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Socio-Economic Determinants of Climate Change Adaptation Strategies Among Smallholder Farmers in Mbombela: A Binary Logistic Regression Analysis

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Abstract: Climate change poses significant challenges to smallholder farmers, particularly in sub-Saharan Africa, where agriculture is highly vulnerable to changing climatic conditions. This study examines the socioeconomic determinants influencing the adoption of strategies for adapting to climate change among smallholder farmers in Mbombela, South Africa. A quantitative research approach was employed, using structured questionnaires to collect data from 308 randomly selected smallholder farmers. Furthermore, the study utilised binary logistic regression to analyse the relationship between socioeconomic factors and the adoption of adaptation strategies. The results revealed that gender, age, income sources, access to climate information, and cooperative membership significantly influenced farmers' adoption of adaptation strategies. Findings further showed that female farmers, older farmers, and those relying solely on farming income were less likely to adopt adaptation strategies, while younger farmers and those with diversified income sources were more likely to embrace adaptation strategies. Moreover, the study found that access to climate information and cooperative membership were negatively associated with the adoption of adaptation strategies. This negative association may be attributed to inefficiencies in current information dissemination, where climate-related information may not be tailored to the specific needs of farmers, or to cooperative structures that may not effectively facilitate knowledge sharing or collective action. The study concludes that targeted interventions, such as gender-sensitive policies, livelihood diversification, improved extension services, and strengthened cooperative structures, are essential to enhance smallholder farmers' adaptive capacity.

Keywords: climate change adaptation; smallholder farmers; socioeconomic determinants; adaptation strategies; agricultural resilience

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1. Introduction

Climate change is widely recognised as one of the biggest global challenges, with serious implications for development, especially in developing and underdeveloped countries [1]. Its impact affects livelihoods, ecosystems, and socioeconomic growth, with agriculture being one of the most vulnerable sectors [2]. The agricultural sector, especially in sub-Saharan Africa, faces severe challenges due to changing climate conditions that threaten food security and the livelihoods of smallholder farmers [3]. In South Africa, smallholder farmers are particularly vulnerable due to the country's semi-arid climate and reliance on rain-fed agriculture [4]. The increasing frequency of extreme weather events, such as droughts and floods, exacerbates these challenges, reducing agricultural productivity and increasing food insecurity [4]. Smallholder farmers, who often lack the resources and infrastructure to cope with these changes, are disproportionately affected, further entrenching poverty and inequality in rural communities [5].

The ability of smallholder farmers to adapt to climate change is influenced by a range of socioeconomic factors, including income levels, education, access to resources, and social networks [6]. For instance, farmers with higher incomes have more capacity to invest in adaptive technologies and practices, while those with limited financial resources may struggle to implement even basic adaptation measures [7]. Education also plays an important role, as it enhances farmers' awareness of climate risks and their capacity to adopt innovative strategies [8]. Additionally, access to information, extension services, and credit facilities significantly influence the adoption of adaptation practices [7].

Despite the growing body of research on climate change impacts, there is a notable gap in understanding how socioeconomic factors such as gender, age, level of education, farm size, household size, source of income, access to extension services, climate change information, and cooperative membership influence the adoption of adaptation strategies among smallholder farmers in specific regions, like Mbombela. While several studies have explored adaptation in broader South African contexts [4,5,7], few have focused on the localised dynamics in peri-urban municipalities such as Mbombela, where rural–urban linkages and diverse livelihood strategies complicate adaptation decisions. Mbombela, located in the Mpumalanga province of South Africa, presents a unique case due to its distinct agroecological context, which is characterised by a mix of semi-arid and subtropical climates. These conditions, coupled with a reliance on rain-fed agriculture, make the region particularly vulnerable to climate variability. Furthermore, the socioeconomic conditions in Mbombela, including limited access to resources, low literacy levels, and high poverty rates [9], reflect broader challenges faced by rural communities in sub-Saharan Africa. These factors make it an important case study for understanding adaptation in vulnerable farming communities.

Although strategies for adapting to climate change have been studied in broader contexts, there is limited research focusing specifically on the intersection of socioeconomic factors and adaptation practices in Mbombela. Recent studies, such as those by Tagwi and Khoza [10], have explored adaptation strategies in similar regions of South Africa, but the specific socioeconomic dynamics of Mbombela have yet to be fully addressed. This study aims to address this gap by examining the socioeconomic determinants of climate change adaptation strategies among smallholder farmers in Mbombela. The research seeks to analyse the relationship between different socioeconomic factors and the adoption of climate change adaptation strategies. By doing so, the study contributes to the broader understanding of climate change adaptation in vulnerable communities and provides insights that can inform policy and practice. The findings of this research will be valuable for policymakers, climate researchers, and academics, offering a framework for enhancing rural livelihoods and informing future adaptation strategies.

2. Literature Review

2.1. Climate Change Impact on Agriculture

Climate change is described as a global disaster, with notable harmful effects already affecting farmers and farming communities in different countries [11]. According to the IPCC AR6 Synthesis Report (2023) [12], climate-related impacts are already being observed in all regions, disproportionately affecting low-income populations who largely depend on agriculture. The report highlights the increasing risks to food security, water availability, and livelihoods, particularly in regions like sub-Saharan Africa where adaptive capacity remains low. These challenges highlight the urgent need for transformative adaptation strategies that enhance agricultural resilience, promote sustainable land use, and empower vulnerable populations such as smallholder farmers to navigate climate risks effectively [12]. Research further indicates that extended droughts with warmer temperatures and extreme weather are all signs or effects of climate change, particularly in agriculture [13]. Climate change also poses substantial challenges to global agriculture, impacting crop yields, water availability, and agricultural productivity [11].

Smallholder farmers face several difficulties as a result of climate change, particularly in areas like Mbombela in the Mpumalanga Province of South Africa [14]. Due to the limited resources and reliance on rain-fed crops, these farmers are enormously vulnerable [14]. According to previous studies, the region's rainfall patterns have become more unpredictable, resulting in flash floods and prolonged dry periods [15]. The rise in temperature changes, which interferes with the customary planting and harvesting seasons, is one of the most urgent issues [16]. Moreover, rising temperatures speed up evaporation, which lowers soil moisture content and intensifies drought situations. Food shortages and unstable finances for farming households result from these situations, which also negatively impact crop growth and yields.

Studies reveal that in recent years, the hostile effect of climate change on soil properties in the agricultural sector has become a terrible certainty globally [17,18]. Furthermore, climate change-driven abiotic shocks such as salinity, drought, and temperature fluctuations cause distress to crops' physiological responses, productivity, and total yield, eventually causing a serious risk to global food security and agroecosystems [18].

2.2. Economic Impacts of Climate Change on Smallholder Farmers

2.2.1. Impact of Climate Change on Crop Yields

Decreases in agricultural yields have been documented in the literature as a major problem within the climate change and agriculture nexus [19]. The climate-dependent characteristics of smallholder agriculture render productivity susceptible to climate change. Farmers in Africa, particularly in South Africa, have expressed concerns regarding the deteriorating condition of agriculture attributed to alterations in rainfall and temperature, which are critical climate factors for smallholder farming [20,21]. A notable drop in crop production on the continent has been connected to extreme climatic events such as floods and droughts [22].

2.2.2. Impact of Climate Change on Farmers' Incomes

The rural population relies largely on income derived from agriculture and related activities. The impact of climate change on agricultural revenue thus affects the socioeconomic conditions of farming households specifically and landless farming households broadly [23]. A study by Habtemariam et al. [24] revealed that the percentage of farms adversely affected by climate change differed significantly across socioeconomic scenarios. The percentage of farms adversely affected is greater under low economic development scenarios [24].

