in dimension 1. Crop rotation and mulch tillage were perceived as effective (E) in improving all the three dimensions. Agroforestry and rainwater harvesting were perceived as moderately effective (M-E) in all the three dimensions. In contrast, mulching was perceived least effective (L-E) in improving all the three dimensions. Integrated crop-livestock was perceived least effective in improving dimensions 1 and 2, and effective (E) in dimension 3.

4.2.1 Relative importance index (RII) of the perceived co-benefits

Relative importance values of the perceived co-benefits (Appendix IV, Table 4, p. 8) indicate that under dimension 1 (Ecosystem Service Provision), improvement of soil fertility and quality was ranked highest (RII = 0.91) followed by improvement of soil nutrient regulation and water infiltration and erosion control (RII = 0.81). Improvement of surface runoff regulation ranked lower (RII = 0.59), while enhancement of agrobiodiversity, including pollinators and vegetation diversity received the lowest ranking (RII = 0.40). These findings suggest that smallholder farmers perceived soil-related ecosystem services as the most important co-benefits of adopting EbA practices for dry spell resilience.

For dimension 2 (Adaptation Benefits), the highest ranked co-benefit was improvement of crop productivity (RII = 0.93), followed by improvement of soil's water retention capacity (RII = 0.86), improvement of buffering capacity (RII = 0.84) and reduction of pests and diseases incidents (RII = 0.61).

These results showed that smallholder farmers perceived improvement of crop productivity, soil water retention capacity and reduction of damage caused by dry spell, heat wave, and reduction of pests and diseases incidents on the farming systems as important co-benefits gained from implementing ecosystem-based adaptation practices on their farms.

For dimension 3 (Livelihood and Food Security Improvement), food security improvement was the highest-ranked co-benefits (RII = 0.80). Other highly ranked co-benefits included the use of local traditional knowledge (RII = 0.79), low implementation and labour costs (RII = 0.79), diversification of food sources and varieties (RII = 0.78), use of local inputs (RII = 0.77), and increased and diversified local income (RII = 0.73). These findings indicate that smallholder farmers perceived EbA practices as important not only for strengthening agricultural resilience, but also for improving livelihoods and household food security.

4.3. Relationships between perceived co-benefits and adopted EbA practices

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) shows that the chi-squares for the three separate analyses revealed statistically significant relationships between perceived co-benefits and EbA practices at 5% significance level (p-value < 0.001).

4.3.1. Ecosystem service provision

The value of the total chi-square (1402.726) and p-value < 0.001 indicate a statistically significant association between the variables analyzed (Appendix V, Table 2, p. 13). 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.

The biplot (Appendix V, Figure 4, p. 14) revealed that the two Axes (Axis-1 and Axis-2) accounted for 97.3% of the total inertia. This suggests that the analysis of the two axes explained 97.3% of the information.

4.3.2. Adaptation benefits

The summary table (Appendix V, Table 4, p. 15) 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. The results of the correspondence factorial analysis shown on the biplot (Appendix V, Figure 5, p. 15) 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.

4.3.3. Livelihood and food Security improvement

The summary table (Appendix V, Table 6, p. 16) 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. The result on the biplot (Appendix V, Figure 6, p. 17) 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.

4.4. Identified underlying co-benefits that influence adoption intensity of EbA practices among smallholder farmers

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. 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 (Appendix V, Table 7, p. 17).

The result of the factor analysis (Appendix V, Table 8, p. 18) 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 (Phong et al., 2020).

Three factors emerged from the pattern matrix (Appendix V, Table 9, p. 19), 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.

4.4.1 Influence of the identified underlying factors on the adoption intensity of EbA practices among smallholder farmers

The results of negative binomial regression analysis (Appendix V, Table 10, p. 19) 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.

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.

CHAPTER FIVE

INTEGRATIVE DISCUSSION

The findings of this study provide empirical evidence for understanding ecosystem-based adaptation within the context of semi-arid smallholder farming systems. While this study adopted the Vignola (2015) concept of EbA as the use of biodiversity and ecosystem services to help crops and livestock adopt to or recover from the adverse impacts of climate change, the realities of the farming systems in Mabalane district suggest that this definition of this concept may require contextual interpretation. In environment characterized by recurrent dry spells and irregular rainfall patterns, smallholder farmers adopt practices that do not only utilize biodiversity and ecosystem services, but also actively manage ecological processes that enhance the adoptive capacity of agricultural systems.

The predominance of mixed cropping, integrated cop-livestock systems, and mulch tillage demonstrates that smallholder farmers prioritize ecosystem-based adaptation practices that are affordable, cost effective, labour affordable and compatible with existing traditional farming systems while addressing recurrent dry spells and irregular rainfall pattern. Importantly, the adaptive benefits of these practices arise not merely from the diverse type of crop species, but from ecological functions and processes that they generate within the farming system. Smallholder farmers reported that mixed cropping emerged as a dominant practice because of being perceived as a primary risk management strategy in rainfed and semi-arid agricultural context. Mixed cropping practice in Mabalane district include maize cultivated in combination with beans, pumpkin, or watermelon on the same plot of land. This traditional farming practice enables smallholder farmers to cope with climatic variabilities.

Mixed cropping system provides a clear example of the broader interpretation of ecosystem-based adaptation. Although smallholder farmers may not consciously adopt mixed cropping to conserve biodiversity, the practice introduces functional diversity into agricultural fields creating ecological interactions that improve resilience to climate variabilities. Smallholder farmers in Mabalane district reported that in mixed cropping of maize with beans, pumpkin or watermelon, maize provides partial shading that moderates field micro-climates, while crops such as pumpkin and watermelon reduce soil exposure to direct solar radiation and help conserve soil moisture. Leguminous crops such as beans contribute to biological nitrogen fixation, improving nutrient availability for companion crops (Massawe et al., 2016). From an agroecological perspective, these interactions collectively enhance soil fertility, moisture conservation, water infiltration and erosion control (Altieri et al., 2015). Thus, the adaptation benefits observed by the smallholder farmers are mediated through ecosystem processes rather than through biodiversity and ecosystem services. This finding supports the argument that EbA should be understood not only in terms of biodiversity utilization but also in terms of the management of ecosystem functions that strengthen resilience. The adaptive value of mixed cropping in Mabalane emerges from the ecological conditions crated by crop diversity, including improved nutrient cycling, microclimate regulation, and soil moisture retention. These ecosystem processes enable crops to better withstand prolonged dry spells and rainfall variability. Consequently, mixed cropping functions as a form of ecosystem-based adaptation because adaptation outcomes are achieved through ecological mechanisms operating within the farming systems. Furthermore, smallholder farmers' characterization of mixed cropping as a bet-hedging strategy highlights the linkage between ecological resilience and livelihood resilience. The cultivation of crops with differing drought tolerances reduces the risk of complete harvest failure during adverse climatic conditions. Even when maize yield declines due to drought stress, beans, pumpkin, or watermelon may still provide harvests ensuring a minimum food availability for households. This is consistent with the findings from the study conducted by Léonidas et al. (2024) in eastern Rwanda on monocropping verses mixed cropping systems under a changing climate where it was found that smallholder farmers perceived mixed cropping to be more resilience because it stabilizes yields, enhance soil health and diversify food sources for households. The multifunctionality of mixed cropping therefore extends beyond ecological benefits to encompass livelihood stabilization and risk reduction. Such finding reinforces the argument that EbA generates both ecological and socio-economic adaptation outcomes (Baker et al., 2023).

Therefore, the multifunctional nature of mixed cropping system contributes not only to ecological resilience, but also to livelihood security by diversifying food sources and reducing the risk of total crop failure. This outcome aligns with the bet-hedging rationale reported by the smallholder farmers in Mabalane district.

Furthermore, integrated crop-livestock systems play a central role in local adaptation strategies as it aligns with the community's existing farming practices and seasonal cycles. These systems illustrate how ecosystem processes can serve as mechanisms of adaptation not derived from biodiversity and ecosystem services, but from the enhancement of nutrient cycling and soil ecosystem functioning. In integrated crop-livestock system, smallholder farmers graze their livestock particularly cattle during dry season on maize stover left in the fields after harvest.

This practice maximizes resource use efficiency by converting crop residues into livestock feed, while simultaneously depositing manure directly onto the agricultural fields (Castellanos-Navarrete et al., 2015). Smallholder farmers perceived this practice as beneficial for improving soil fertility by the increased soil organic matter that enhances soil structure. The accumulation of soil organic carbon improves nutrient cycle, water infiltration, and a better soil water holding capacity (Blanco-Canqui & Lal, 2007). This process creates more favourable conditions for crops establishment in the next planting season. In addition to nutrient cycling, farmers also reported that livestock grazing contributes to the mechanical and biological breakdown of crop residues. The trampling and grazing on maize stover reduce particle size and accelerate the decomposition of organic materials thereby facilitating their incorporation into the soil during land preparation using the traditional ox-drown ploughs. This process creates favourable conditions for adoption of mulch tillage, which is widely practiced as a land preparation method due to its low-cost, labour efficiency and reliance on locally available inputs. Smallholder farmers associated mulch tillage with improvements in soil fertility, enhanced water infiltration, effective erosion control and increased soil moisture retention. Thus, integrated crop-livestock system creates a closed-loop agricultural system that supports long-term soil productivity while reducing dependence on external inputs (Bansal et al., 2022).

Although smallholder farmers perceived multiple co-benefits from the adoption of crop rotation, agroforestry, mulching and rain water harvesting; their adoption remain very low. Farmers acknowledged that crop rotation regulate soil nutrients, improve soil fertility, reduce pests and diseases, and enhance crop productivity, however, its adoption remained low because household food security largely depends on continuous cultivation of single staple food crop such as maize. Additionally, limited land availability makes crop rotation a less viable option since smallholder farmers prioritize food crops year-round. This finding is consistent with the study conducted by Nyamayevu et al. (2024) in Malawi where it was found that small land sizes and dependency on maize for food security forces farmers to prioritize continuous cereal production, limiting crop diversification and rotation. This finding is contracting the strategies suggested in the review study conducted by Mondlane et al. (2025), that conservation agriculture as one of the most promising solutions for smallholder farmers in the southern region of Mozambique under crop diversification via crop rotation or intercropping. This finding is consistent with the review study conducted by Araya et al. (2024) on challenges and constraints of conservation agriculture adoption in smallholder farms in sub-Saharan Africa where it was found that conservation agriculture through crop diversification and rotation is frequently reported to be challenging or less effective for smallholder farmers, primarily because it conflicts with their need for immediate food security, income, and livestock fodder from a single crop, often limited, fragmented land. In addition, intercropping is often limited in adoption because many smallholder farmers rely on traditional mixed cropping as their established practice. Though both techniques involve growing multiple crops together, they differ significantly in management and purpose. Mixed cropping is deeply rooted in local traditions, offering a low-cost, low-risk approach to farming, which makes farmers reluctant to adopt the more complex, structured methods of intercropping (Aliyu et al., 2021).

The adoption of agroforestry was reported to be constrained by livestock management practice despite its contribution towards improved agrobiodiversity and habitat for pollinators. In addition, livestock ownership was perceived to reduced likelihood of agroforestry adaptation due to browsing damage caused from open grazing. Mulching and rainwater harvesting also face adoption barriers despite their recognized advantages. Rainwater harvesting was perceived to minimize the risk of crop failure during dry spells and improve crop productivity. However, its implementation was limited by lack of technical skills and financial resources that are not readily accessible to many smallholder farmers. Although mulching is one of the most promoted ecosystem-based adaptation practices in drought prone areas, its adoption is being limited by the use of maize stover as animal feeds. Farmers reported that maize stover in dry season represents an essential feed resource for livestock through either in-situ grazing or forage collection, leaving limited residues available for soil cover. This finding is consistent with the study conducted by Rusinamhodzi et al. (2015) in Zimbabwe on maize crop residue use and trade-off on smallholder crop-livestock farms where it was found that maize stover are essential for sustaining livestock during dry season. Crop residues retention for soil cover compute with animal feed, making it difficult for farmers to allocate residues to mulching. This trade-off between soil conservation and livestock feeding illustrates resource competition that shapes farmers' adoption decision (Valbuena et al., 2012).

Although smallholder farmers perceived multiple co-benefits associated with ecosystem-based adaptation practices, these perceptions do not necessarily translate into higher adoption intensity. Statistical analysis revealed no significant relationship between perceived co-benefits and the number of ecosystem-based adaptation practice adopted by individual farmers. This finding underscores a potential gap between perception and behavioural uptake. It reflects the concept of value-action gap or intensity behaviour gap whereby farmers recognize the benefits derived from ecosystem-based adaptation practices without necessarily integrating them into sustained or strategic adaptation decisions. Moreover, structural constraints including limited financial capital, labour shortage, limited agricultural land, and inadequate extension services continue to amplify the impediment of the adoption process. Consequently, perceived co-benefits become a necessity, but insufficient condition for adoption. Addressing these structural barriers is therefore essential for scaling up the implementation of ecosystem-based adaptation practices among smallholder farmers in semi-arid regions.

