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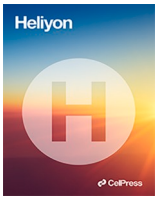

Research article

A systematic literature review on the impact of climate change on the livelihoods of smallholder farmers in South Africa

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A B S T R A C T

Smallholder farmers in South Africa are increasingly vulnerable to the adverse effects of climate change, posing significant threats to their livelihoods and food security. This systematic literature review investigates the several impacts of climate change on smallholder farmers across the country. The literature review used a systematic approach to search for relevant research across three academic databases such as Google scholar, Consensus, and Zendy. Based on the inclusion criteria for the literature review, 261 articles were initially screened, and 35 articles were included in the systematic review. This process helped to identify the most relevant and high-quality studies on the topic. The data extracted from the 35 articles were analyzed and synthesized to identify the impact of climate change on the livelihoods of smallholder farmers. This helped to identify commonalities and differences across the literature, and to draw conclusions about the impact of climate change on the livelihoods of smallholder farmers. The study identified and examined the specific challenges faced by smallholder farmers, including the loss of livestock, reduced crop yields and heightened economic hardship. Additionally, the review explores the coping strategies employed by farmers to mitigate these challenges and adapt to the evolving climatic conditions. The findings highlight the urgent need for targeted interventions and support mechanisms aimed at enhancing the resilience of smallholder farmers and ensuring the long-term sustainability of agricultural practices amidst the challenges posed by climate change. Furthermore, the study provides valuable recommendations for policymakers, agriculturalists, and other stakeholders to address the identified issues and support smallholder farmers in adapting to climate change.

1. Introduction

Smallholder farming plays a vital role in the livelihoods of rural populations around the world [1,2]. Smallholder farmers manage up to 75 % of the world's agricultural land [3,4]. In South Africa, smallholder farmers play a pivotal role in bolstering food security, their productivity and efficiency being essential in combating food poverty and malnutrition [5,6]. The United Nations' Sustainable Development Goals (SDGs) consist of 17 goals, and while climate change is an important aspect, not all of them focus directly on it [7]. Specifically, SDG 13 is the primary goal that focuses on taking urgent action to combat climate change and its impacts [7]. Climate change can be defined as a long-term trend in one or more climatic variables, characterized by a consistent increase or decrease of average values over a prolonged period of time [8]. This includes, but is not limited to, increasing surface temperatures, more frequent

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and severe floods and droughts, more powerful storms, and rising sea levels. Subsequently, there has been a growing body of literature addressing climate change due to concerns regarding its negative effects on agricultural output [9]. Research on climate change and food security is important at both the national and global level. It provides information that can be used to inform policy decisions and actions to address the impact of climate change on food security [10]. This research also helps to highlight the challenges that are currently being faced, as well as potential solutions that can be implemented to improve food security, sustainability and resilience of smallholder farmers in the future.

In most parts of African countries, the productivity of agriculture heavily depends on the prevailing weather patterns and the accessibility of water resources [11–15]. However, the livelihoods of smallholder farmers are increasingly imperiled by the specter of climate change [16–18]. Climate forecasts for South Africa indicated a rise in temperatures and greater fluctuations in rainfall, which are exacerbating food insecurity in the area [19–22]. Climate change poses significant dangers and undermines the fundamental means of survival for those who are impoverished and marginalized [23–25].

Various research conducted in South Africa have indicated that small-scale farmers observe alterations in the climate across different dimensions [26,27]. Climate change is expected to have a significant impact on the livelihoods of rural farmers in South Africa, especially smallholder farmers who rely heavily on rain-fed agriculture [12], [28–34]. Climate change disproportionately harms impoverished households due to their limited ability to adjust to shifting climate conditions [12].

The semi-arid rainfall regime of much of South Africa, which typically ranges from 400 to 650 mm per year, poses a significant challenge for water resources management in the region due to high inter-annual variability (Fallon et al., [35]. Climate change-induced extreme weather events, such as droughts and floods, have become the leading concerns for Southern Africa's growing and emerging economies [36,37]. These weather events have increased in frequency and intensity, causing significant disruptions to agricultural production and food security [38–40]. During the 20th century, there have been significant changes in climate conditions in many regions around the world, driven by the ongoing increase in global greenhouse gas emissions [41]. This has resulted in rising temperatures, changing precipitation patterns, and more frequent extreme weather events, such as heatwaves, floods, and droughts. Small-scale farmers are anticipated to adapt to increasing temperatures and irregular rainfall patterns by employing on-site agricultural techniques and branching out into non-farming activities [42].

Small-scale farmers cope with increased temperatures temporarily, yet over time, they encounter difficulties in adjusting to temperatures above the norm. This ultimately leads to a decline in agricultural output and limited options for diversification. Consequently, this prolonged exposure to higher temperatures gradually diminishes agricultural productivity, making it harder for farmers to sustain their livelihoods. Moreover, the reduced yields and limited crop options limit their ability to diversify their income sources, further exacerbating their struggles in the long run. The changing climate is also intensifying challenges related to resources beyond food security, such as water scarcity, pollution, and soil degradation [43]. These interrelated problems pose significant threats to the sustainability of ecosystems, agricultural productivity, and the overall well-being of communities worldwide.