2.2.3. Impact of Climate Change on Market Price Fluctuation

Rising temperatures and changing rainfall patterns have negative effects on food production and market pricing, according to researchers [25]. The influence on agriculture and food prices impacts all aspects of food security, encompassing quantity, quality, and accessibility [26]. Several assessments [27–29] indicate that climate change exacerbates global food insecurity by diminishing agricultural yields, elevating drought-related costs, and inflating food prices. The IPCC [11] anticipates an escalation in climate extremes. These occurrences could exert pressure on the global food system and agricultural commodities markets.

2.3. Social Impacts of Climate Change on Smallholder Farmers

2.3.1. Impact of Climate Change on Food Security

Food insecurity is common in South African households, particularly in rural regions; however, the country is well known for its national food security program. Statistics South Africa found that in the year 2020, 15% of the population experienced severe food insecurity, and over 23% experienced moderate to severe impacts of food insecurity. Therefore, smallholder farmers experience food insecurity due to climate change causing declining crop yields, driving a scarcity of food and increasing food prices.

2.3.2. Climate Change and Farmers' Health

Climate change impacts the health of farmers in numerous ways. With climate change, an increasing number of individuals may encounter severe weather events such as heatwaves, floods, droughts, storms, and wildfires [30]. The World Health Organization estimates that between 2030 and 2050, climate change could cause 250,000 extra deaths annually [31]. Smallholder farmers' health effects of climate change can be divided into four groups: transmittable diseases; non-transmissible diseases; mental health; and occupational health, safety, and other health concerns.

2.3.3. Impact of Climate Change on Migration

Research in the literature has revealed that smallholder farmers migrate to other areas to find other sources of income in the face of crop loss or reduced agricultural productivity as a result of climate change impacts [32–34]. Extreme weather events, such as increased temperature and precipitation on farming outputs, have been identified as one of the likely main causes of migratory push in the latest research on climate change and migration [35].

2.4. Effects of Climate Change and Farmers' Adaptive Responses

Extensive research on agricultural adaptation to climate change has sought to identify the key drivers and obstacles that influence farmers' adoption of adaptive practices [35]. Within the traditional economic framework, farmers are viewed as rational decision-makers who respond to climate-related risks by optimizing the use of their available resources. When prioritising crop yields and short-term financial gains, farmers are likely to adopt adaptive strategies that help safeguard agricultural profitability in the face of climate challenges [36]. Conversely, if conventional intensive farming practices lead to the degradation of agroecosystems, farmers may shift their focus towards long-term sustainability, adjusting their behaviours to mitigate the effects of climate change and preserve future agricultural returns [36]. These behavioural changes underscore farmers' responses to evolving climate conditions. Typically, analyses of farmers' adaptation decisions take into account four categories of influencing factors: individual characteristics (e.g., gender, age, education level, and farming experience), household resources (e.g., family size, land area, and farm income), broader socioeconomic conditions (e.g., social norms, community networks, market access, and economic structure), and institutional or external factors (e.g., availability of credit, government subsidies, and agricultural extension services) [30,35,37]

2.5. Climate Change Adaptation Strategies

Adaptation involves implementing strategies that enhance the capacity of individuals and communities to respond effectively to the impacts of climate change across various aspects of human life [1,33]. It includes taking proactive steps to minimise the adverse effects of climate change or to capitalise on any potential benefits through appropriate adjustments and modifications [38]. In this context, an adaptation strategy refers to a comprehensive plan designed to address the challenges posed by climate variability and extreme weather events. Such strategies typically comprise a combination of policies and interventions aimed at reducing a nation's overall vulnerability. Encouraging the adoption of climate change adaptation strategies is essential for strengthening smallholder farmers' resilience, minimising the adverse effects of climate change, and contributing to the achievement of the United Nations Sustainable Development Goals [39]. Climate change adaptation strategies are discussed below:

2.5.1. Pest and Disease Control

The agricultural sector in Africa has been significantly challenged by climate variability, the emergence of uncontrollable and destructive crop pests, and frequent disease outbreaks [40]. Crop diseases and pests can significantly reduce crop quality or even result in total crop failure. In rural Ghana, tomatoes have been severely affected by pests such as caterpillars, thrips, worms, and whiteflies. Major diseases impacting tomato production in the region include bacterial wilt, blight, leaf spot, and various viral infections, which have in many cases devastated harvests and left farmers with little to no yield [41]. While farmers have traditionally managed these outbreaks using chemical sprays, rogueing, hand-picking, ash, organic extracts, urine, and frequent weeding, these methods are increasingly proving inadequate in controlling the growing intensity and frequency of pest and disease infestations [41].

2.5.2. Crop Diversification

The method of growing multiple crop types from the same or distinct species in a specific region through intercropping or rotations is known as crop diversification [42]. Crop diversity is a high-priority adaptation measure in both irrigated and non-irrigated areas. Crop diversification was employed by farmers as an adaptation tactic to lessen the negative effects of climate change [43]. Fahad et al. [44] claim that crop diversity is a means of maximising land, water, and other resources while lowering risk and uncertainty about weather and climate change.

2.5.3. Change in Calendar of Planting

Climate change adversely affects crop production through long-term alterations in rainfall, resulting in changes in cropping patterns and the calendar of operations. Adjusting planting and ploughing dates is a good way to lessen and balance the negative effects of climate change on crop production [44,45]. One of the most common farmer reactions to rising rainfall variability is to change the date of ploughing and planting, thus minimising the damage to their livelihoods [46]. Studies conducted in Zimbabwe, Zambia, and Mozambique have revealed that planting maize as soon as the rains arrive is now frequent in order to raise the likelihood of the maize producing cobs before rainfall ends [46].

2.5.4. Intercropping

Intercropping is the farming of two or more crops concurrently on the same piece of land over the same cropping season or year [47]. Legumes, including beans, cowpeas, and soybeans, are common crops used in intercropping. This procedure helps restore the soil's fertility and supplies residual nutrients for the next cereal harvests [48]. In Malawi, farmers are progressively intercropping their tea with maize as a risk management tool to ensure that even if one crop fails, there is another from which they can make a livelihood. Intercropping has been observed as a common response strategy [46].

2.5.5. Planting Different Crop Varieties

New crop types can have adaptive advantages [49]. Drought resilience, heat tolerance, salinity tolerance, and fast-maturing cultivars cultivated to match shorter growing seasons are characteristics of possible benefits to smallholders [50]. Improved breeding technology has made more seed varieties accessible now than several years ago. To maximise yields in ever shorter and more erratic cropping seasons, many smallholder farmers use hybrid and early-maturing cultivars [46]. Adoption of early-maturing crop types, including pearl millet, is one of the most successful recorded adaptations to climate variability in Namibia [50].

2.5.6. Migration

Migration is sometimes regarded as an efficient adaptation option by agricultural families to maintain their livelihood in challenging conditions as a consequence of climatic and environmental change [22]. Although there are possible advantages, migration is not the initial adaptive reaction to climate change. When other adaptation techniques fall short of household needs, it is sometimes regarded as a last alternative [51]. Migration enables agricultural households to create additional income and sustain household spending in difficult times. Migration also enables farm households to learn new techniques and farming methods, increasing agricultural income [22].

2.5.7. Water Management and Conservation

There are numerous in-field water conservation practices that have been implemented in various regions of Africa, such as earth bunds, planting trenches or planting basins, mulching, dead-level contours, and their modifications [52]. Several investigations have emphasised the existence of indigenous water management techniques. Some smallholder farmers in Malawi cultivate vegetables in their fields during the drought season by participating in micro-irrigation activities [46]. In the Free State of South Africa, local farmers employ a technique known as "matangwana" to capture in-field rainwater runoff to facilitate plant growth and apply mulch as a method of conserving soil [53].