CHAPTER SIX

GENERAL CONCLUSION

The study concludes that smallholder farmers predominantly rely on low-cost, locally adaptable ecosystem-based adaptation practices that align with their local farming systems centred on the cultivation of maize, beans and pumpkin, and livestock rearing. The perceived effectiveness in enhancing soil fertility, water retention, crop productivity and the overall livelihood resilience was associated to the most widely adopted ecosystem-based adaptation practices. The effectiveness of ecosystem-based adaptation strategies was enhanced by the implementation of multiple practices in combination to generate interconnected agronomic, ecological and socioeconomic co-benefits. Mixed cropping was perceived as highly effective in improving soil fertility, water infiltration, pest regulation, income diversification, food security and ecosystem service provision. Integrated crop-livestock was valued for improving nutrient cycling and soil fertility, while mulch tillage contributed to soil moisture retention, erosion control, and higher crop yields. The perceptions of the smallholder farmers of the co-benefits clustered around key ecosystem functions that include soil fertility and nutrients cycling, biodiversity enhancement, and soil water regulation and erosion control. The smallholder farmers' perceptions align with empirical scientific evidence, reinforcing the effectiveness of diversified and integrated farming systems in enhancing resource-use efficiency, reducing pest and disease pressure strengthening household resilience.

However, these perceived co-benefits were not statistically significant to explain the adoption intensity of EbA practices among smallholder farmers. Meaning that, the adoption of EbA practices is not determine solely by the presence or recognition of co-benefits, rather, by a combination of enabling conditions and resource endowments available to smallholder farmers.

Therefore, the study recommends the integration of ecosystem-based adaptation practices that align with smallholder farmers' priorities and socioeconomic realities. Policymakers and development partners should prioritize the promotion of locally appropriate, resource-efficient, and low-cost adaptation strategies through participatory research and extension programs. Integrating indigenous and local knowledge with scientific innovation is essential to enhance adoption of ecosystem-based adaptation practices, optimize resilience, and ensure long-term sustainability of smallholder farming systems.

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APPENDICES

Appendix I: Ethical clearance

UNIVERSIDADE EDUARDO MONDLANE

Faculdade de Agronomia e Engenharia Florestal
Conselho Científico

To Whom It May Concern

Subject: Exemption from Ethical Approval

This is to certify that the research study entitled: "**Ecosystem-based Adaptation Practices for Climate Resilience: Evidence from Smallholder Farmers' Perceptions of Co-benefits and Adoption Decisions in Mabalane District, Mozambique**", conducted by **Claudius Patrick Waran, Jaime Carlos Macuácua and Nícia Givá** does not require ethical clearance from the Institutional Research Ethics Committee of Eduardo Mondlane University.

The study involves the collection of non-sensitive information related to co-benefits from adopting ecosystem-based adaptation practices and examines how the perceived co-benefits shape adoption decisions among smallholder farmers. Data collection was carried out using a mixed-method approach that includes semi-structured questionnaires, key informant interviews, and gendered specific focus group discussions to allow free sharing of information. Survey questionnaires were used to collect data at farm household level targeting farm household heads (husband or wife). The questionnaires topics included: socio-demographic characteristics of the respondents, farming practices, perceived effectiveness of the practices, perceived co-benefits from the practices, factors influencing farmers' adoption decision.

No personal or identifiable data from individuals was collected, and no human interventions were performed. As the data did not pose physical, psychological, or social risk, after due consideration, this research is hereby exempted from formal ethical approval requirements.

Should there be any need for further clarification, please do not hesitate to contact our office.

Sincerely,

The President of the Scientific Council

(Doutora Laura [illegible])

Av. Julius Nyerere, nº 3453, Campus Principal, C. Postal 257, Tel.: [illegible] Maputo – Moçambique

Appendix II: Data collection tool

UNIVERSIDADE EDUARDO MONDLANE

FACULTY OF AGRONOMY AND FORESTRY ENGINEERING

Course: MSc. in Climate Change in Agrarian Systems

Title: Ecosystem-based Adaptation for Smallholder Farmers to Improve Crop Yield in Semi-arid areas

Students' name: Claudius Patrick Taban WARAN

Registration number: 20235548

Supervisor: Prof. Nicia Giva, PhD

The aim of this research is to assess the effectiveness of ecosystem-based adaptation practice in improving crop yield in semi-arid area.

The research focus on understanding how ecosystem-based adaptation practices can help smallholder farmers mitigate the impacts of dry spells and enhance their crop production.

All response will be treated with Strick confidentiality and the data collected will be used strictly for the purpose of academic research.

Your participation is voluntarily and the survey will take approximately 30 – 40 minutes to complete.

For any inquiries or clarification, please contact: **Claudius Patrick Taban WARAN**

Email : w.taban@yahoo.com

Tel : +25886509932

Thank you for your time and participation in this survey and your input is very crucial for the success of this research

Research Questionnaires

Section A : Demographic Information

Tick (√) in the box provided

1. **Name of the administrative post: ……………………… village: ……………….………**

2. **Gender:** Male ☐ Female ☐

3. **Age:** < 20 ☐ **,** 20 – 25 ☐ **,** 26 – 30 ☐ **,** 31 – 35 ☐ , 36 – 40 ☐ , 41 – 45 ☐, > 45 ☐

4. **Marital status:** Single ☐ Married ☐ Widowed ☐ Divorced ☐

5. **Level of education:** Non ☐ , completed 5th grade ☐ , completed 7th grade ☐ completed 10th grade ☐ Completed 12th grade ☐ , University ☐ , Others……………

6. **Number of family members:** Less than 5 ☐ 5 – 10 ☐ More than 10 ☐

Section B: Farming Practices

7. **What is your main source of livelihood?**

   a. **crop farming** ☐ **, b. livestock keeping** ☐ **, c. fishing** ☐**, d. wage** ☐ **, c. Others** ☐

8. **For how many years have you been practicing farming in this area(village)?**

   5 – 9 years ☐ 10 – 19 years ☐ , 20 – 29 years ☐ , > 30 years ☐

9. **What is the size of your farm?**

less than 0.5 hectare ☐, 0.5 to 1 hectare ☐, 1.5 hectare ☐, 2 hectares ☐, 3 hectares ☐ > 3 hectares ☐

10. **What type of farming systems do you practice?** *(if it is crops farming select also the crops you grow and if you keep livestock also, select the one you have by a* ***TICK (√))****.*

TYPE OF FARMING SYSTEM				
A		**B**		**No. of livestock**
Crop farming		**Livestock farming**		
maize		goats		
cowpeas		sheep		
sorghum		cattle		

groundnuts		pigs		
pumpkin		chicken		
sweet potato		duck		
cassava		turkey		
tomato		pigeon		

11. Select by ticking (√) the season for start and end of rain and particular farming activity in the table below:

FARMING ACTIVITIES	**SEASON**											
Start of rains	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
End of rains	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Land preparation	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Planting crops	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
maize												
cowpeas												
sorghum												
groundnuts												
pumpkin												
cassava												
Weeding crops	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Harvesting crops	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*

<u>Section C: Effects of dry spells on crop yield</u> *(chose by circling any that is applied)*

12. What factor mostly affect your crop yield?

(1). Mid-season dry spells (2). heat wave (3). delay in rain and early cessation

(4). all the above If any other, please mention: …………………………………………

13. What negative effects does dry spell cause on your farm?

(a). poor seeds germination (b). poor yields and crops failure (c). heat burns
(c). pest and diseases outbreak (d). delays planting dates (e). all the above

If any other, mention………………………………………………………………

14. In the last growing seasons, in which months have you experienced dry spell occurrence, and how many times has it happened over a complete growing season? *(Select the month by a tick* ***(√)*** *and provide the number of occurrence).*

DRY SPELL	**SEASON**												**No. of dry spells**
Months in season	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	
Months of dry spell occurrence													

15. When do you experience dry spell occurrences during cultivation season? *(chose by circling)*

(1) beginning of growing season (2) middle of growing season

(3) end of growing season (4) throughout the growing season

16. What is the average range of dry spell duration/length you have ever experienced over the crop cycle?

(a). 7 days (b). 10 days (c). 15 days (d). 20 or more days

17. From your farming experience over the number of past years, since which year have you been experiencing the occurrences of dry spells?

……………………………………………………………………………………………..…

18. What do you think could be the main cause of dry spells?

……………………………………………………………………………………………..

19. **Consider the occurrence of dry spells over the past growing seasons, what was the least Kgs of maize you were able to harvest from your farm?** *(Choose by ticketing under the yield Kgs)* (*1200Kgs = no effect, 900 - 1199Kgs = less effect, 600 – 899 Kgs = moderate effect, 240 - 599 Kgs = high effect, less than 240 = total loss*)

Maize yield /hectare				
Kgs	*1200Kgs*	*900 - 1199Kgs*	*600 – 899 Kgs*	*240 - 599 Kgs*
Yield harvested				

Section D: Adaptation strategies

20. **What are the farming practices that you apply to help your crops grow and yield from the effects of dry spells?**

☐ mixed-cropping ☐ crop rotation ☐ mulch tillage

☐ mulching ☐ agroforestry ☐ crop integrated-livestock

☐ rain water harvesting

21. **From the farming practices you have selected, tick (√) for the benefits (co-benefits) you get from each practice in the table below according to Dimension 1: ecosystem service provision, Dimension 2: adaptation benefits and Dimension 3: livelihood and food security improvement**

S/N	**Farming Practices (EbA)**	**Dimension 1: Ecosystem Service Provision (Perception of farmers on the adapted practice, 1 = Yes, 0 = No)**					
		improved soil fertility and quality	**soil nutrient regulation**	**improved water infiltration and erosion control**	**regulate surface run off**	**agrobiodiversity improvement-vegetation diversity**	**Agrobiodiversity improvement-pollinators**
1							
2							
3							
4							

s/n	Farming practices (EbA)	Dimension 2: Adaptation benefits (Perception of farmers on the adapted practice, 1 = Yes, 0 = No)			
		Improve crop productivity	Reduce crop pests and disease incidents	Reduce damage from dry spell, heat (improved buffering capacity)	Maintain water availability in the soil
1					
2					
3					
4					
5					
6					

S/N	Farming Practices (EbA)	Dimension 3: Livelihood and food security improvement (Perception of farmers on the adapted practice, 1 = Yes, 0 = No)					
		Improved food security	Diversify sources and variety of food	Increase and diversify local income	use local inputs	Use local traditional knowledge	Low implementation cost and labour affordable
1							
2							
3							
4							
5							
6							

22. **Which specific practice do you use to harvest rain water during dry spell?** *(circle the choice)*

(a). Reservoir and ponds (b). Zai and half-moon (c). Stone bunds

(d). Terracing systems (e). Vegetative barriers If any, please specify…...………………

23. **For how long have you been applying these practices?**

…………………………………………………………………………………………..……………

<u>Section F: knowledge on ecosystem-based practice</u> (_chose by circling_)

24. **How did you know that using those local farming practices can reduce the negative effects of dry spell and improve crop yields?**

(1) Government extension services (2) NGOs extension services

(3) Farmers group meetings/trainings/workshops (4) family/community members

If others, specify………………………………………...…………………………………………..

<u>Section E: The effectiveness of the farming practices (EbA)</u>

25. **From your farming experience, how do those practices help or improve the crop yield you harvested? (**_select the scales rating from 1 to 5 to indicate the performance practices)_

1 = strongly disagreed, 2 = disagreed, 3 = neutral, 4 = agreed, 5 = strongly agreed

Dimension 1		**Perception of Farmers on Ecosystem Service Provision**	**Rating Scales**				
s/n	**EbA practices**	**Indicator statement (*roles of the practices*)**	**1**	**2**	**3**	**4**	**5**
		1. The practice improved soil fertility and quality					
		2. The practice improved soil nutrients regulation					
		3. The practice improved water infiltration and soil erosion control					
		4. The practice improved surface run off regulation					
		5. Number of birds, insects have increased in the farm (agrobiodiversity improvement-pollinators)					
1		**6.** The practice has increased more vegetation and tree cover (agrobiodiversity improvement-plant diversity)					

2		**1**. The practice improved soil fertility and quality					
		2. The practice improved soil nutrients regulation					
		3. The practice improved water infiltration and soil erosion control					
		4. The practice improved surface run off regulation					
		5. Number of birds, insects have increased in the farm (agrobiodiversity improvement-pollinators)					
		6. The practice has increased more vegetation and tree cover (agrobiodiversity improvement-plant diversity)					
3		**1.** The practice improved soil fertility and quality					
		2. The practice improved soil nutrients regulation					
		3. The practice improved water infiltration and soil erosion control					
		4. The practice improved surface run off regulation					
		5. Number of birds, insects have increased in the farm (agrobiodiversity improvement-pollinators)					
		6. The practice has increased more vegetation and tree cover (agrobiodiversity improvement-plant diversity)					
4		**1.** The practice improved soil quality and fertility					
		2. The practice improved soil nutrients regulation					
		3. The practice improved water infiltration and soil erosion control					
		4. The practice improved surface run off regulation					
		5. Number of birds, insects have increased in the farm (agrobiodiversity improvement-pollinators)					
		6. The practice has increased more vegetation and tree cover (agrobiodiversity improvement-plan diversity)					
5		**1.** The practice improved soil fertility and quality					