2.5.8. Soil Management and Conservation

The United Nations Sustainable Development Goals can be achieved through the implementation of sustainable soil management and conservation [48]. In recent years, there has been a particular interest in the implications of this approach for the mitigation of climate change [54]. It has been reported that through a low-input approach based on three principles—mulching, crop rotation, and minimum/zero tillage—conservation agriculture is practised by smallholder farmers in Southern Africa [46,55,56], and that small tea producers use grass mulching in the spaces between plants to mitigate water stress and preserve moisture in their tea fields [46].

2.5.9. Off-/Non-Farm Work

A common practice in Southern Africa is diversification outside the farm into off-farm and non-farm activities. Other research has demonstrated that households can improve their food security, increase their income, and increase agricultural production by diversifying to non-farm livelihood strategies and securing capital [57]. It has been shown that the erratic nature of rainfall has caused farmers in Nigeria to migrate from agriculture as their main source of income to the development of non-farm activities, including micro-enterprises and off-farm activities [58].

2.5.10. Crop Insurance

Crop insurance is essential for adaptation to the effects of climate change; it has the potential to mitigate the financial repercussions of unintended crop failures that occur in the aftermath of extreme events such as droughts and flooding [59]. In undeveloped countries, insurance is a necessary tool; however, various limitations greatly reduce its availability. Insurance products today are either not affordable or not meant to fit the needs of underprivileged people [60].

2.5.11. Knowledge Management

Knowledge management is a set of methods and techniques that are designed to facilitate the adoption of insights and experiences, as well as to identify, create, represent, distribute, and enhance decision-making, in order to attain a competitive advantage [61]. Indigenous and traditional knowledge systems have consistently fostered a profound awareness of environmental processes among rural residents [62]. Farmers in Southern Africa have historically used local knowledge to address escalating climate variability and change [46]. For example, in certain regions of South Africa, residents rely on birds, toads, and termites to forecast the summer season, the arrival of rains, and temperature variations, whereas in Tanzania, they observe the behavioural patterns of avian and mammalian species [46].

2.6. Socioeconomic Determinants of Adaptation Strategies

Factors such as education attainment, non-farm employment, and farming experience are considerable factors that increase smallholder farmers' adaptive capacity through the adoption of many adaptation approaches [63]. Furthermore, access to extension services was found to be a key determinant for Climate Smart Agriculture (CSA) adoption [64]. Government subsidies for electricity use in farming were also found to be an influential strategy for CSA adoption that was significantly positive [64]. Lastly, training of extension staff and raising funding for CSA initiatives are also recommended to promote the adoption of climate change adaptation strategies [64]. Different socioeconomic factors such as gender, age, and experience in crop farming, along with institutional factors like access to extension services and access to climate change information, significantly influenced the adoption of climate change adaptation strategies among beneficiaries of land reform in South Africa [63]. In addition, Skevas et al. [65] found that age, educational level, farming experience, on-farm training, off-farm income, access to information, and locational variables are significant determinants of the intensity of adaptation strategies adoption.

According to Ragoasha et al. [9], smallholder farmers in Mbombela have responded to climate difficulties by implementing a range of conventional and modern adaptation techniques to mitigate the effects of climate change. Crop diversity, in which farmers cultivate several crop types to lower the risk of complete crop failure, is one commonly used approach [9]. Due to their increased resistance to unpredictable rainfall patterns, drought-resistant crops like millet and sorghum have become more and more popular [66]. Changing the planting dates in accordance with the local climate forecasts and indigenous knowledge is another popular adaptation strategy Mbombela farmers have been reported to use [9]. By utilising these strategies, farmers have a better capability to optimise production during challenging climatic times and cope with extreme weather events. However, some of these strategies require substantial capital and skills to implement. This highlights the influence of education, training, and economic status on the ability of farmers to adopt adaptation strategies. In other areas, farmers have also embraced conservation agricultural practices like agroforestry, mulching, and minimum tillage to enhance soil health and preserve moisture [67]. However, Lee and Gambiza [68] have indicated that socioeconomic factors, including age, education, household income, and access to information, affect the adoption of conservation agriculture practices.

In terms of technological adaptation, farmers who have access to capital have become more dependent on irrigation systems, investing in drip irrigation and boreholes to guarantee a steady supply of water [69]. However, resource-poor farmers are unable to widely implement irrigation infrastructure due to its high prices. Additionally, non-governmental organisations (NGOs) and government extension agencies have pushed climate-smart farming practices, like the use of organic fertilisers and improved seed varieties [67]. By increasing agricultural yields and enhancing soil fertility, these programmes seek to strengthen farmers' resilience [70]. Despite these adaptation efforts, most of the smallholder farmers in Mbombela still encounter significant limitations to adaptation, including limited access to financial resources, inadequate extension services, and inadequate market opportunities [71].

While several socioeconomic determinants have been found to influence climate adaptation, some findings across regions present conflicting evidence. For instance, gender is widely acknowledged as a determinant, with studies such as Ojo et al. [7] showing that male farmers are more likely to adopt adaptation practices due to better access to land and credit. However, Rankoana [72] reported that women, despite resource constraints, often employ a broader range of household-level and indigenous adaptation strategies, suggesting that gender roles may drive different types of climate change responses. Similarly, age is generally associated with lower adoption rates among older farmers due to reluctance to change and fear of risk [70]. However, other studies like Mugisho et al. [73] emphasise the value of older farmers' accumulated experience and indigenous knowledge, especially in traditional or subsistence farming. In terms of access to climate information, while Sargani et al. [8] found that it positively influences adaptation, Pickson and He [74] argued that poorly contextualised, complex, or inaccessible information may confuse or overwhelm farmers, discouraging the adoption of adaptation strategies. These variations highlight the context-dependent nature of adaptation behaviour and the importance of not treating socioeconomic factors as universally predictive.

Effective climate change adaptation by smallholder farmers is influenced by a number of socioeconomic factors. Farmers' capacity to invest in climate-resilient infrastructure, better seed types/varieties, and irrigation systems is largely determined by their access to financial resources [70]. However, a lack of collateral and high interest rates imposed by banking institutions make it difficult for many smallholder farmers to obtain credit [67]. Access to climatic data and extension services is another important consideration. Farmers are better prepared to make sound decisions about their farming operations when they receive training in weather forecasting and climate-smart agriculture [71]. However, studies show that most smallholder farmers rely on traditional knowledge that might not necessarily be in line with current climate issues and have little access to extension agents [74]. Enhancing farmers' ability to adapt requires strengthening agricultural extension services [68].

The capacity of smallholder farmers to adapt to climate change is also influenced by market accessibility [6]. Better prices for their produce can be obtained by farmers with established market relationships, allowing them to reinvest in adaptable business strategies. However, a lot of rural farmers deal with issues such as inadequate infrastructure, expensive transportation, and the exploitation of middlemen, all of which lower their profitability [74]. Farmers' economic resilience may be increased by strengthening market connections through cooperatives and online platforms [67]. Farmers' adaptation strategies are also greatly influenced by institutional assistance and governmental policy. Climate-smart technology subsidies, crop insurance programmes, and climate adaptation funds are examples of policy interventions that can improve farmers' resilience to climate shocks.

However, research shows that the efficacy of such initiatives in South Africa has been hampered by bureaucratic inefficiencies and improper execution [75].

Dechezleprêtre et al. [76] stated that, if no action is taken, climate change may cause some rural areas to experience a 30% drop in household incomes. Meanwhile, research shows that households now have less access to staple crops due to falling agricultural productivity, which makes them less nourished and more susceptible to malnutrition, especially among pregnant women and children [77]. The problem has become worse due to fluctuations in food prices, which make it harder for low-income families to buy enough wholesome food. Many smallholder farmers are consequently compelled to augment their income through alternative livelihood strategies like wage labour or informal trading [78]. The agricultural labour force is progressively weakened by the movement of physically fit people, especially young people, leaving older generations to manage farms in increasingly difficult circumstances [79].