		2. The practice improved soil nutrients regulation					
		3. The practice improved water infiltration and soil erosion control					
		4. The practice improved surface run off regulation					
		5. Number of birds, insects have increased in the farm (agrobiodiversity improvement-pollinators)					
		6. The practice has increased more vegetation and tree cover (agrobiodiversity improvement-plant diversity)					
6		1. The practice improved soil fertility and quality					
		2. The practice improved soil nutrients regulation					
		3. The practice improved water infiltration and soil erosion control					
		4. The practice improved surface run off regulation					
		5. Number of birds, insects have increased in the farm (agrobiodiversity improvement-pollinators)					
		6. The practice has increased more vegetation and tree cover (agrobiodiversity improvement-plant diversity)					

Dimension 2		**Perception of Farmers on Adaptation Benefits**	**Rating Scales**				
s/n	**EbA practices**	**Indicator statement (*roles of the practices*)**	**1**	**2**	**3**	**4**	**5**
1		**1.** The practice improves crop productivity					
		2. The practice reduces crop pests and disease incidents					
		3. The practice reduces damage from dry spell, heat (improved buffering capacity)					
		4. The practice maintains water availability in the soil					
2		**1.** The practice improves crop productivity					
		2. The practice reduces crop pests and disease incident					

		3. The practice reduces damage from dry spell, heat (improved buffering capacity)					
		4. Maintain water availability in the soil					
		1. The practice improves crop productivity					
		2. The practice reduces crop pests and disease incident					
		3. The practice reduces damage from dry spell, heat (improved buffering capacity)					
3		**4.** Maintain water availability in the soil					
		1. The practice improves crop productivity					
		2. The practice reduces crop pests and disease incident					
		3. The practice reduces damage from dry spell, heat (improved buffering capacity)					
4		**4.** The practice maintains water availability in the soil					
		1. The practice improves crop productivity					
		2. The practice reduces crop pests and disease incident					
		3. The practice reduces damage from dry spell, heat (improved buffering capacity)					
5		**4.** The practice maintains water availability in the soil					
		1. The practice improves crop productivity					
		2. The practice reduces crop pests and disease incident					
		3. The practice reduces damage from dry spell, heat (improved buffering capacity)					
6		**4.** The practice maintains water availability in the soil					

Dimension 3		**Perception of Farmers on Livelihood Benefits and Food Security Improvement**	**Rating Scales**				
s/n	**Farming practices**	**Indicator statement (roles of the practices)**	**1**	**2**	**3**	**4**	**5**

		1. Improve food security					
		2. Diversify sources and variety of food					
		3. Increase and diversify local income					
		4. Use local inputs					
		5. Use local traditional knowledge					
1		6. Low cost of implementation and labour affordable					
		1. Improve food security					
		2. Diversify sources and variety of food					
		3. Increase and diversify local income					
		4. Use local inputs					
		5. Use local traditional knowledge					
2		6. Low cost of implementation and labour affordable					
		1. Improve food security					
		2. Diversify sources and variety of food					
		3. Increase and diversify local income					
		4. Use local inputs					
		5. Use local traditional knowledge					
3		6. Low cost of implementation and labour affordable					
		1. Improve food security					
		2. Diversify sources and variety of food					
		3. Increase and diversify local income					
		4. Increase and diversify local sources of income					
		5. Use local inputs					
4		6. Use local traditional knowledge					
5		1. Improve food security					

		2. Diversify sources and variety of food					
		3. Increase and diversify local income					
		4. Increase and diversify local sources of income					
		5. Use local inputs					
		6. Use local traditional knowledge					
		1. Improve food security					
		2. Diversify sources and variety of food					
		3. Increase and diversify local income					
		4. Increase and diversify local sources of income					
		5. Use local inputs					
6		**6.** Use local traditional knowledge					

Section G: Importance of benefits (co-benefits) of ecosystem-based practices

26. In the table below, rate the co-benefits of the farming practices (EbA) you use in your farm according to their importance following the rating scales from 1 to 5.

(1= Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree)

n/s	Ecosystem Service Provision indicator statement (co-benefits)	Rating scale				
		1	2	3	4	5
1	Improvement of soil fertility and quality					
2	Improvement of soil nutrients regulation					
3	Improvement of water infiltration and water erosion control					
4	Improvement of surface run off regulation					
5	Improvement of agrobiodiversity-pollinators (Number of birds, insects have increased in the farm)					

6	Improvement of agrobiodiversity-plant diversity (Increased more vegetation and tree cover)					

n/s	**Adaptation Benefits**	**rating scale**				
	indicator statement (co-benefits)	1	2	3	4	5
1	Improvement of crop productivity					
2	Reduce crop pests and disease incidents					
3	Reduce damage from dry spell, heat (improvement of buffering capacity)					
4	Maintain water availability in the soil					

n/s	**Livelihood and Food Security Improvement**	**rating scale**				
	indicator statement (co-benefits)	1	2	3	4	5
1	Improvement of food security					
2	Diversify sources and variety of food					
3	Increase and diversify local income					
4	Increase and diversify local sources of income					
5	Use local inputs					
6	Use local traditional knowledge					

Section H: Factors influencing adoption *(choose by circling)*

27. What motivated you to adopt ecosystem-based practices in your farming system?

- **a.** Benefits of the practices
- **b.** Changes in the climate
- **c.** Government technical support and training
- **d.** NGOs technical support and training

e. Land tenure right

f. Financial capability

g. Labour availability

If any other, please mention…………………………………………………………….

28. Is it easy for you to apply ecosystem-based practices on your farm?

Yes ☐ No ☐

Give reason why?..

29. Would you recommend ecosystem-based adaptation practices to other farmers?

(a) Yes ☐ (b) No ☐

Give reason why? ………………………………………………………………………………

30. Are you planning to adapt more ecosystem-based adaptation practices in future?

Yes ☐ No ☐

Give any reasons why?...

31. What resources would allow you adopt more ecosystem-based adaptation practices?

………………………………………………..……………………..………………………………

……………………………………….……………………..…………………………………………

32. Do you believe ecosystem-based practices can help your farming practices continue for good number of years with good yields?

a. Yes ☐

b. No ☐

c. Not sure, ☐

Can you give reasons?..

....

....

33. In your opinion, what will motivate other farmers to adapt ecosystem-based practices?

……

……

34. In your opinion what will not motivate other farmers to adapt ecosystem-based practices?

……
……
……
……

35. Choose from 1 to 5 to express the level of your satisfaction with the performance of ecosystem-based adaptation practices in addressing the negative effect of dry spell on crop yields.

1 = Very dissatisfied, 2 = Dissatisfied, 3 = Neutral, 4 = Satisfied, 5 = Very satisfied

The performance of the roles played by ecosystem-based adaptation practices at farm level address the effects of dry spell on crop yields	**1**	**2**	**3**	**4**	**5**

<u>Section I: Challenges in adoption process</u>

36. What challenges do you face in adapting ecosystem-based practices

1. ………………………………………… 2. …………………………………………

37. If you have additional suggestion, please fill it below:

……
……
……
……
……
……
……

THANKS, YOU VERY MUCH FOR YOUR TIME

<u>Focus Group Discussion Guide</u>

<u>Title: Assessing the effectiveness of ecosystem-based adaptation practices in improving crop yield in semi-arid areas</u>

Target participants: Smallholder Farmers

Duration: Maximum 90 minutes

Facilitator: ………………………………………………………………………………

Note taker: ………………………………………………………………………………

Date and location: …………………………………………………………………………

Opening instruction (5 – 10 minutes)

- ➢ You are all welcomed and thank you for joining us today. We are here to learn about farming practices specially related to dry spells and how you respond to change in the climate. There is no right or wrong answer, we are here to listen and understand your perspectives. Everything shared in this discussion will remain confidential and used for the purpose of this research only.

Icebreaker:

- Can you tell us your names, how long you have been farming, and what crops you mostly grow?

1. **Farming practices and cropping calenda**

Objective: <u>To understand local agricultural practices and farming cycles.</u>

- What are the main farming practices used in this community
- Do farmers used more than one practice in the farm? For example, like which ones being used together?
- How large are the farms smallholders typically cultivate?
- Can you describe the farming calenda (prob for: when do you usually start land preparation, planting seeds, weeding and harvesting).
- Has any of these farming practices changed in recent years? If yes, why?

2. **Dry spells and their impacts on crop yields**

Objective: <u>Explore negative effects of dry spells on crop yields</u>

- how would you describe the rain pattern in this area?
- Can you explain what a dry spell looks like here? (timing, duration and frequency)
- How do dry spell affect your crops specially in terms of yield?
- Have these effects become worse, less severe, or stay the same over the years?
- How does rain variability affect they farming calenda, looking at planting, weeding and harvesting.
- Can you recall a season when crops failed due to poor rains or dry spells? What happened in terms of yield? How did people cope up with the situation?

3. **Adaptation strategies to dry spell**

Objective: <u>To identify the current adaptation strategies, use by famers.</u>

- What local farming strategies do you used to cope with dry spell and delay in rains?
- Are there other local methods that you use to help reduce the impacts of no rain during growing season?
- Have you changed planting date, crop varieties or the way you do farming in response to dry spell or delay in rains?

4. **Effectiveness of current farming practices**

Objective: <u>To assess how well existing practices help address dry spell impacts</u>

- From your experience, do the current practices help deal with dry spell?
- Which practices seem to work best during a dry year?
- Are there practices that used to work but no longer do? Why?

5. **Knowledge of ecosystem-based adaptation practices**

Objective: <u>To explore awareness of ecosystem-based practices and its sources</u>

- Have you heard of farming practices that use nature to adopt to climate condition? (e.g agroforestry, mulching etc….)
- Do you understand what is meant by the use of nature to help your farming practices stand against dry spell?
- Where do you get new farming techniques or knowledge from? (prob for: agricultural extension workers, NGO's, radio farmers group, local leaders)

6. **Factors influencing adoption of ecosystem-based adaptation practice among farmers**

Objective: To understand what helps or hinders the adoption of ecosystem-based practices

- What do you thing influence farmers to adopt ecosystem-based practice?
- Are there enabling programs promoting adaptation of ecosystem-based practices? If yes who are running the program?
- Is there difference in adoption among different groups? (young vs elderly, men vs women).

7. **Challenges in adopting ecosystem-based adaptation practices**

Objective: To identify challenges specific to ecosystem-based practices

- What are the key challenges farmers face in adopting ecosystem-based practices?
- What interventions are needed to overcome these challenges?

8. **Co-benefits of ecosystem-based practices**

- Apart from improving crop yield, what other benefits have farmers experienced or reported when using ecosystem-based practices?
- Are these co-benefits motivating more farmers to adopt ecosystem-based practices?

Closing questions

- If you had opportunity, what practices would you want to adopt to better deal with dry spell?
- What advice would you give other farmers about managing dry spell effectively?
- Is there anything you would like to share about farming and dealing with dry that is not asked?

To be completed by the facilitator:

1. **Notable quotes:**

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

2. **Emerging themes:**

…………………………………………………………………………………………………
…………………………………………………………………………………………………

…………………………..………………………………………………………………………………
……………………………………………………………………………………………………..……

3. **Group participation level**: ……………………………………………………………………
4. **Recommendations:**

………………………………………………………………………………………………………
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Appendix III: Inform consent

REPÚBLICA DE MOÇAMBIQUE
PROVÍNCIA DE GAZA
GOVERNO DO DISTRITO DE MABALANE
SERVIÇO DISTRITAL DE ACTIVIDADES ECONÓMICAS

Assunto: Declaração de Consentimento Informado

O Serviço Distrital de Actividades Económicas (SDAE) do distrito de Mabalane concede, por meio deste documento, permissão ao Sr. Claudius Patrick Taban WARAN, estudante da Universidade Eduardo Mondlane, para conduzir o projeto de investigação intitulado "Práticas de adaptação baseadas em ecossistemas para resiliência climática: Evidências das perceções de pequenos agricultores sobre os benefícios colaterais e decisões de adoção no distrito de Mabalane".

O estudo está autorizado a ser realizado nas comunidades locais de Mabalane, de 11/08/2025 a 11/09/2025. Esta autorização é concedida no entendimento de que a investigação respeitará as normas da comunidade, garantirá a confidencialidade dos participantes e será utilizada estritamente para fins académicos.

Autorizado por:____________________

Posição: Gestor de Recursos Humanos

Data: 11 Agosto de 2025

Appendix IV: Article 1

TYPE Original Research
PUBLISHED 04 May 2026
DOI 10.3389/fagro.2026.1790242

frontiers in Agronomy

Check for updates

OPEN ACCESS

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Ecosystem-based adaptation practices for smallholder farmers′ climate resilience: perceived effectiveness and co-benefit importance in Mabalane District-Mozambique

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Ecosystem-based adaptation practices among smallholder farmers in drought-prone areas provides a positive response strategy to the increasing challenges posed by climate change, particularly declining crop yield under dry spells condition. Despite increasing acknowledgement of the role ecosystem-based adaptation practices play in enhancing agricultural resilience, very little studies have been done on the perception of smallholder farmers of the effectiveness of these practices. The objective of this study was to assess the perceived effectiveness of ecosystem-based adaptation practices adopted by smallholder farmers and the co-benefits importance in enhancing climate resilience. The study used a mixed-method approach involving a one-time household survey conducted from 11 September to 11 October 2025, lasting one month, with 360 smallholder farmers targeting household heads in Mabalane district in centre of Gaza Province of Mozambique. Purposive sampling, focus group discussions and key informants′ interviews were used for data collection. The results of the study revealed three key ecosystem-based adaptation practices namely mixed cropping (83.9%), integrated crop-livestock management (57.2%) and mulch-tillage (51.1%) as the most widely adapted practices among smallholder farmers. Perceived effectiveness was highest for practices that visibly improved soil fertility and quality, crop productivity and food security. Furthermore, the study revealed that smallholder farmers prioritize soil fertility improvement, increased crop productivity, enhanced soil moisture retention, and food security improvement. It is concluded that the predominance of the key ecosystem-based adaptation practices in the study area is attributed to their perceived effectiveness and their direct and synergistic contributions to climate resilience within the community′s traditional farming system, and in the context of locally important staple food crops.