3. Theoretical Framework: The Sustainable Livelihoods Approach

The Sustainable Livelihood Approach (SLA), introduced by Scoones [80] and further refined by Serrat [81], provides the theoretical foundation for this study. Core to SLA is an assessment of how individuals and families manage livelihoods in a world that includes unpredictable climate change, economic fluctuations, and institutional contexts. The approach focuses on the relationship between assets, policies, institutions, and vulnerability, thus providing a holistic viewpoint on the nature and sustainability of livelihoods [82]. This framework is particularly relevant for this study, as it provides a holistic perspective on individual farmers' capacity, access to resources, and their role in influencing institutional processes, which are all important factors for smallholder farmers' adaptation to climate change. The SLA also focuses on factors that either constrain or enhance livelihood opportunities, making it a useful tool for analysing the socioeconomic determinants of climate change adaptation strategies among smallholder farmers in Mbombela.

In the SLA, assets are categorised into five groups: human, social, natural, physical, and financial capital [81]. These assets are used by households to build resilience and adapt to external shocks. For smallholder farmers, access to these assets is crucial for the implementation of climate-resilient practices [83]. Human capital, such as education and skills, enhances the farmers' capacity to adopt innovative strategies, including climate-resilient strategies. Financial capital enhances farmers' capacity to invest in adaptive technologies such as irrigation systems or drought-resistant crop varieties. Moreover, institutional factors and policies, whether formal or informal, also have a substantial influence on farmers' livelihood outcomes [82]. The SLA highlights the role of policies, extension services, and cooperative membership in enhancing or hindering adaptation efforts. In Mbombela, access to extension services and climate information are critical institutional factors that may influence farmers' ability to adapt to climate change. The approach also underscores how external shocks and stresses, such as climate-induced challenges (droughts, floods, and unpredictable rainfall) and long-term environmental stresses like soil degradation and declining water availability, are important factors to consider as part of the vulnerability context. These challenges have led to reduced agricultural productivity, income loss, and food insecurity, highlighting the need for effective adaptation strategies.

In this study, the five livelihood capitals outlined by the Sustainable Livelihoods Approach were operationalised through selected socioeconomic variables. Human capital was reflected in the farmers' age, education level, and farming experience, which influence their knowledge, skills, and decision-making ability. Social capital was captured through cooperative membership and household size, both of which affect access to social networks, shared labour, and collective knowledge. Financial capital was assessed through the primary source of income, which indicates the availability of funds that farmers can allocate to adaptation strategies. Physical capital was represented by farm size and land ownership, which determine the farmers' capacity to implement practices like irrigation, fencing, or infrastructure changes. Although natural capital such as soil quality, rainfall, and biodiversity was not directly measured, land access indirectly reflects this dimension. By aligning these capitals with the study variables, the SLA framework provided a comprehensive background for analysing how different socioeconomic factors affect farmers' ability to adapt to climate change.

The SLA was used as the theoretical framework for this study because it addresses sustainability, which is an important milestone for smallholder farmers. A sustainable livelihood is one that can withstand and recover from shocks while conserving or enhancing its assets and capabilities for future generations [84]. The SLA also emphasises that livelihoods are multi-sectoral, integrating environmental, economic, and social dimensions into a cohesive framework [82]. This is important for understanding how smallholder farmers can diversify their livelihood strategies, such as engaging in off-farm income activities or adopting climate-smart agricultural practices, to mitigate their vulnerability to climate change [85]. Ultimately, the SLA offers a comprehensive framework to examine the complex relationship between different factors that influence the adoption of climate change adaptation strategies.

4. Materials and Methods

4.1. Study Area Description

This study was conducted in Mbombela, Ehlanzeni District, Mpumalanga (Figure 1). The municipality's geographic coordinates are 25.4° South and 30.9° East [86]. Regarding climatic trends, Mbombela Local Municipality exhibits a gradient of rising average annual temperatures from 18 °C to 22 °C in the interior and southern regions and 27 °C in the north and eastern regions. Mbombela Local Municipality experiences an average of 1200 mm of rainfall per year inland, with this gradient extending towards the north and east of the local municipality. During this time, some regions of the west see higher annual rainfall of up to 1600 mm [9]. Mpumalanga produces a wide range of vegetables and an abundance of citrus and other subtropical fruits. Mbombela is regarded as the second-largest citrus-producing region in South Africa, accounting for a quarter of the country's orange exports [87].

The overall population of the Mbombela municipal area is 818,925. The population represents 36.0% of Ehlanzeni District's total population. Accordingly, the Ehlanzeni District's most populated municipal area is Mbombela [88]. The population of Mbombela is comparatively young, as evidenced by the 56.0% of individuals whose ages range between 15 and 34, 11.6% of individuals between the ages of 35 and 64, 27.9% of children between the ages of 0 and 10, and 4.6% of older individuals. The gender composition of the total population comprises 51.7% women and 48.3% males. Black Africans, who make up 94.6% of the total population, dominate the racial profile of the municipal area, with the majority of these individuals speaking the SiSwati language, while Whites make up 4.3% of the population, 0.6% are of Coloured descent, and 0.5% are Asian [86].