KEYWORDS
climate change, dry spells, ecosystem-based adaptation, effectiveness, resilience, smallholder farmers

1. Introduction

Rural communities in sub-Sahara Africa rely more on agriculture, which remains the cornerstone of livelihoods employing over 60% of the population and serving as the primary source of income, food security, and social stability (Boahen et al., 2023). Changes in the climatic conditions have directly impacted agriculture, a very important sector among the rural communities across sub-Sahara Africa (Nath and Behera, 2011). Especially in Mozambique with estimated 32 million people, agriculture is the basis of its economy contributing 27.5% of the total Gross Domestic Product (GDP) of which 4.3 million farmers operate in small scale level (Mondlhane et al., 2025). Smallholder farmers in Mozambique rely almost entirely on rainfall as the main source of water for crops production, putting them at a very high risk of climate vulnerability (Silva and Matyas, 2014). Factors such as erratic rainfall patterns, rising temperatures, and more frequent extreme weather events are undermining agricultural productivity, livestock production, food security, income, and the well-being of rainfed smallholder farmers (Harvey et al., 2018). The severity of climate change on subsistence farming largely depends on agroecological condition particularly the antecedent soil moisture content and the crops growth stage (Barron et al., 2003).

For instant in Mabalane district, the rural communities depend on agroecosystems and woodland ecosystem services such as firewood, charcoal, wild edible fruits, building materials, medicinal plants, livestock grazing and subsistence farming to support almost the entirety of rural households' livelihoods (Woollen et al., 2016). The agroecosystems' livelihood-supporting services and resources contribute nearly 90% of rural households (Munang et al., 2013). However, the district is one of the areas in the southern region of Mozambique that is the driest and highly susceptible to land degradation caused by soil erosion due to the physical characteristics of its soil (fragile structure, low water retention capacity), and loss of biodiversity due to anthropogenic activities such as deforestation mainly for charcoal production and commercialization as the dominant economic activity, animal grazing and farming practices (Woollen et al., 2016). Dry spells caused by late onset (delayed November rains) and early cessation (lack of February – March rains) is a critical issue that heightened droughts impacts on crop yields among the rainfed farming communities in this region (Baez et al., 2020). A dry spell is defined as a sequence of dry days including days with rainfall less than 1 mm as threshold value during growing season and is forecasted to intensify in east and southern Africa in the future (Chimimba et al., 2023). Dry spell is different from drought in terms of duration, intensity and impact on crops, and drought is defined as a period of time when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems (Haile et al., 2020). About 75% of lands in Mabalane district are arid and semi-arid, receive low and variable rainfall between 616 mm and 766 mm per year and show a strong seasonal distribution with more than 80% falling in the warm and wet season from November to March (Araneda-Cabrera et al., 2021). In addition, potential evapotranspiration ranges from 1000 to 1300 mm per year largely exceeds precipitation level (de Sousa et al., 2017). Observed trends showed a decline in November rains (planting onset) and reduced heavy rain periods, leading to fewer rainfall events and extended dry spells mid-season (Takele et al., 2023). For instant, the 2001/2002 main season was characterized by irregular and insufficient rains in the southern and central regions of the country, rains started in October, then stopped briefly and resumed in November-December and then ceased completely in January (Takele et al., 2023). In some places, the rain stopped as early as mid-December, while in other locations rain stopped in January. There was virtually no rain in the southern region from January to March, resulting to poor grain-filling in maize, with around 60, 000 hectors yielding less than 10% of typical output (FAO, 2014). Another scenario includes the 2015–2016 El-Nino event across southern Africa, where the southern and central regions of Mozambique also experienced severe drought conditions which caused significant reduction in maize yields by 20%-30% affecting the staple crop for the majority of the population; the large proportion of maize failure was due to the irregular rainfall patterns that resulted in a delayed onset and early cessation of rains during the growing season (Rembold et al., 2016).

Therefore, a midst the many constrains, smallholder farmers in fragile agroecological zones such as arid and semi-arid lands try out various actions and innovations to enhance their resilience and adaptation. Adaptation is defined as the initiatives and measures to reduce the vulnerability of nature and human systems against actual or expected climate change effects (IPCC, 2014). Smallholder farmers may opt for adaptation strategies such as irrigation, the use of early-maturing and drought resistance crop varieties, shift planting dates, use of inorganic fertilizers among others (Nelson et al., 2022). However, such adaptation strategies are limited in terms of costs and sustainable ecosystem management (Nanfuka et al., 2020). Research studies conducted in various countries across sub-Sahara Africa showed that, one effective method to supporting smallholder farmers in maintaining their farm-based livelihoods amidst the growing challenges of climate change and variability is by promoting farms management practices that utilize agrobiodiversity and ecosystem services which offer valuable adaptation benefits (Mburu et al., 2016). Several studies proved ecosystem-based adaptation practices as suitable strategy in response to climatic challenges by leveraging the services provided by healthy ecosystems to help communities adapt to climate impacts (Vella et al., 2012).

Ecosystem-based adaptation practice in the context of agriculture is defined 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 variabilities (Vignola et al., 2015). Additionally, a review by Mondlhane et al., 2025, pointed out conservation agriculture as one of the best and most promising solution 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. The above principle can ultimately result in the reduction of soil erosion, the improvement of water use efficiency, and regulation of the upper soil temperature among other beneficial effects. For instance, maize is the most cultivated crop in the southern region of Mozambique, the use of maize stover to cover the surface can be an advantage due to its availability, and it can be used as mulching. Another common practice used also include diversification of crops by rotation with cereals and legumes such as cowpea and peanut or cereals-legume intercropping, as these strategies provide insurance against environmental fluctuations, since the different species occupy different niches and respond in different manners to the changes (Zakir et al., 2023).

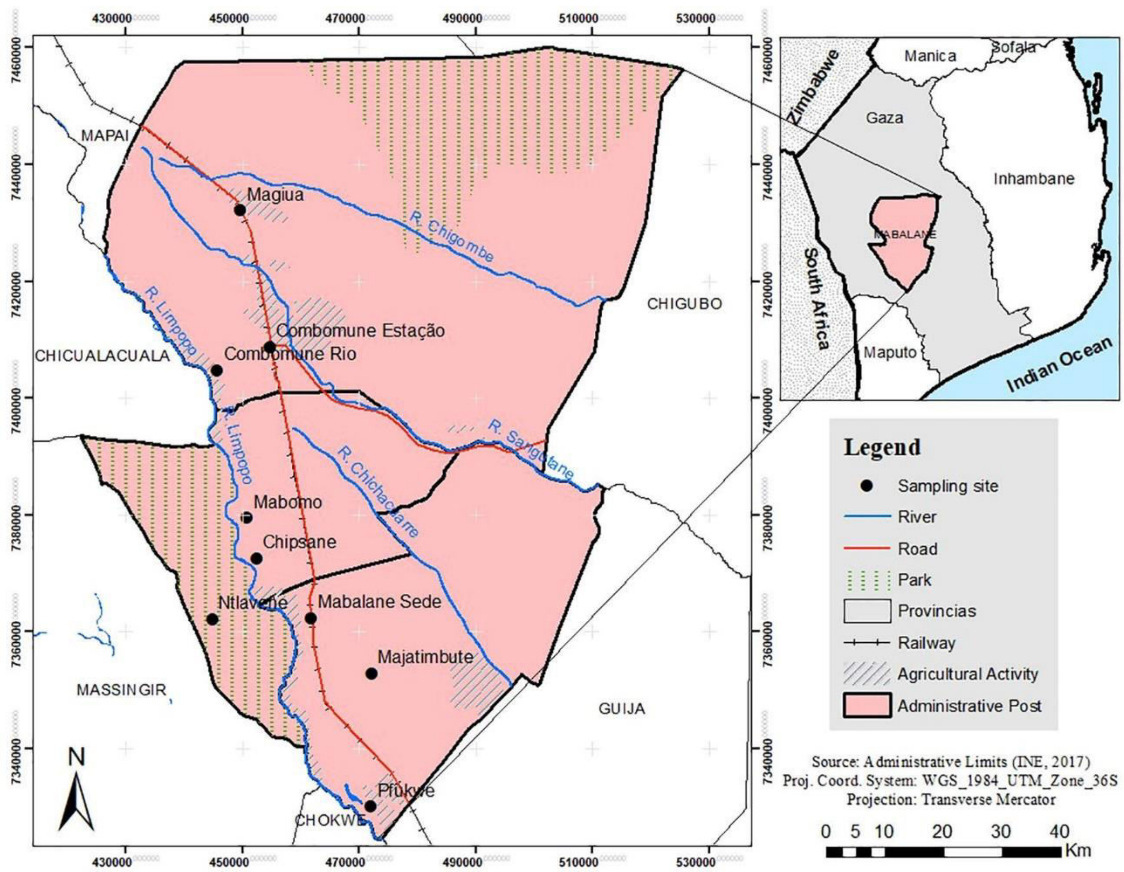
Furthermore, implementing approaches such as agroforestry, uses of local tree species as crop covers, inclusion of perennial crops in agriculture fields can maintain complex agrobiodiversity by providing essential habitat for pollination species and predators of pest species and by this regulate the functioning of biological control (against insects and weeds). Although perennial crops are not considered to have higher economical profits for smallholder farmers, the role they play in enhancement of biodiversity help in sustaining agricultural production (Maskell et al., 2023). The results from these studies revealed the opportunities of ecosystem-based adaptation use that include improvement and maintenance of farm production, buffering of biophysical impacts of climate change, increase of food security while providing multiple co-benefits which contribute to poverty alleviation, resilient livelihood and biodiversity conservation (Dorren and Schwarz, 2016).

Although ecosystem-based adaptation practices are widely recognized for their potential to sustain farm-based livelihoods, very few studies have investigated their effectiveness from the perspective of smallholder farmers highlighting critical research gap between scientific investigations and smallholder farmers' real-world experiences. Therefore, the objective of the study was to assess the effectiveness of ecosystem-based adaptation practices that smallholder farmers use at farm-level. To achieve the above objective, the study investigated a range of ecosystem-based adaptation practices used by smallholder farmers as strategies to improve crop yield. In addition, to understand these strategies requires examining not only what practices were being used but also how smallholder farmers evaluate them. This study therefore identified the specific ecosystem-based adaptation practices adopted by smallholder farmers, explored smallholder farmers' perceptions of the effectiveness of these practices in enhancing crop productivity, and assessed how smallholder farmers perceive the importance of the co-benefits in their farming system. These inquiries together provide a comprehensive picture of how ecosystem-based adaptation practices contribute to climate resilience and farm productivity in smallholder farming system in the study area.

2. Materials and methods

2.1 Study area

Mabalane District shown on Figure 1 is located at the centre of Gaza Province 23.849°S 32.62°E. The province is South-east



Mozambique, stretching from the coast to the border with South Africa and Zimbabwe. Much of the province is very dry and beyond the narrow coastal strip centred on Xai-Xai, rainfed agriculture is confined to the river valleys of the Limpopo, Changane and Elephant rivers.

Mabalane District is approximately 314 Km North of the capital Maputo, and it covers an area of 9580 Km^2 of which 75% is ASALs (arid and semi-arid lands) with a population of 32, 040 inhabitants, and the population density of 3 people per Km^2, far below the national average of 25 people per Km^2 (Ng'ang'a et al., 2011). The district shares 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 which is perennial and River Chigombe, River Sungutane and River Chichakuarre which are seasonal rivers respectively (Ministério de Administração Estatal, 2005).

The climate is tropical arid with average temperature of 24 °C, rainfall is low and variable between 616 and 766 mm/year falling mostly from November to March, evapotranspiration is very high at 1000 to 1300 mm/year more than the rainfall (de Sousa et al., 2017). The forest ecosystems consist of woodland that cover greater than 80% of the land mainly consisting of Mopane woodlands. Mopane (*Colophospermun mopane*) is one of the preferred indigenous hardwood species for charcoal production as the dense wood produces slow-burning charcoal (Falcão, 2008).

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. Soil 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) (Woollen et al., 2016). These latter areas are disconnected by large shallow depression of clay soils that forms watercourses for few weeks in a year (Ng'ang'a et al., 2011).

The major economic activity is charcoal production and commercialization (the district with the highest number of licenses for charcoal production in Gaza province), with households' livelihoods depend traditionally on rainfed agriculture and livestock keeping (Baumert et al., 2016). The communities raise livestock mainly cattle, goats, pigs and chicken, and their farms have an average 4.1 hectors with the main agricultural products including maize, cowpea, pumpkins, water melon, groundnuts and sweet potato. Both livestock and farms are threatened by the negative effects of climate change (CIAT; World Bank, 2017).