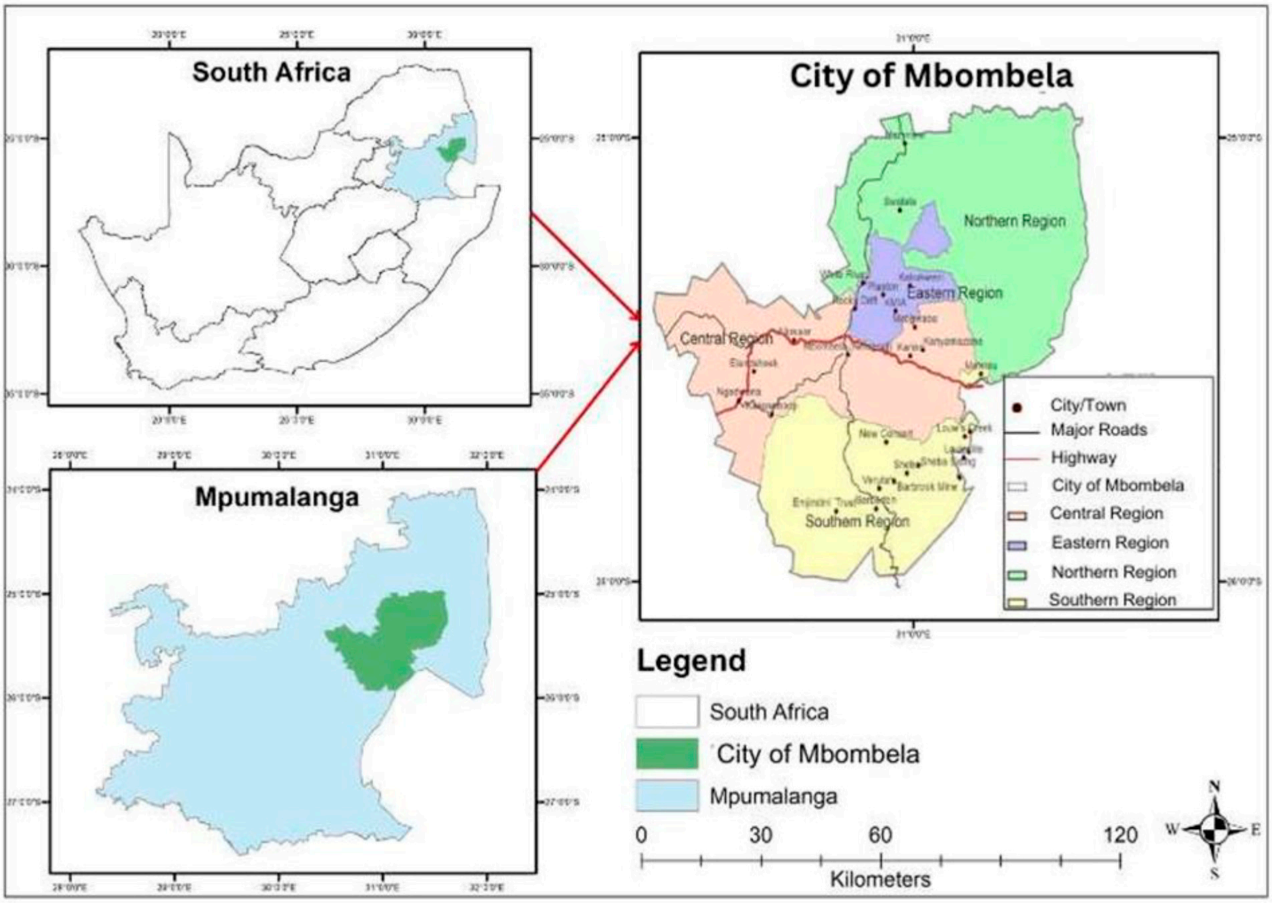

Figure 1. Map of South Africa showing the location of Mbombela [89].

4.2. Research Design and Target Population

A quantitative research technique was adopted for this study. Quantitative research employs numerical data, which are collected via structured and standardised instruments such as experiments and surveys. Such data are well-suited for statistical analysis, which aids in objective hypothesis validation [90]. The target population of this study was smallholder farmers who grow crops. They had to be at least 18 years old, have access to agricultural land (either owned, leased, or shared), be able to give accurate information about climate change, and be of any gender, marital status, and level of education.

4.3. Sampling Method and Sample Size

This study utilised a simple random sampling method, guaranteeing that no individual received preferential treatment. To achieve the randomisation, the study used an online random number generator to select 308 farmers from a total of 1343 farmers who were registered with the Department of Agriculture. The sample size for this study was calculated using Slovin's formula. Slovin's formula is used to determine the smallest sample size required to obtain a realistic sample with an acceptable margin of error, which in this case was 0.05. There are a total number of 1343 smallholder farmers registered with the Department of Agriculture in Mbombela. A total of 308 farmers who were selected were available and agreed to be interviewed. Slovin's formula is computed as follows:

$$n = N/(1 + Ne^2)$$
$$1343/(1 + 1343 \times 0.0025)$$
$$= 308$$

where:

n = number of samples
N = total population
e = margin of error

4.4. Instrument for Data Collection

One-on-one interviews were used to collect the primary data used in the present study. Data were gathered from the farmers using a structured questionnaire (Supplementary File S1). The questionnaire used to collect data was divided into two sections focusing on the socioeconomic characteristics of the farmers and their adoption of local climate change adaptation strategies. Five Siswati-speaking enumerators were appointed and trained to assist with the data collection procedure. The questionnaire was written in English. However, it was translated into SiSwati during the interviews by the enumerators, which is the local and most spoken language in Mbombela. The gathered datasets were reviewed for errors and properly coded and entered into the Statistical Package for Social Sciences (SPSS) Version 27 program before data analysis. A preliminary visit to the Mbombela Local Municipality and a questionnaire pre-test were conducted prior to data collection to assess and improve the calibre and efficacy of primary research.

4.5. Data Analysis Methods

Data analysis was completed using version 27.0 of SPSS software. The socioeconomic characteristics of the participants were analysed using descriptive statistics, including frequencies and percentages. The challenges related to climate change were assessed using the Severity Index (SI), while the adaptation strategies employed by farmers were analysed descriptively through percentages. To identify the determinants influencing the adoption of climate change adaptation strategies, a binary logistic regression analysis was performed

Severity Index (estimation)

The study employed the Severity Index (SI), which was adopted from Pickson and He [74], to measure the climate challenges for farmers. Farmers were presented with a series of statements and asked to respond using a Likert-type scale ranging from 0 to 4, where 0 indicated "strongly disagree" and 4 indicated "strongly agree." The data collected through this scale were analysed using statistical methods, including frequency distribution, percentage calculations, and Severity Index (SI) estimation:

$$Severity\ Index,\ SI = \frac{\sum_{i=0}^{4} \mathrm{a}_1\ \mathrm{X1}}{4\sum_{i=0}^{4} \mathrm{X1}}\ (100\%)$$

where a_1 indicates the index of a class; the constant denotes the weight assigned to the class; and X1 denotes the frequency of response, which is 0, 1, 2, 3, or 4, as shown below. In addition, a_0, a_1, a_2, a_3, and a_4 represent the response frequencies corresponding to X0 = 0, X1 = 1, X2 = 2, X3 = 3, and X4 = 4. Hence, with reference to Majid and McCaffer [91], the valuation arrangement is as follows:

X0: Strongly disagree $0.00 \leq SI < 12.5$
X1: Disagree $12.5 \leq SI < 37.5$
X2: Neutral $37.5 \leq SI < 62.5$
X3: Agree $62.5 \leq SI < 87.5$
X4: Strongly agree $87.5 \leq SI < 100$

The Adopted Model

The model of binary logistic regression helps in estimating the likelihood of occurrences concerning a group of independent factors that are assumed to have an impact on the results [92]. This model is used to categorise people into a group of not more than two when only one set of predictor variables is available, and it may also be used to determine which characteristics or traits are most effective in predicting decision-making [93]. There are no assumptions made regarding the distribution of the predictor variables X, though, which may be continuous [94]. As per Castro and Ferreira [95], Ri represents the binary dependent variable that is equal to 1 if smallholder farmers adopt local adaptation strategies and 0 otherwise.

The binary logistics model was applied in this study as per the variables illustrated below. In this study, the dependent variable, "adoption of local adaptation strategies", was operationalised based on whether the farmer reported using at least one or more adaptation strategies. Specifically, farmers were asked whether they had implemented any adaptation strategies related to climate change. If a farmer reported using at least one adaptation strategy, they were coded as 1 (indicating adoption), and if no adaptation strategies were reported, they were coded as 0 (indicating no adoption). The aim was to ascertain whether the different socioeconomic characteristics of smallholder farmers have a significant influence on their adoption of local climate change adaptation strategies. When categorical and numerical variables are present, logistic regression is seen as the most appropriate.

Logistic Function:

$$P(Y = 1) = \frac{1}{1 + e - (\beta 0 + \beta 1X1 + \beta 2X2 + \cdots + \beta nXn)}$$

where:

- $P(Y = 1)$ is the probability of the outcome (adopting climate adaptation strategies)
- Bo is the intercept term
- $\beta 1$, $\beta 2$ ………………… $+\beta n$ are the coefficient for the predictor variable

The following method was used to identify significant independent variables that influence the outcome:

$$Y = \beta o + \beta 1X1 + \beta 2X2 + \ldots\ldots\ldots\ldots\ldots\ldots + \beta 11X11 + \mu$$

where the variables are represented as follows:

Y = adoption of local climate change adaptation strategies (smallholder adopts local climate change adaptation strategies = 1, O = otherwise)
X1–X9 = predictor variables demarcated as:
X1 = Gender (Male = 1, Female = 0)
X2 = Age (Years)
X3 = Educational level (No school = 0, ABET = 1, Primary school = 2, Secondary = 3, Tertiary = 4)
X4 = Farm size (Ha)
X5 = Household size
X6 = Primary source of income (Pension = 0, Farming = 1, Off-farm employment = 2, Remittances = 3, Social grants = 4)
X7 = Access to extension services (yes = 1, no = 0)
X8 = Access to climate change information (yes = 1, no = 0)
X9 = Cooperative membership (yes = 1, no = 0)
$\beta 0$ = Constant
$\beta 1$–$\beta 9$ = Regression coefficients
μ = Error term

While several socioeconomic variables were collected, only those with theoretical relevance and statistical justification were included in the final regression model. Variables such as marital status, land ownership, and farming experience were excluded because preliminary correlation and multicollinearity tests showed minimal influence on the adoption outcome. For instance, marital status was closely aligned with household size and cooperative membership, potentially leading to collinearity issues. Similarly, farming experience was strongly correlated with age, which was retained as the more comprehensive variable for analysis. The exclusion of these variables ensured a more parsimonious model and reduced the risk of overfitting or misleading interpretations.

4.6. Ethical Considerations

This section emphasises the ethical considerations integral to the research, aligning with established principles of respect, privacy, confidentiality, voluntary participation, and informed consent. Participants' rights were prioritised, ensuring anonymity, confidentiality, and the freedom to withdraw from the study at any stage. Informed consent was obtained by clearly explaining the study's purpose, procedures, and voluntary participation nature. Participants were asked to sign consent forms to declare their voluntary participation. Data security measures, such as secure storage and restricted access, were implemented to protect participants' information. The study adhered to ethical guidelines, safeguarding participants from physical, psychological, or emotional harm, and upheld the moral responsibility of minimising risks while maximising the benefits of research participation. Ethical clearance for the study was granted by the University of Mpumalanga Research Ethics Committee (protocol reference: UMP/Dyanty/219031614/MAGR/2023).

5. Results

5.1. Socioeconomic Characteristics of Respondents

Based on the sample of 308 smallholder farmers, the study investigated sociodemographic patterns, which are summarised in Table 1. As shown in the table, female farmers constitute 51.0% of the sampled smallholder farmers, while their male counterparts account for 49.0%. Although the difference is marginal, this finding aligns with existing literature that emphasises the significant presence of female farmers in the agricultural sector [70,96]. Table 1 also presents the age distribution of respondents, showing that the largest group (26.0%) falls between 46 and 55 years. This is followed by 23.7% aged 56–65 years, 18.2% aged 36–45 years, 16.6% aged $\leq$ 35 years, and 15.6% aged $\geq$ 66 years. These findings align with those of Maziya et al. [97], indicating that smallholder farming is dominated by older farmers.

Furthermore, respondents' education levels differed, with the majority (32.8%) having completed secondary education, followed by 23.7% with primary education, 20.5% with no formal education, 11.7% with tertiary education, and 11.4% having attended adult school (ABET). These findings align with Jamshidi et al. [98], who reported that most farmers had formal education. As shown in Table 1, the distribution of marital status indicates that most respondents (49.7%) were married, followed by 31.8% who were single. Widows accounted for 6.8%, while both widowers and divorced individuals made up 5.8% each. This aligns with previous research, which found that farming is predominantly practised by married individuals [10,98]. Atube et al. [6] further argued that married farmers are more aware of and adaptable to climate change, enabling them to implement strategies that mitigate its effects.

Table 1. Socioeconomic characteristics of smallholder farmers in the study area.

Variables	Categories	Percentages (%)
Gender	Male	49.0%
	Female	51.0%
Age	≤35	16.6%
	36–45	18.2%
	46–55	26.0%
	56–65	23.7%
	≥66	15.6%
Education level	No school	20.5%
	ABET education	11.4%
	Primary education	23.7%
	Secondary education	32.8%
	Tertiary education	11.7%
Marital status	Single	31.8%
	Married	49.7%
	Divorced	5.8%
	Widow	6.8%
	Widower	5.8%
Farming experience	≤5	24.0%
	6–10	27.6%
	11–15	17.2%
	16–20	12.7%
	≥21	18.5%
Land ownership	Own	57.8%
	Lease	10.1%
	Tribal authority	18.8%
	Land reform	13.3%
Farm size	≤5 hectares	66.5%
	6–10 hectares	23.3%
	11–15 hectares	5.5%
	16–20 hectares	1.0%
	≥21 hectares	1.0%
Household size	≤5	41.6%
	6–10	47.1%
	11–15	11.0%
	≥21	0.3%

Table 1 also shows that most respondents had 6–10 years of farming experience (27.6%), followed by 24.0% with 5 or less years. A small proportion had 21 or fewer years (18.5%), 11–15 years (17.2%), and 16–20 years (12.7%). These results are consistent with Qange and Mdoda [99], who discovered that most farmers had an average of 10 years of farming experience. Furthermore, experienced farmers are more aware of climate change, shaping their decisions [100]. Table 1 further shows the distribution of ownership of land, with 57.8% owning their land, 18.8% acquiring their land from tribal authority, 13.3% acquiring their land from land reform, and 10.1% on leased land. The findings support prior studies which found that about 92.2% of agricultural land was privately owned [101]. Moreover, Kangogo et al. [102] and Irshad Irshad et al. [103] argued that land ownership significantly impacts farmers' adoption of climate change adaptation strategies.

Additionally, Table 1 highlights the distribution of respondents' farm sizes. Notably, 66.2% of the respondents owned 5 or fewer hectares, 26.3% had 6–10 ha, and 5.5% had 11–15 ha. Furthermore, 1% of the respondents had 16–20 ha or 21 or more hectares. The results indicate that respondents operate on relatively small farm sizes, which is expected, as smallholder farmers are typically characterised by limited land access and ownership [103]. Lastly, Table 1 indicates the household size of the respondents, revealing that most respondents (47.1%) had households of 6–10 members, 41.0% had households of 5 or fewer members, 11.0% had households of 11–15 members, and a small proportion (0.3%) had households of 21 or more members. These findings indicate that most participants had relatively large household sizes, which likely mitigated labour shortages, as smallholder farmers predominantly rely on family labour for agricultural activities [104]. Ndlazilwana et al. [105] argued that family members are a vital source of climate change information, and larger households may facilitate adaptation by providing additional labour and fostering knowledge exchange on mitigation strategies.

5.2. Climate-Related Challenges Faced by Smallholder Farmers in Mbombela

Climate change has posed a range of significant challenges for smallholder farmers in Mbombela, particularly in relation to agricultural productivity and food security. Farmers who participated in the study reported a decline in crop yields due to unpredictable rainfall patterns, prolonged dry periods, and increased temperature fluctuations. The climate challenges and adaptation strategies employed by farmers in Mbombela are shown in Table 2. The Severity Index for decreased crop yields is notably high (78.40), indicating that crop productivity has been severely impacted by these climatic changes. Furthermore, the availability of water, which is crucial for rain-fed agriculture, has decreased as a result of changing rainfall patterns and extended dry periods. The Severity Index for water availability is 73.30, reflecting the widespread concern among farmers regarding the insufficient and inconsistent distribution of water resources. Another significant challenge reported by farmers is the increased prevalence of pests and diseases, which are exacerbated by changing climatic conditions such as rising temperatures and humidity [98]. The Severity Index for pests and diseases is 63.39, showing that these factors are also a growing concern for farmers, leading to further yield loss and the need for greater pest control efforts.

Table 2. Climate challenges and adaptation strategies in Mbombela.