2.2 Theoretical framework

Ecosystem-based adaptation was derived from the concept of ecosystem which evolved in the field of ecology into one of the most fundamental ideas which has a wide range of application in ecological research and problem management (Dong-Uuro and Peprah, 2024). The ecosystem-based adaptation is focused on the premise that ecosystem services are very key in helping people adapt to the adverse impacts of climate change (Secretariat of the Convention on Biological Diversity, 2009). To explore the concept of ecosystem-based adaptation practices in the context of agriculture to improve smallholder farmers' climate resilience, the theoretical framework is drawn on interdisciplinary synthesis of ecological science, resilience theory and development studies that reflect the inherently complex, dynamic and adaptive characteristics of coupled human-environment systems (Folke, 2006). This integrative foundation provides a rigorous basis for evaluating the extent to which ecosystem-based intervention can sustainably enhance climate-resilient livelihood, with particular emphasis on the vulnerability and adaptive capacities of smallholder farmers (Reid, 2016). Different theoretical frameworks have been developed with key elements and criteria to evaluate the effectiveness of ecosystem-based adaptation and to select practices that fit to be ecosystem-based helped to evaluate the measures' efficacy in promoting adaptive capacity and resilience while providing multiple benefits.

For the purpose of this study, Vignola et al. (2015) framework was adopted to identify ecosystem-based adaptation practices and assessing their effectiveness. Vignola et al. (2015) framework is relevant for use in the context of smallholder farmers and is valuable in simulating 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 (Kissi et al., 2023). Vignola et al. (2015) framework is based on applied interdisciplinary theories that are drawn from various disciplines such as ecology, sociology and economics to develop practical strategies for climate change adaptation in the agricultural communities.

The key theories and concepts upon which Vignola et al. (2015) framework is linked include: Firstly, the ecosystem services theory, that points ecosystem services such as water regulation, soil fertility, and pollination as crucial for human well-being and agricultural productivity (Smith et al., 2013). Ecosystem-based adaptation aims to conserve and sustainably manage these services to support climate adaptation. Secondly, the Socio-ecological systems theory that views human and ecological systems as interconnected and co-evolving. The socio-ecological theory expresses the fundamental of understanding the interactions between social and ecological components to develop effective adaptation strategies (Anderies et al., 2004). Thirdly, the sustainable livelihood theory that focuses on the assets and capabilities that individuals and communities utilize to achieve well-being. Ecosystem-based approach aims to enhance these assets such as nature, social and financial to improve resilience to the negative impacts of climate change (Silva and Matyas, 2014). Fourthly, the institutional theory that expresses the arrangement and governance structures that play a critical role in the implementation of ecosystem-based strategies where effective policies and institutions are necessary to support the adoption and scaling of ecosystem-based adaptation practices (Iza, 2021). As such, Vignola et al. (2015) framework has been applied to the wide variety of agricultural systems that exist globally, for instant, the successful application of Vignola et al. (2015) framework include the smallholder coffee farmers in Mesoamerica (Vignola et al., 2015), smallholder farmers in the Otti basin, Togo (Abbey, 2023), and in contrast (Nanfuka et al., 2020), use the same framework for characterizing ecosystem-based adaptation practices for drought for smallholder cattle farmers in the central Uganda.

Therefore, Vignola et al. (2015) framework was adopted in the context of this study to select agricultural practices that fit to be considered ecosystem-based adaptation practices appropriate for smallholder farmers and also to provide indicators that assess the effectiveness of the identified ecosystem-based adaptation practices at farm level.

A given agricultural practice that met at least one criterion in each of the "ecosystem service provision" and "adaptive benefits" dimensions were considered ecosystem-based adaptation practice. However, practices that fulfil at least one criterion in all the three dimensions ("ecosystem service provision", "adaptation benefits", "livelihood and food security improvement") were considered ecosystem-based adaptation practices appropriate for smallholder farmers (Vignola et al., 2015). The underlying criteria for each dimension are presented in Table 1.

2.3 Sampling and data collection

The sample size (n = 360) was derived from Cochran's formula for sample size of finite population given by: $S = Z^2 PQ/E^2$ (Hasan and Kumar, 2024), where S is the sample size, Z^2 is the deviation set at 1.96, P is the estimated number of population proportion, Q = 1-P, and E is 5% margin of error.

The source of the statistics of the smallholder farmers was Serviço Distrital de Actividades Económicas (SDAE), a government institution that provides technical support to local communities and stakeholders particularly in the sector of agriculture, fisheries and climate resilience at district level. The district registered a total of 5479 producer farmers, 1643 men and 3836 women. A total number of 44 farmer's associations are registered of which 33 are active with 754 members composing of 226 men and 528 women.

TABLE 1 Theoretical framework (Source: adopted and modified from Vignola et al. (2015).

Dimension 1 Ecosystem Service Provision	Dimension 2 Adaptation Benefits	Dimension 3 Livelihood and Food Security Improvement
1. Improve soil fertility and quality	1. Improve crop productivity	1. Improve food security
2. Improve soil nutrient regulation	2. Reduce pests and diseases incidents	2. Diversify sources and variety of food
3. Improve water infiltration and erosion control	3. Reduce damage from climate variability	3. Increase and diversify local income
4. Improve surface runoff regulation	4. Maintain water availability in soil	4. Use local inputs
5. Improve agrobiodiversity-pollinators		5. Use local traditional knowledge
6. Improve agrobiodiversity-plant diversity		6. Low cost of implementation and labour affordable

$$S = \frac{Z^2 PQ}{E^2}$$

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:

$$n = \frac{S}{1 + \frac{S-1}{N}}$$

Therefore, substituting the values, n ≈ 359.05.

Due to lack of detailed statistics of the producer 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 of the district (approximately 120 farmers per administrative post) and further sub-divided for the nine localities where the data were collected across the district (three localities in each of the three administrative post with approximately 40 farmers per locality). The localities were selected randomly to include agricultural land near River Limpopo where most farming activities take place due to the fertile soils and water availability for irrigation and also agricultural lands in dry areas far away from River Limpopo to cover diverse agroecological niche. Within each locality, household heads were selected using a random walk sampling method. When sample quota was not met in a selected locality data collection was extended to the nearest eligible village to complete the shortfall.

The data collection was carried out using a mixed-method approach that includes semi-structured questionnaires, key informant interviews, and gendered specific focus group discussions to allow free sharing of information. A pretest of the questionnaires was conducted during renaissance survey to obtain prior information that could be essential for data collection. The questionnaire was readjusted during renaissance survey where the term intercropping was changed to mixed cropping appropriate for the farming practice farmers adopt in the study area. Survey questionnaires were used to collect data at farm household level targeting farm household heads (husband or wife). The questionnaires topics included: socio-demographic characteristics of the respondents, farming practices, perceived effectiveness of adopted ecosystem-based adaptation practices, co-benefits farmers perceived from the practices and their level of importance.

The study was conducted in English language; however, the majority of the smallholder farmers speak local language Changana not even Portuguese which is the official language in the country. As such, a guided interviews using questionnaires were conducted in the local language to allow establishment of trustworthiness with the respondent hence providing validation of the responses (Nanfuka et al., 2020). The questionnaires provided opportunity for the respondent to add any other information if necessary and were not among those in the questions. The respondents were interviewed in their homestead or farms to avoid interruption of their work.

In each administrative post, 5 key informant interviews were held with individuals selected based on their technical skills, social position, experience and knowledge to capture diverse perspective without redundancy (Muellmann et al., 2021). To supplement the information and ensure quality control check of the data, two gender specific focus group discussions were conducted in both Portuguese and Changana language in each administrative post: (Mabalane Sede, Ntlavene and Combomune respectively). Each focus group consisted of a maximum 12 participants optimal for facilitating interaction and ensuring diverse perspectives (O.Nyumba et al., 2018).The representative group of both male and female were selected with the help of the district agriculture extension officers. Participants were chosen based on their direct experience with farming practices and yields in semi-arid conditions, and duration of residence in the study area which was taken into account to be at least more than 5 years. Smallholder farmers who practice monoculture under irrigation for commercial purposes were excluded from the survey.

2.4 Data analysis

The theoretical framework guide was followed to select the farming practices that fit to be ecosystem-based adaptation practices from the list of the farming practices that were identified to be employed by smallholder farmers in the study area. A descriptive statistic of the identified ecosystem-based adaptation practices was done using IBM SPSS statistical package version 25 to know the most commonly adopted ecosystem-based adaptation practices, where the frequency of each identified ecosystem-based practice was expressed in percentage of the overall total frequencies. The perceived effectiveness of the identified ecosystem-based adaptation practices was assessed using Weighted Average Index (WAI) in Excel. Weighted Average is a type of average where each observation in a data set is multiplied by the assigned weight reflecting its importance before summing all data into a single average value (Abbey, 2023). The Weighted Average Index is an important approach commonly used in Likert-scale questionnaires or Rating-scale questionnaires where respondents indicate their level of agreement, importance, satisfaction or frequency using a predefined ordinal scale. This approach is effectively applied in survey involving perceptions, attitudes, or prioritization of factors (Joshi et al., 2015).

The co-benefits of each identified ecosystem-based adaptation practice were categorized into three dimensions based on the theoretical framework such as: (1) Ecosystem service provision, (2) Adaptation benefits and (3) Livelihood and food security improvement and then rated using a rating scale adopted from (Kissi et al., 2023) to compute five effectiveness levels from Weighted Average Index (WAI) values: Highly effective = (3.49 – 4.28); effective = (2.69 – 3.48); moderately effective = (1.89 – 2.68); less effective = (1.09 – 1.88) and not effective = (1 – 1.08) (Akadiri et al., 2013).

The formula for computing Weighted Average Index is given by:

$WAI = \sum (W_iX_i = W_i)$ Where W_i indicates the respective weights for the items, and X_i indicates the value of each item.

Based on the three dimensions of the framework, the results showed which practice has the most effective and suitable role in mitigating the effects of dry spells on crop yield.

Furthermore, Relative Importance Index (RII) analysis was done in Excel to rank the perceived co-benefits of the identified ecosystem-based adaptation practices according to their relative importance. Relative Importance Index (RII) was used to prioritize the indicators in this study. The Relative Importance Index (RII) is one of the most reliable approaches for rating variable using a structured questionnaires on a Likert Scale (Abinaya Ishwarya and Rajkumar, 2020). The Relative Importance Index (RII) approach has been used successfully in similar studies by value (Abbey, 2023; Vignola et al., 2015) and the formula is given below as:

$RII = \frac{\sum W}{A} * N$, whereas W = weighting assigned by each respondent on a scale of 1 to 5, with 1 applying for strongly disagreed and 5 strongly agreed. A = the highest weight, and N the total number of the sample.

Five importance levels was drawn from Relative Importance Index (RII) values such as: High (H) = ($0.8 \leq RI \leq 1$), High-Medium (H-M) = ($0.6 \leq RI < 0.8$), Medium (M) = ($0.4 \leq RI < 0.6$), Medium Low (M-L) = ($0.2 \leq RI < 0.4$), and Low (L) = ($0 \leq RI < 0.2$) (Rooshdi et al., 2018).

3. Results

3.1 Identified ecosystem-based adaptation practices

The results from the descriptive statistics shown on Figure 2, revealed that mixed cropping, integrated crop-livestock, mulch tillage, crop rotation, agroforestry, mulching and rainwater harvesting were the common ecosystem-based adaptation practices used by the respondents as adaptation strategies to cope up with the effects of dry spells in their farming systems. The practices can be categorized into three groups such as: (1) Conservation agriculture practices (mixed cropping, crop rotation, mulch tillage and mulching), (2) Soil and water conservation practices (rainwater harvesting); (3) Integrated soil fertility management practices (agroforestry and integrated crop-livestock) (Abbey, 2023).

The study found a mean of 2.4 ecosystem-based adaptation practices respondents applied per farm, with the number of practices ranging from a minimum of one to a maximum of five practices being applied on a single farm land by smallholder farmers. The distribution of ecosystem-based adaptation practices varies from one administrative post to another in the district as shown in Table 2, in which rainwater harvesting was recorded only in Mabalane Sede. The result shown in Figure 1 revealed that mixed cropping, integrated crop-livestock and mulch tillage were the most highly adopted ecosystem-based adaptation practices compared to the other identified practices.

3.2 Perceived effectiveness of ecosystem-based adaptation Practices

The result of the perceived effectiveness is shown in Table 3, where mixed cropping was perceived by the respondents as highly effective (H-E) in improving dimension 2 and 3 and effective (E) in dimension 1. Both crop rotation and mulch tillage were perceived as effective (E) in improving all the three dimensions. Agroforestry and rainwater harvesting were perceived as moderately effective (M-E) in all the three dimensions. Mulching was perceived least effective (L-E) in improving all the three dimensions. Integrated crop-livestock was perceived least effective in improving dimensions 1 and 2, and effective (E) in dimension 3.

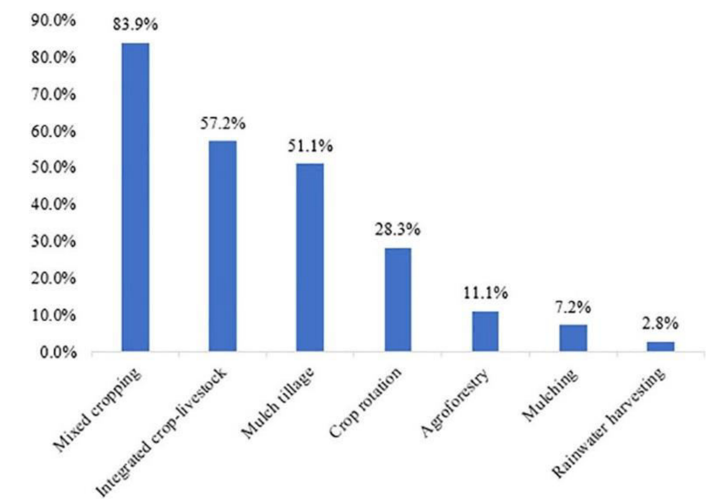


TABLE 2 Distribution of EbA practices across the three administrative posts of Mabalane district.

EbA practices	Mabalane Sede	Ntlavene	Combomune	Total
Mixed cropping	29.2%	29.7%	25.0%	83.9%
Integrated crop-livestock	23.3%	17.2%	16.7%	57.2%
Mulch tillage	16.1%	19.7%	15.3%	51.1%
Crop rotation	9.7%	7.8%	10.8%	28.3%
Agroforestry	5.0%	1.4%	4.7%	11.1%
Mulching	2.8%	1.7%	2.8%	7.2%
Rain water harvesting	2.8%	0.0%	0.0%	2.8%
Total sample size	120	120	120	360
	33.3%	33.3%	33.3%	100.0%

TABLE 3 Perceived effectiveness of ecosystem-based adaptation practices.

EbA practices	Dimension (1) (Ecosystem service provision)		Dimension (2) (Adaptation benefits)		Dimension (3) (Livelihood & food security improvement)	
	Weighted average index	Level of effectiveness	Weighted average index	Level of effectiveness	Weighted average index	Level of effectiveness
Mixed cropping	2.84	E	3.65	H-E	3.90	H-E
Integrated crop-livestock	1.76	L-E	1.84	L-E	2.84	E
Mulch tillage	3.04	E	3.06	E	3.16	E
Crop rotation	2.70	E	2.99	E	3.02	E
Agroforestry	2.62	M-E	2.06	M-E	2.46	M-E
Mulching	1.88	L-E	1.82	L-E	1.88	L-E
Rain water harvesting	1.93	M-E	2.68	M-E	2.48	M-E

Weighted Average Index (WAI) values: Highly Effective (H-E) = (3.49 – 4.28); Effective (E) = (2.69 – 3.48); Moderately Effective (M-E) = (1.89 – 2.68); Less Effective (L-E) = (1.09 – 1.88) and Not Effective (N-E) = (1 – 1.08) (Akadiri et al., 2013).

3.3 Relative Importance Index (RII) of the perceived co-benefits

Relative importance values of each co-benefit as perceived by the respondents are represented in Table 4.

For Dimension 1 (Ecosystem Service Provision); improvement of soil fertility and quality is highly ranked (0.91) followed by improvement of soil nutrients regulation and improvement of water infiltration and erosion control (0.81), then improvement of surface runoff regulation (0.59) and the least ranked was agrobiodiversity improvement for both pollinators and vegetation diversity (0.40). From these results, smallholder farmers perceived these ecosystem services as important co-benefits of implementing ecosystem-based adaptation practices for dry spell resilience.

For Dimension 2 (Adaptation Benefits); the most highly ranked co-benefit was improvement of crop productivity (0.93), followed by improvement of soil's water retention capacity (0.86), then improvement of buffering capacity (0.84) and reduction of pests and diseases incidents (0.61).

These results showed that smallholder farmers perceived improvement of crop productivity, soil water retention capacity and reduction of damage caused by dry spell, heat wave, and reduction of pests and diseases incidents on the farming systems as important co-benefits gained from implementing ecosystem- based adaptation practices on their farms.

For Dimension 3 (Livelihood and Food Security Improvement); the most highly ranked co-benefit was food security improvement (0.80), smallholder farmers perceived it as most important co-benefit of implementing ecosystem-based adaptation practices to improve their livelihoods and well-being. Both diversify sources and variety of food (0.78), increase and diversify local income (0.73), use local inputs (0.77), use local traditional knowledge (0.79), low cost of implementation and labour affordable (0.79) were perceived as high-medium important co-benefits.

4. Discussion

Smallholder farmers adopt ecosystem-based adaptation practices as an alternative way to reduce the effects of climate change on their crops for better improved yields. The results of the analysis revealed that mixed cropping, integrated crop-livestock and mulch tillage were highly implemented by smallholder farmers in their farms and were considered being cheap, use local materials and skills, and labour affordable. Additionally, the predominance of these practices is attributed to the community's traditional farming systems, livelihood needs, and immediate biophysical constraints of the local environment such as the recurrent dry spells. This finding aligns with some studies from semi-arid areas where farmers prefer practices that require low capital inputs to be integrated into existing farming systems without major trade-offs (Altieri and Nicholls, 2017). The study also revealed that smallholder farmers in the study area perceived a wider range of co-benefits from

TABLE 4 Relative Importance Index (RII) of the perceived co-benefits.

Agricultural EbA Dimension	Benefits Smallholder farmers Perceived from adoption of EbA	Relative Importance Index	Importance Level	Ranking
Dimension 1 (Ecosystem Service Provision)	Improvement of soil fertility and quality	0.91	H	1
	Improvement of soil nutrients regulation	0.81	H	2
	Improvement of water infiltration and soil erosion control	0.81	H	2
	Improvement of surface runoff regulation	0.59	H-M	3
	Improvement of agrobiodiversity-pollinators (insects and birds)	0.40	M	4
	Improvement of agrobiodiversity-vegetation diversity (trees and shrubs)	0.40	M	4
Dimension 2 (Adaptation Benefits)	Improvement of crop productivity	0.93	H	1
	Reduction of pests and diseases incidents	0.61	H-M	4
	Reduction of damage caused by dry spell, heat wave (improved buffering capacity)	0.84	H	3
	Improvement of soil's water retention capacity	0.86	H	2
Dimension 3 (Livelihood & Food Security Improvement)	Improvement of food security	0.80	H	1
	Diversify sources and variety of food	0.76	H-M	4
	Increase and diversify local income	0.73	H-M	5
	Use local inputs	0.77	H-M	3
	Use local traditional knowledge	0.79	H-M	2
	Low cost of implementation and labour affordable	0.79	H-M	2

Relative Importance Index (RII) values: High (H) = (0.8 ≤ RI ≤ 1), High-Medium (H-M) = (0.6 ≤ RI ≤ 0.8), Medium (M) = (0.4 ≤ RI ≤ 0.6), Medium Low (M-L) = (0.2 ≤ RI ≤ 0.4), and Low (L) = (0 ≤ RI ≤ 0.2) (Rooshdi et al., 2018).
Ranking numbers signify the hierarchical priority of the perceived co-benefits.

practicing multiple ecosystem-based adaptation practices than a single practice. This is consistent with the finding of Abbey (2023) that states smallholder farmers who adopt multiple practices on the same farm are likely to benefit from multiple co-benefits and adopt easily to climate variabilities compare to those farmers who adopt less practices. Additionally, the practice of mixed cropping as the most dominant practice in arid and semi-arid lands of the study areas by smallholder farmers is a key risk management strategy to address the challenges posed by climate variability, especially dry spells and erratic rainfall. Thus, smallholder farmers purposely incorporate different crops on the same piece of land to provide a variety of co-benefits and services. The study revealed that smallholder farmers commonly adopt mixed cropping systems that include mostly maize mixed with beans, pumpkins, or watermelon where multiple co-benefits perceived from the combination of those mentioned crops included improved soil fertility and quality, water infiltration and soil erosion control, reduce pests and diseases, increase and diversify local income and, diversify sources and food variety. This observation is consistent with the findings of Abbey (2023) where he reported that primarily combination of pulse and cereals maintain crop productivity, and soil moisture and reduce the risk of soil erosion, conserve agrobiodiversity, manage soil fertility and weed control. Furthermore, this practice of mixed cropping system is a refined traditional system that directly addresses the challenges of dry spells and erratic rainfalls. Smallholder farmers perceived that when maize is mixed with crops such as beans, pumpkin, and watermelon; maize provides partial shading that moderates the microclimatic conditions for the understory crops. Beans, pumpkin, and watermelon act as a living mulch by reducing direct solar radiation on the soil surface thereby lowering soil temperature and conserving soil moisture. Mixed cropping system is being regarded as bet-hedging strategy by the smallholder farmers. In seasons where maize yields decline due to droughts, beans being more tolerant to drought, and the moisture-rich crops such as pumpkin and watermelon can still provide a harvest for the households. Integrated crop-livestock practice in the study area involved feeding livestock on maize stover in an open-grazing after harvesting maize from the farms. This practice maximizes resource use efficiency by recycling on-farm biomass to feed livestock during dry season and reduce the cost of buying animal feeds. Integrated crop-livestock is perceived by the smallholder farmers to use local inputs, local traditional knowledge, low cost and labour affordable. Smallholder farmers believed that integrated crop-livestock improve soil fertility, nutrient regulation and crop productivity. Similar finding has been reported by Tarawali et al. (2015) in his reviews on the evolution of crop-livestock systems, and the contribution of livestock to soil fertility in dry savanna regions of West Africa.

Furthermore, the study revealed that mulch tillage is among the most adopted ecosystem-based adaptation practices in the study area. Since maize is the main food crop planted in the study area, large quantity of stover is produced and grazing livestock in the farms after harvesting the maize plays a mechanical and biological role in breaking down crop residues, transforming them into smaller, more decomposable particles that are ideal for mulch tillage. Practicing mulch tillage offers a sustainable low-input strategy for climate-resilient agriculture (Mhlanga, 2021). Mulch tillage was perceived by the smallholder farmers to provide multiple co-benefits including improve crop yield, water infiltration and erosion control, soil water retention, improvement of soil fertility and quality, soil nutrients regulation, low cost and labour affordable and use local traditional knowledge. In contrary, crop rotation, agroforestry, mulching, and rainwater harvesting were found to be the least adopted ecosystem-based adaptation practices despite being perceived to offer multiple co-benefits. The adoption of crop rotation is very low despite the multiple co-benefits perceived such as soil nutrients regulation, improve soil fertility and quality, reduce pests and diseases, improve crop productivity and food security. This could be due to the reason that, household food security in the study area relies on continuous cultivation of a single staple food crop (maize). Limited land availability makes crop rotation a less viable option for smallholder farmers who prioritize food crops year-round (Kangogo et al., 2021). Agroforestry is perceived to relate to co-benefits such as improvement of agrobiodiversity for both pollinators and vegetation diversity and were rated as of medium importance by smallholder farmers. Livestock ownership has reduced the likelihood of agroforestry adaptation due to browsing damage caused from the open grazing of the livestock. In livestock systems, tree seedlings are often damage or eaten by free-grazing animals, discouraging tree planting without fencing or protection. In addition to limited agricultural lands in the arid and semi-arid areas, smallholder farmers tend not to trade-off crop planting to trees planting that will occupy land limiting grazing and farming lands. The study revealed that rainwater harvesting is perceived to improve the adaption benefits and livelihood and food security. This finding is consistent with the studies of Biazin et al. (2012) that rainwater harvesting reduce the risk of total crop failure due to dry spells and substantially improves water availability and crop productivity. However, the adoption is being constrained by lack of resources and technical skills, especially for smallholder farmers in dry areas (Mfitumukiza et al., 2022). Mulching is among the rarely used ecosystem-based adaptation practices despite its promotion among smallholder farmers (Abbey, 2023). In the study area, grazing livestock on crop residues especially maize stover during dry season is prioritized over using it as mulch. Maize stover is an important by-product, primarily for feed use during dry season often through *in-situ* stubble grazing or *ex-situ* forage. Smallholder farmers are hesitant to retain maize stover as mulch, as this competes with livestock feed needs and purchased feed is expensive. This finding is in consistent with findings reported in the studies of Hellin et al. (2013) in Mexico on maize stover use and sustainable crop production in mixed crop-livestock systems in semi-arid area where farmers were found to be generally hesitant to adopt conservation agricultural practices that require the retention of stover for mulch as this competes with their livestock feed needs.

The ranking of co-benefits across the three dimensions provides a comprehensive understanding of farmers' priorities and their rationale for adopting ecosystem-based practices. Across all the three dimensions, the results consistently showed that smallholder farmers valued practices that enhance soil health, strengthening adaptation capacity, and improve household food security. Soil fertility improvement and water infiltration/erosion control were ranked highest in dimension 1 suggesting that smallholder farmers recognize ecosystem-based adaptation practices primarily for their role in improving soil health, which is consistent with widespread concerns about soil degradation in semi-arid agriculture (Kissi et al., 2023). The importance of soil health translate directly into farmers' adaptation needs as reflected in the ranking for dimension 2 where improved crop productivity and enhanced soil water retention capacity were the most valued co-benefits. This underscoring the smallholder farmers' preferences for practices that buffer their crops against the increasingly frequent dry spells and heat stress. Similar findings have been reported in other climate-vulnerable farming systems where productivity stabilization is central to farmers' adaptive strategies (Diallo et al., 2021). The relatively high ranking of reduced pest and disease incidence reflects the growing awareness of ecological regulation function embedded within the practices. The ecological and adaptive benefits feed directly into the livelihood and food security outcomes captured in dimension 3 where food security improvement was perceived as the most important co-benefit. This highlights the centrality of household food availability in guiding smallholder farmers' decisions to adopt ecosystem-based adaptation practices. Such prioritization aligns with the existing evidence showing that smallholder farmers are more likely to invest in adaptation options that have immediate and tangible implications for food access and reduced vulnerability to climate shocks (Jellason et al., 2022). The medium-to high ranking of diversified food sources, increased income, use of local inputs, and reliance on traditional knowledge highlights how ecosystem-based adaptation practices align with indigenous farming systems and livelihood strategies, an aspect increasingly recognized in adaptation research (Reid et al., 2019).