Climate Challenge	Severity Index (SI)	Adaptation Strategy	Percentage of Farmers Adopting
Decreased Crop Yields	78.40	Pest and Disease Control	79.9%
Decreased Water Availability	73.30	Changing Planting Dates	74.7%
Increased Pests and Diseases	63.39	Soil Conservation and Water Management	50.6%
Crop Failure due to Drought	68.40	Crop Diversification	52.5%
Soil Erosion and Degradation	72.00	Intercropping	47.2%

Table 2. *Cont.*

Climate Challenge	Severity Index (SI)	Adaptation Strategy	Percentage of Farmers Adopting
Loss of Soil Fertility	66.70	Use of Improved Seed Varieties	56.1%
Flooding and Waterlogging	65.00	Use of Drip Irrigation	33.0%
Increased Temperature and Heat Stress	70.10	Adjustment of Harvesting Seasons	63.3%

5.3. Adaptation Strategies Adopted by Smallholder Farmers in Mbombela

In response to these climate-related challenges, smallholder farmers in Mbombela have employed a variety of adaptation strategies aimed at mitigating the negative effects of climate change. As shown in Table 2, the most widely adopted strategy is pest and disease control, with 79.9% of farmers utilising integrated pest management techniques to reduce crop losses from pest outbreaks. Another prevalent strategy is changing planting dates, with 74.7% of farmers adjusting their planting schedules to better align with shifting rainfall patterns. This strategy is intended to maximise the growing season and reduce the risk of crop failure [101]. Additionally, soil conservation and water management techniques are commonly used to improve soil fertility and conserve moisture in the midst of prolonged dry periods. About 50.6% of farmers engage in these practices, which include mulching, contour farming, and water harvesting. These efforts are aimed at improving the resilience of crops to climate variability and enhancing overall productivity.

5.4. The Socioeconomic Determinants and Adoption of Local Adaptation Strategies

The statistical relationship between selected socioeconomic characteristics of smallholder farmers and their adoption behaviour to climate change adaptation strategies is illustrated in Table 3. The analysis of the logistic regression model summary in Table 3 reveals a −2 log-likelihood value of 58.171 and a Cox and Snell R square of 0.166, indicating a moderate level of variability explanation. In contrast, the Nagelkerke R square of 0.535 exhibits a stronger explanatory power, accounting for nearly 53.5% of the variance in the outcome. The Hosmer and Lemeshow test yielded a chi-square of 1.072 and a p-value of 0.998, indicating no significant difference between the actual and estimated values, thus confirming a robust model fit. The tests indicate that the model performs well in interpreting the relationship between the independent variables and the outcome.

The findings, as presented in Table 3, reveal that gender ($p = 0.055$) significantly influenced the adoption of local climate change adaptation strategies, suggesting that female farmers may face greater barriers to adopting these practices compared to their male counterparts. Similarly, age ($p = 0.003$) was found to be a significant variable influencing adoption, indicating that younger farmers are more likely to embrace climate-resilient strategies than older farmers. The source of income ($p = 0.018$) also had a significant influence, implying that farmers relying solely on farming income may struggle to adopt adaptation strategies compared to those with diversified income sources. Access to climate change information ($p = 0.029$) was also a significant variable influencing adoption, raising questions about the effectiveness of current information dissemination methods. Finally, cooperative membership ($p = 0.053$) was also found to influence adoption, suggesting that cooperative structures in the study area may not be effectively promoting climate-resilient practices. These results highlight the complex interplay of demographic, economic, and institutional factors in shaping the adoption of local climate change adaptation strategies.

Table 3. Regression results on adaptation strategies adoption and the influence of socioeconomic characteristics.

Independent Variables	B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower Bound	Upper Bound
Gender	−1.407	0.732	3.689	1	0.055 *	0.245	0.058	1.029
Age	−1.611	0.542	8.825	1	0.003 *	0.200	0.069	0.578
Level of education	0.346	0.434	0.635	1	0.426	1.413	0.604	3.305
Farm size	0.471	0.661	0.509	1	0.476	1.602	0.439	5.849
Household size	−0.988	0.565	3.053	1	0.081	0.372	0.123	1.128
Source of income	−0.902	0.382	5.558	1	0.018 *	0.406	0.192	0.859
Access to extension services	−1.282	0.783	2.685	1	0.101	0.277	0.060	1.286
Access to information on climate change	−0.735	0.337	4.763	1	0.029 *	0.480	0.248	0.928
Cooperative membership	−1.538	0.796	3.735	1	0.053 *	0.215	0.045	1.022
Constant	21.791	4.889	19.870	1	<0.001	29,080,719.83.585		
−2 Log-likelihood	58.171							
Cox and Snell R square	0.166							
Nagelkerke R square	0.535							
Hosmer and Lemeshow Test	Chi-square 1.072 df 8 Sig 0.998							

Significant level: 0.05–0.10 *.

6. Discussion

6.1. Socioeconomic Characteristics of Respondents

Socioeconomic characteristics among smallholder farmers in Mbombela are a rich source of insights into their capacity to adopt strategies for adapting to climate change. The results illustrate that participants showed nearly equal gender distribution, with 51% women and 49% men farmers. This is consistent with the findings of Agholor [106], who found that women greatly contribute to agriculture, especially in Sub-Saharan Africa. However, female farmers frequently face significant constraints such as limited access to resources and decision-making power. This highlights the need for gender-sensitive policies and interventions that will enhance women farmers' capacity to adopt resilient practices. The majority of farmers (65.3%) were over 45 years old. This aligns with previous research which found that older farmers dominate smallholder farming [97]. While older farmers bring important indigenous knowledge, their hesitation to try new methods could slow progress towards adaptation. Thus, there is a need to encourage intergenerational knowledge transfer. Additionally, the provision of incentives for older farmers who embrace modern practices can help encourage the adoption of adaptation strategies among these farmers. This is consistent with the SLA's assertion that human capital, such as age and experience, shapes the ability to adapt [81], but younger generations may require support to build the capacity for adaptation, reinforcing the need for targeted educational initiatives.

Most of the farmers have secondary education (32.8%), while 20.5% have no formal education. This is consistent with findings from Girei et al. [107], who found that formal education boosts farmers' access to information and ultimately enhances their capacity to adopt improved practices. However, with only 11.7% of the farmers having tertiary education, there is a clear need for targeted educational programmes to increase literacy and awareness of climate adaptation strategies. This is in line with the SLA's focus on human capital. Educational levels directly influence the effectiveness of adaptation strategies, as better-educated farmers are more likely to engage in climate-resilient practices [83].

Married farmers constitute an overwhelming majority (49.7%) of the participants, while 31.8% are single. This is consistent with a previous study, which found that smallholder farming is mostly practised by married individuals [108]. Married farmers have more access to family labour and shared decision-making, which facilitates adaptation strategy adoption. However, the presence of single farmers shows the need for inclusive policies which focus on unique challenges faced by diverse household structures.

Most of the farmers (27.6%) had 6–10 years of experience, while 18.5% had over 21 years of experience. This is consistent with Agholor et al. [109], who maintained that farming experience highly affects the way farmers make decisions and their awareness of climate change. Experienced farmers are more likely to adopt new strategies for coping because they are used to navigating local conditions. However, younger farmers with less experience need more help to become better prepared for dealing with weather changes that come with climate change. A significant percentage of the farmers (57.8%) owned their land, while others acquired land through tribal authority (18.8%) or land reform (13.3%). This aligns with Paudel et al. [101], who found that private land ownership is common among smallholder farmers. Land ownership can enhance farmers' willingness to invest in long-term adaptation strategies, as they have greater control over their resources. However, farmers without land ownership may face challenges in adopting such practices, highlighting the need for secure land tenure policies. This relates to the SLA's focus on natural capital, particularly the importance of land rights in providing the foundation for farmers to invest in long-term adaptive measures.

The majority of farmers (66.2%) operated on small plots of land ($\leq$5 hectares). This finding is consistent with Dick-Sagoe et al. [110], who found that smallholder farmers generally operate on small farms. As a result, the ability of smallholder farmers to invest in large-scale adaptation strategies is usually limited. This underscores the need for policies that promote land consolidation or cooperative farming to help smallholder farmers overcome these limitations. Most of the farmers (47.1%) had household sizes of 6–10 members, indicating substantial availability of family labour for agricultural activities. This aligns with Ndlazilwana et al. [105], who noted that larger households have a greater ability to facilitate knowledge exchange and labour-sharing, enhancing adaptation efforts. However, additional support may be required for smaller households to address labour shortages.