5. Limitation

The study is based on cross-sectional data and is geographically limited to the selected study area, which may restrict the generalizability of the findings to other contexts. The study did not examine the underlying determinants, drivers, and constraints influencing adoption and non-adoption decisions. Due to the absence of relevant data, key socioeconomic, institutional, behavioural, and biophysical factors that may affect farmers' adoption choices were not analysed. A comprehensive understanding of these determinants and their associated constraints is essential for the design of effective policy interventions and for scaling up of EbA practices.

Therefore, future research should prioritize investigating factors influencing both adoption and non-adoption decisions, with particular focus on institutional support, resource access, market conditions, knowledge systems, and policy environments. Such investigation would yield robust empirical evidence required to develop strategies and policy framework aimed at enhancing EbA adoption among smallholder farmers.

6. Conclusion and recommendation

The study concludes that smallholder farmers predominantly rely on low-cost and locally adaptable practices, particularly mixed cropping, integrated crop-livestock and mulch tillage. The predominance of these practices aligned with the local farming systems centred on maize and beans production as the main staple food crops and livestock rearing. The study further revealed that the effectiveness of ecosystem-based adaptation strategies is enhanced when several practices are implemented in combination to provide multiple agronomic and livelihood co-benefits.

Based on the findings, the study recommends strengthening extension services and promoting integrated ecosystem-based adaptation practices aligning with smallholder farmers' priorities by supporting participatory development of ecosystem-based adaptation strategies grounded in local knowledge and socio-economic realities.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Serviço Distrital de Actividades Económicas (SDAE). The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because Participants cannot write or read Portuguese or English language. Written informed consent from the individual(s) for the publication of any potentially identifiable images or data included in this article was not required because written authorization was obtained from Serviço Distrital de Actividades Económicas (SDAE), the relevant district authority, which approved the publication of this work.

Author contributions

CW: Conceptualization, Formal analysis, Resources, Funding acquisition, Writing – original draft, Methodology, Data curation, Investigation. JM: Writing – review & editing, Software, Visualization. NG: Validation, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix V: Article

sustainability

Article

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

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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 ex- amine 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].

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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.

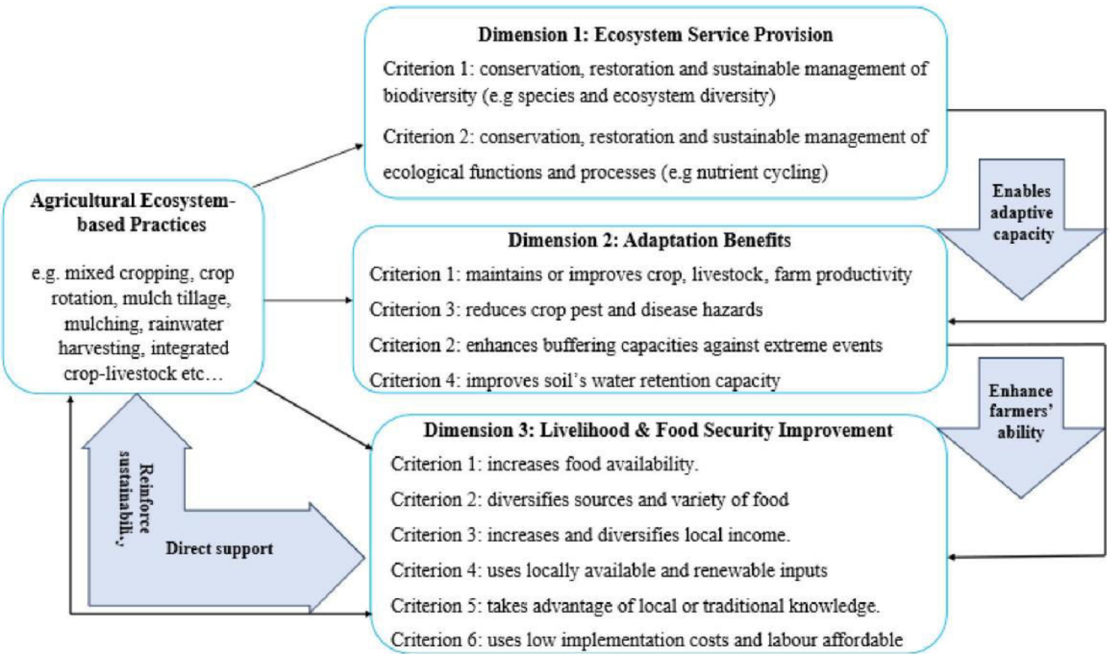

Figure 1. Theoretical framework, source: adopted and modified from [6].

2. Materials and Methods

1.3. 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 km², 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 km², far below the national average of 25 people per km² [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 km² 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.

1.4. Sampling and Data Collection

1.4.1. 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:

$$S = \frac{Z^2PQ}{E^2} \tag{1}$$

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:

$$n = \frac{S}{1 + \frac{S-1}{N}} \tag{2}$$

Therefore, substituting the values, n ≈ 359.05

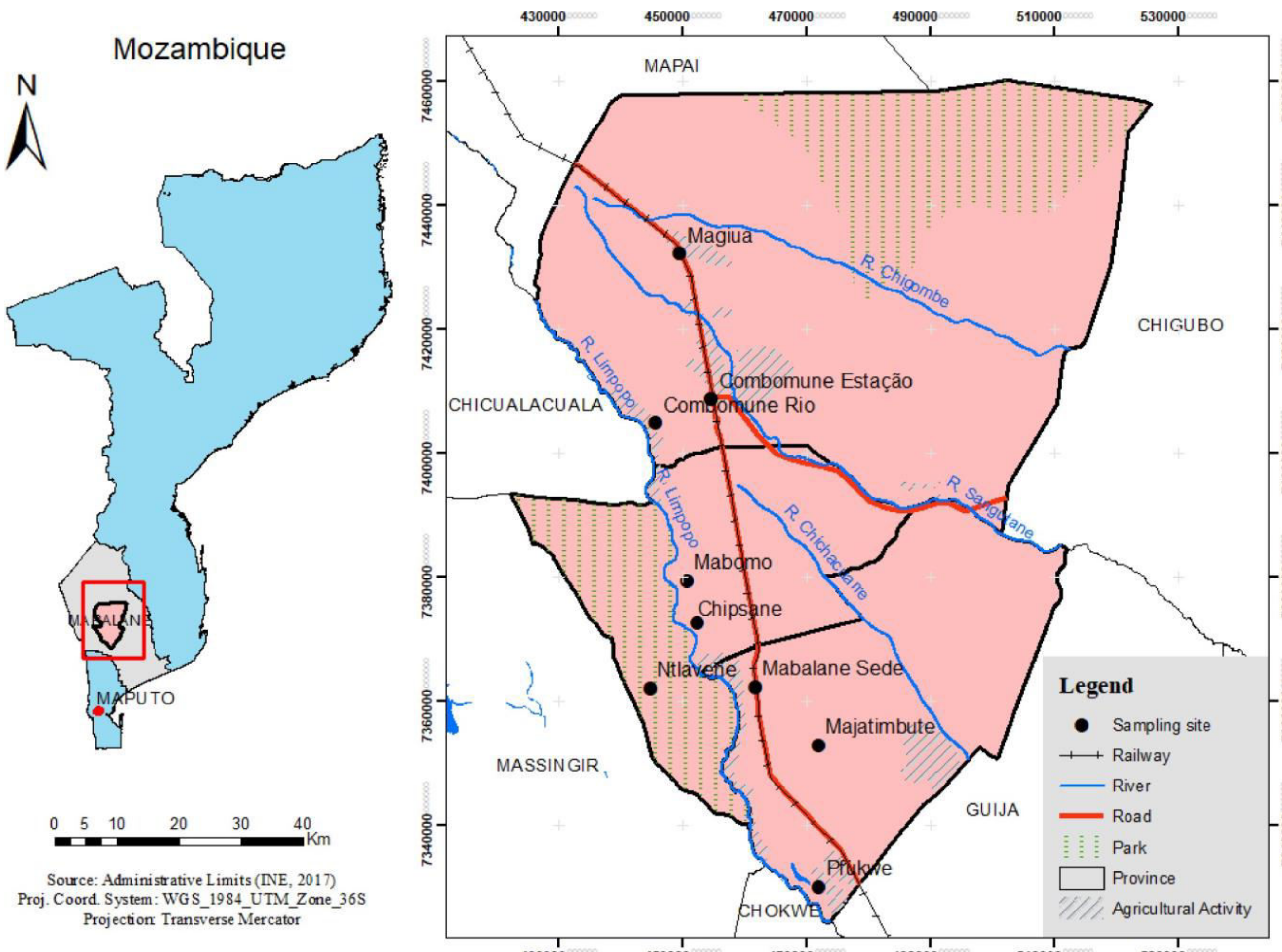

Figure 2. The geographical location of the study area.

1.4.2. 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.

1.4.3. 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.

1.4.4. 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 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: sociodemographic 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].

1.4.5. 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.

1.5. 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 relation- ship [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

1.6. 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.

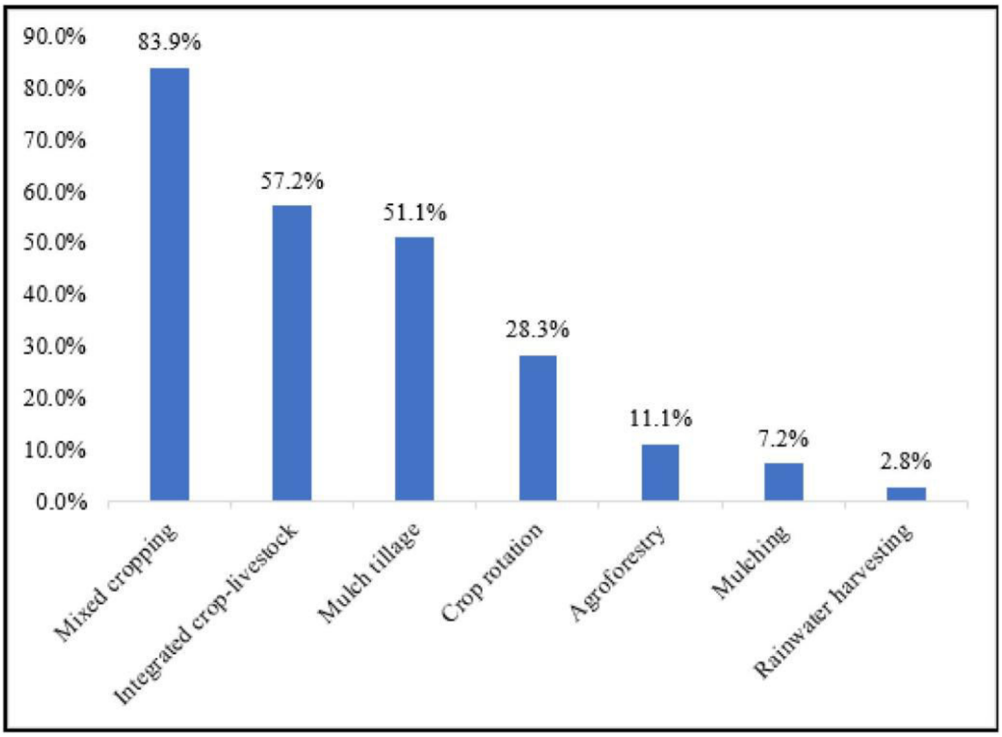

Figure 3. Identified ecosystem-based adaptation (EbA) practices.

1.7. 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.

1.7.1. 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							
	Co-Benefits						
Ecosystem-Based Adaptation Practices	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.

1.7.2. 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.

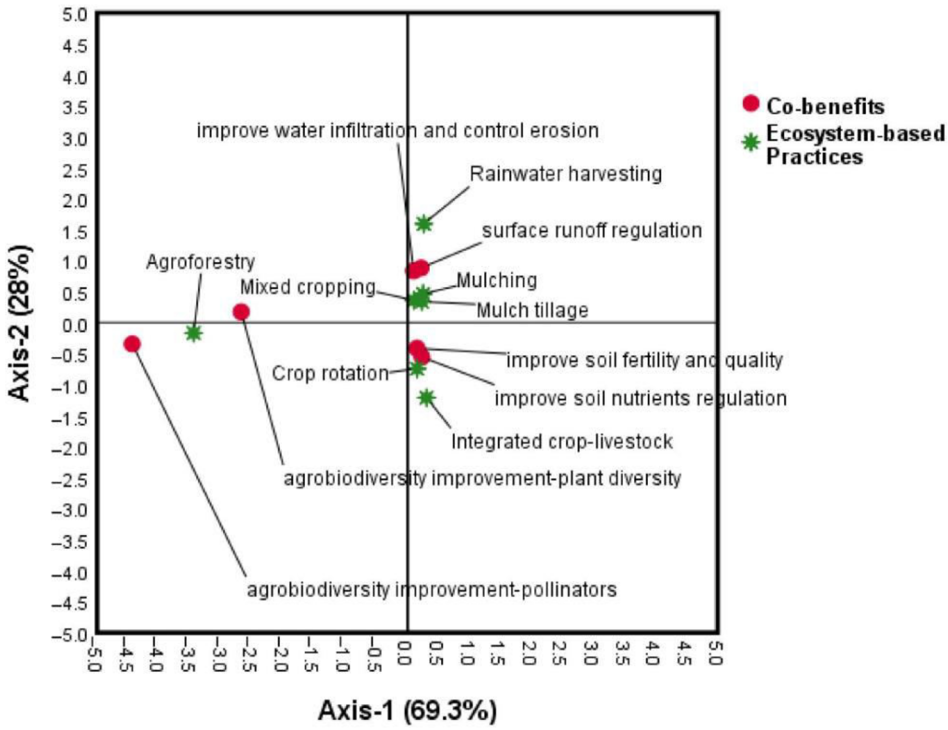

Figure 4. Projection of co-benefits and EbA practices into system of axes for ecosystem service provision.

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.

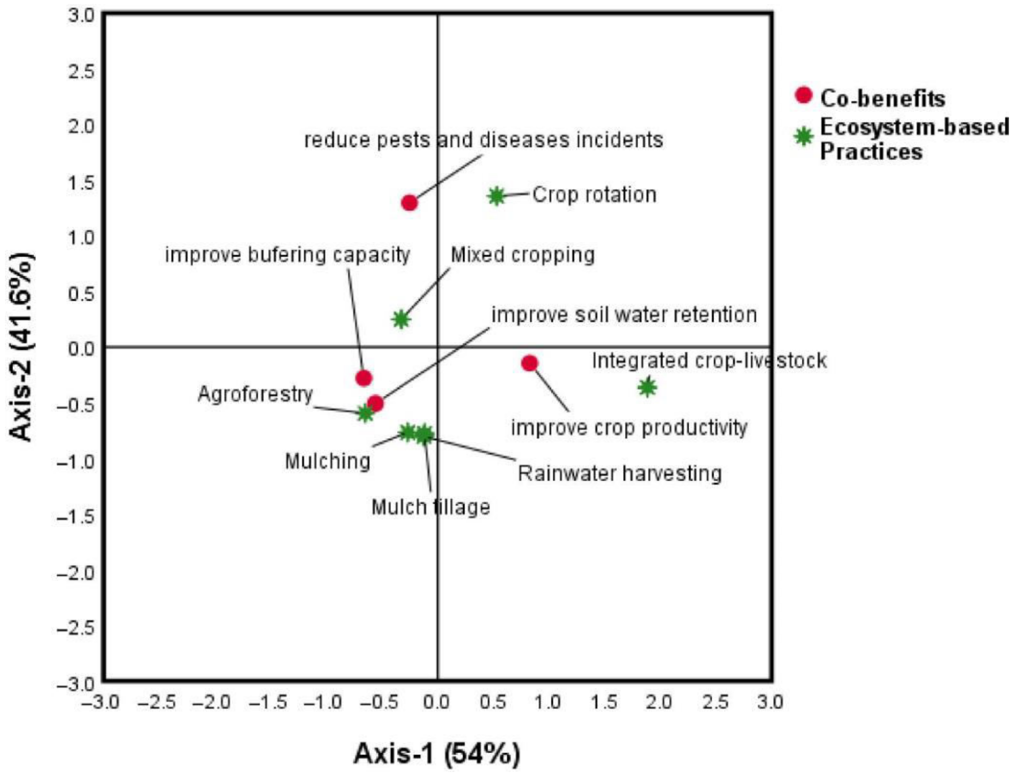

Figure 5. Projection of co-benefits and EbA practices into system of axes for adaptation benefits.

1.7.3. 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							
	Co-Benefits						
Ecosystem-Based Adaptation Practices	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.

1.8. 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].

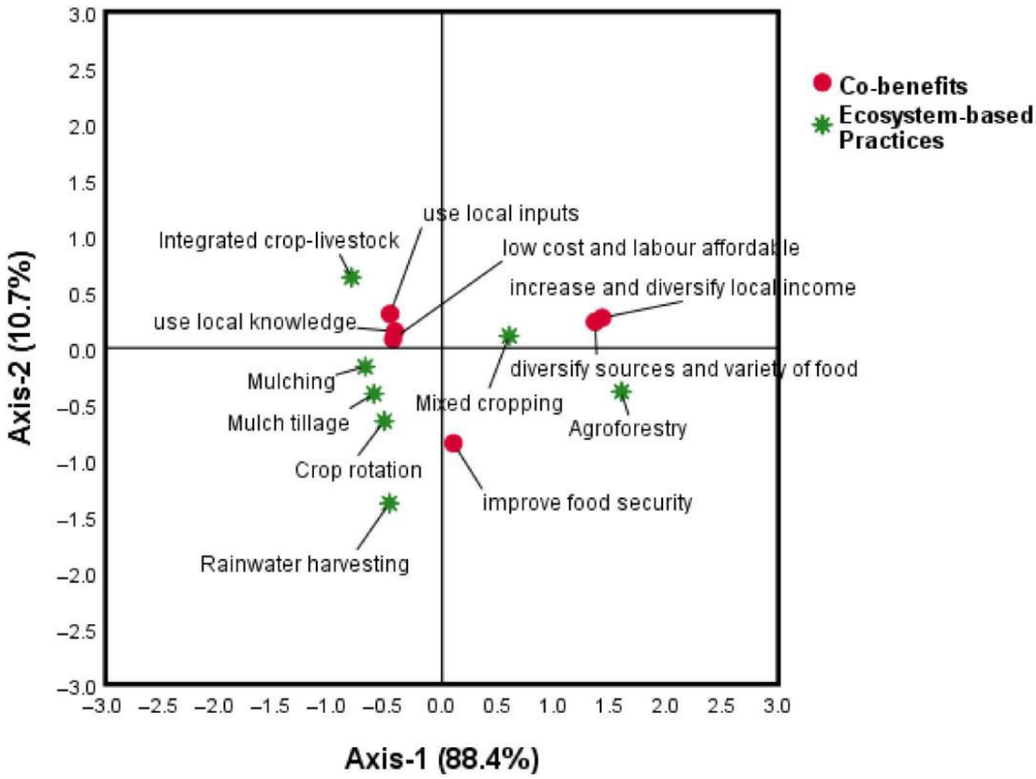

Figure 6. Projection of co-benefits and EbA practices into system of axes for livelihood and food security improvement.

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				

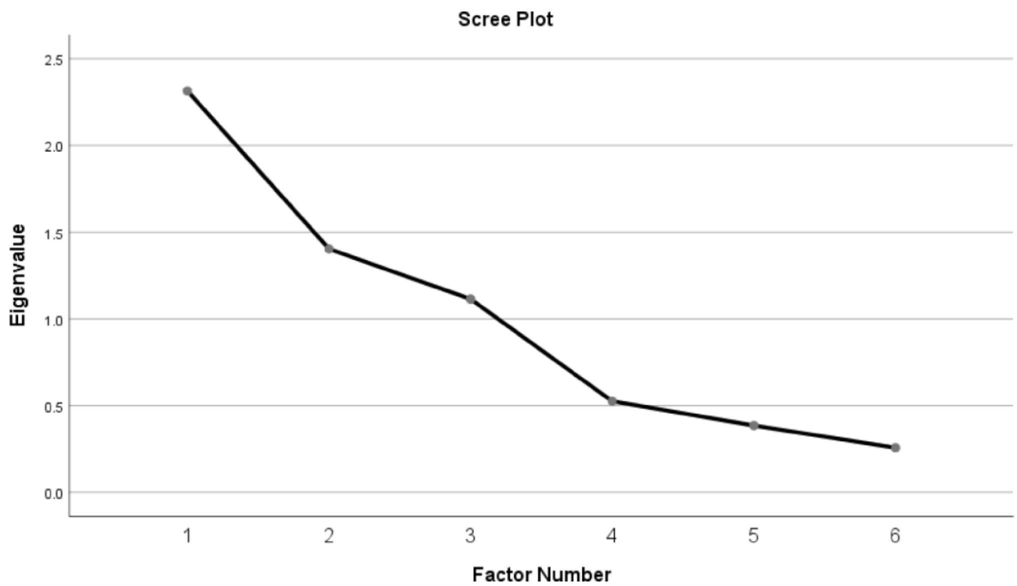

Figure 7. Scree plot showing three-factor solution.

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.

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Table 9. Underlying factors identified from principal axis factoring.

Pattern Matrix [a]			
	Factor		
Co-Benefits	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							
			95% Wald Confidence Interval		Hypothesis Test		
Parameter Error	B	Std.	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.

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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

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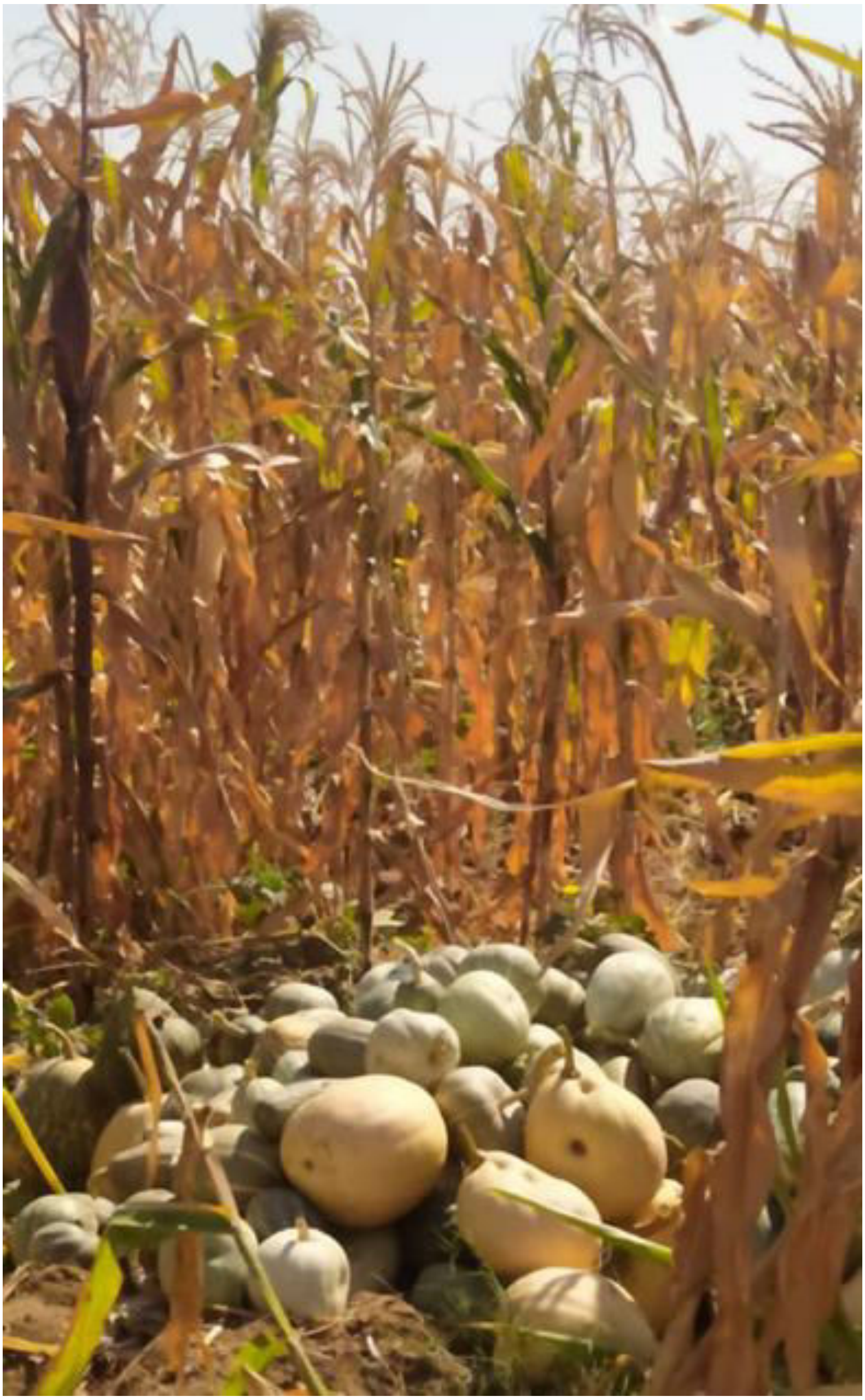
Field photo showing a household farmer taking sweet potatoes to the market in Mabalane Sede
Source: the author
Date:21/8/2025



Field photo showing mixed cropping system of maize combined with pumpkin in Mabalane Sede
Source: the author
Date: 21/8/2025

Field photo showing open grazing in maize field in Pfukwe Locality
Source: the author
Date: 14/8/2025

Field photo showing members of Nkateko Farmers' Association in Pfukwe Locality
Source: the author
Date: 16/8/2025