6.2. The Socioeconomic Determinants and Adoption of Local Adaptation Strategies

The study found several significant socioeconomic factors that influence smallholder farmers' use of adaptation measures for climate change in Mbombela. The results show that women farmers are less likely than men to adopt climate change adaptation strategies. This is consistent with previous studies that suggest women lack access to resources and decision-making power which prevents them from implementing adaptation strategies [111,112]. Another study found that households led by men are more likely to use adaptation strategies [113]. Women farmers also face more challenges accessing credit due to their limited ownership of assets such as land. Furthermore, cultural preferences in the local area suggest that men are generally perceived as household heads, which means that the decision for adoption of innovations at the household level still lies with men. To fill this gap, various targeted interventions like gender-sensitive training and better credit access are necessary for women farmers.

Young farmers were found to be more likely to adopt strategies for adaptation to climate change compared to older farmers. Consistent with Hirpha et al. [114], young farmers are more open to new technologies and farming practices. Older farmers are more likely to stick with traditional methods because they have familiarity and aversion to risk. Promoting the exchange of knowledge among generations and rewarding the adoption of newer modern farming practices has the potential to improve overall rates of adoption. Farmers with diverse sources of income were more likely to adopt adaptation strategies. This suggests that stable income plays a critical role in allowing farmers to invest in resilient practices. The similar stance of Mulwa and Kabubo-Mariara [115] also agreed that income opportunities that are not directly farming-related facilitate long-term adaptation. Policies that promote diversification of income like supporting smaller-scale enterprises or different jobs outside agriculture play effective roles to strengthen farmers' capacity to deal with the challenges of climate change. This connects to the SLA's financial capital component, highlighting how diversified income provides the financial resilience needed for long-term adaptation.

Surprisingly, access to information about climate change was found to be negatively associated with the adoption of adaptation strategies. This result conflicts with the general expectation that information is the catalyst for action [116]. One possible explanation is that the quality, relevance, and credibility of the climate information provided to farmers in the study area may be lacking. If the information is perceived as unreliable, outdated, or not tailored to local agricultural conditions, it is unlikely to inspire changes in farming practices. To address this, improving the quality and relevance of climate information could be achieved by working more closely with local extension services and organising community workshops, ensuring that the information shared is both understandable and actionable.

Moreover, the delivery mechanisms for this information could be another critical factor. If the information is not delivered in a timely, clear, and practical manner, farmers may struggle to incorporate it into their decision-making processes effectively. Another possible explanation for the negative correlation is reverse causality. It could be that farmers facing difficulties adapting to climate change actively seek out information to help them overcome these challenges. However, despite obtaining this information, they may be unable to adopt effective adaptation strategies due to other constraints, such as limited financial resources, inadequate infrastructure, or lack of support.

Similarly, cooperative membership was found to have a negative impact on adoption, which contradicts previous studies in Tanzania, where cooperatives were shown to positively influence the adoption of adaptation strategies [117,118]. This is also reflected in the social capital component of the SLA, suggesting that effective networks within cooperatives could better support adaptation by emphasising climate resilience.

In the case of Mbombela, it seems that cooperatives are not effectively promoting climate-resilient practices. One potential reason for this is the lack of focus on climate adaptation within cooperatives. Many cooperatives in the region may primarily focus on traditional agricultural issues like input supply, marketing, or price stabilisation, rather than offering climate adaptation technologies or promoting resilient practices. If cooperatives fail to prioritise these areas or effectively communicate their benefits, members may not experience tangible improvements, which could explain the negative relationship with adaptation.

Reverse causality could also be at play here. It is possible that farmers struggling with climate adaptation may join cooperatives in search of additional resources or support.

However, without effective climate adaptation programmes within the cooperatives, membership might not lead to increased adoption of resilient practices. The Nagelkerke R^2 value of 0.535 suggests that 53.5% of the variation in adaptation behaviour is explained by the model. The remaining 46.5% may be due to unmeasured factors such as cultural beliefs, trust in information sources, or psychological variables like risk perception [101], which were beyond the scope of this study. These unmeasured factors highlight the need for the SLA's framework to expand to consider other intangible factors such as trust and psychological barriers, which may be equally important in shaping adaptive behaviour.

6.3. Study Limitations

While this study provides valuable insights into the socioeconomic determinants of climate change adaptation strategies among smallholder farmers in Mbombela, it was impacted by different limitations. The study relied on self-reported data from farmers, which may not always be accurate due to the lack of proper record-keeping among the smallholder farmers. The study also focused specifically on the Mbombela area, which means the results may not always be generalisable to other areas with different socioeconomic and climatic conditions. Future research could expand the area of focus to include other regions, which can help to provide a better understanding of adaptation strategies across different regions and contexts.

Additionally, the study employed a cross-sectional design, where data are collected at a single point in time. This limits the ability to assess the long-term adoption patterns of adaptation strategies and how farmers' adoption behaviour may evolve over time. Furthermore, the study focused on specific socioeconomic factors and did not explore other factors such as cultural and traditional practices, which may also be important in understanding farmers' decision-making processes.

7. Conclusions and Recommendations

This study highlights the important role of socioeconomic factors in influencing the adoption of climate change adaptation strategies among smallholder farmers in Mbombela. The study found a near-equal gender distribution among the farmers, with slightly more women than men. This highlights the important role played by women in agriculture. The majority of farmers were over 45 years old, highlighting the overwhelming presence of older farmers in smallholder farming. While older farmers bring valuable indigenous knowledge, they may be adopting fewer modern practices due to familiarity with conventional practices. The level of education varied amongst the farmers, with most farmers having secondary education. However, a significant portion had no formal education at all, underscoring the need for targeted literacy and awareness programmes.

The findings show that gender, age, income sources, access to information, and cooperative membership significantly influence farmers' adoption of adaptation strategies. According to the study findings, female farmers, older farmers, and those relying solely on farming income face greater barriers to adopting climate change adaptation strategies, while younger farmers and those with diversified income sources are more likely to embrace adaptation strategies. Surprisingly, access to climate change information and cooperative membership were found to be negatively associated with adaptation strategy adoption, suggesting that current information dissemination methods and cooperative structures in the area may not be effectively promoting climate-resilient practices.

Based on the findings, the study recommends that policymakers should prioritise gender-sensitive interventions that enhance female farmers' access to resources, credit, and decision-making power. This includes the establishment of women-focused extension programs and microfinance schemes, training programmes, financial incentives, and the promotion of women-led cooperatives. Efforts should also be made to bridge the generational gap in farming by encouraging knowledge sharing between older and younger farmers. Furthermore, the provision of incentives for older farmers to adopt modern practices, together with training programmes for younger farmers, could help improve the adoption of resilient practices.

Government and other stakeholders should also promote the diversification of livelihoods to enhance smallholder farmers' financial resilience. To achieve this, there should be increased support for off-farm employment opportunities, small-scale business enterprises, and market access. Moreover, local extension services and community organisations should work together to improve the quality and relevance of climate change information. This information should be tailored according to the specific situation and needs of the farmers, ensuring that it is practical and actionable. This includes the introduction of mobile-based weather and climate forecast platforms tailored for local dialects. Finally, cooperative structures should receive more support to enhance their capacity to promote climate-resilient practices. This includes the provision of training on climate-smart agriculture, the promotion of knowledge sharing among members, and ensuring that they have adequate access to resources and funding. Cooperative effectiveness can also be enhanced through the development of training modules on climate-smart agriculture for cooperative leaders. Addressing these socioeconomic barriers and enhancing the capacity of smallholder farmers is crucial for building more resilient agricultural systems that can withstand the challenges posed by climate change.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/cli13050090/s1, Supplementary File S1: Questionnaire for Smallholder farmers.

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