Gbetibouo et al. (2010) [44] conducted a comprehensive analysis of South African agriculture's vulnerability to climate change and variability, revealing a nuanced interplay of factors across the country's nine provinces. Their findings underscored the intricate relationship between climate-induced risks and socioeconomic development, with results indicating that provinces such as Limpopo, Kwazulu-Natal, and the Eastern Cape are particularly vulnerable. These regions are characterised by densely populated rural areas, a prevalence of small-scale farming, and heavy reliance on rain-fed agriculture, which accentuates the urgency for tailored interventions.

The ramifications of climate change extend far beyond agricultural realms, permeating urban landscapes within the Southern African Development Community (SADC). Mupedziswa and Kubanga (2017) [45] elucidate the profound human suffering inflicted by climate-induced upheavals in urban areas, underscoring the imperative for regional collaboration in mitigating adverse effects. Mugambiwa and Tirivangasi (2017) [46] further illuminate the multifaceted impact of climate change, elucidating its deleterious effects on drinking water access, public health, and food security in South Africa, precipitating challenges in crop cultivation, livestock management, and poverty alleviation endeavors.

Projections indicate a bleak trajectory for South Africa's socioeconomic landscape in the absence of concerted action against climate change. Cullis et al. (2015) [47] warn of a potential 1.5 % decline in GDP by 2050, accentuating the exigency for mitigation and adaptation measures. Concurrently, agricultural systems face impending threats, with specialised crop farming systems particularly susceptible to diminished productivity [9]. Amid these challenges, smallholder farmers emerge as frontline actors, grappling with prolonged droughts, erratic rainfall patterns, and escalating crop failures, compounded by limited adaptive capacities [48,49]. The influences of climate change can be diverse and difficult to predict, making it a complex and uncertain factor in the production of food [50].

As climate change escalates, the imperative for proactive adaptation strategies becomes increasingly salient. Olabanji et al. (2020) [51] exemplify the efficacy of adaptive measures such as altered planting schedules and rainwater harvesting in bolstering crop production amidst declining yields. However, systemic barriers hinder widespread adoption, necessitating multifaceted interventions to enhance resilience and safeguard livelihoods [33] In essence, the confluence of climate change and smallholder farming in South Africa precipitates a complex tapestry of challenges and opportunities, underscoring the imperative for holistic approaches to foster resilience and sustainability in agrarian landscapes. Studies of historical climate patterns in South Africa show that the nation has encountered substantial and statistically notable rises in temperature throughout the previous century [52]. Climate change forecasts suggest that these patterns are likely to persist, with temperatures projected to rise by 2–3 °C, or potentially even 3–4 °C, by the middle of the century [52]. The exact extent of the increase will depend on how quickly greenhouse gas emissions accumulate in the future. The anticipated alterations in rainfall are not clear. Different climate-related catastrophes, along with susceptibility to dry, semi-dry, and severe weather patterns, can be addressed through diverse adaptation approaches [53]. Yet, these methods can only be effective if

small-scale farmers are knowledgeable about and capable of recognizing the climate changes impacting their surroundings, as well as the available coping and adjustment tactics.

Many adaptive and mitigation approaches necessitate significant time and financial investments [54]. These strategies typically involve comprehensive planning, resource allocation, infrastructure development, and ongoing monitoring and adjustment. They require careful consideration of long-term goals, potential risks, and the allocation of resources to effectively address current and future challenges posed by various environmental, social, or economic factors. The successful implementation of such strategies often relies on sustained commitment, collaboration among stakeholders, and the mobilization of resources to ensure their effectiveness and long-term sustainability. Hence, it is necessary to strategize and implement initiatives for adapting to extreme climate conditions in order to enhance awareness and effectiveness in dealing with them [55].

A systematic review can provide a complete and unbiased overview of the existing evidence on a particular topic, which can be difficult to achieve with more traditional methods of literature review. It can also identify gaps in the existing evidence and suggest new directions for future research. This systematic review endeavors to elucidate the multifaceted impacts of climate change on smallholder farmers' livelihoods, elucidating key findings, identifying gaps in current knowledge, and delineating pathways for future research and policy action. Policymakers, researchers, and practitioners working in the field of sustainable agriculture will be able to use the findings of this review to inform their work and make better decisions. The review can also guide future research, which could help to accelerate the adoption of sustainable agriculture practices among smallholder farmers. These practices could help to improve food security, protect the environment, and increase the resilience of smallholder farmers to climate change.

1.1. Material and methods

We conducted an extensive literature search using Google Scholar, Consensus, and Zendy, focusing on articles published from 2005 onwards and exclusively covering climate change impacts on smallholder farmers in South Africa (Fig. 1). The search terms included "impact" "effect," "vulnerability," "climate change," "smallholder," "farmers," "livelihoods," "agriculture," and "South Africa." Initially, the search yielded 261 articles. After applying the inclusion criteria, which included articles published in English and

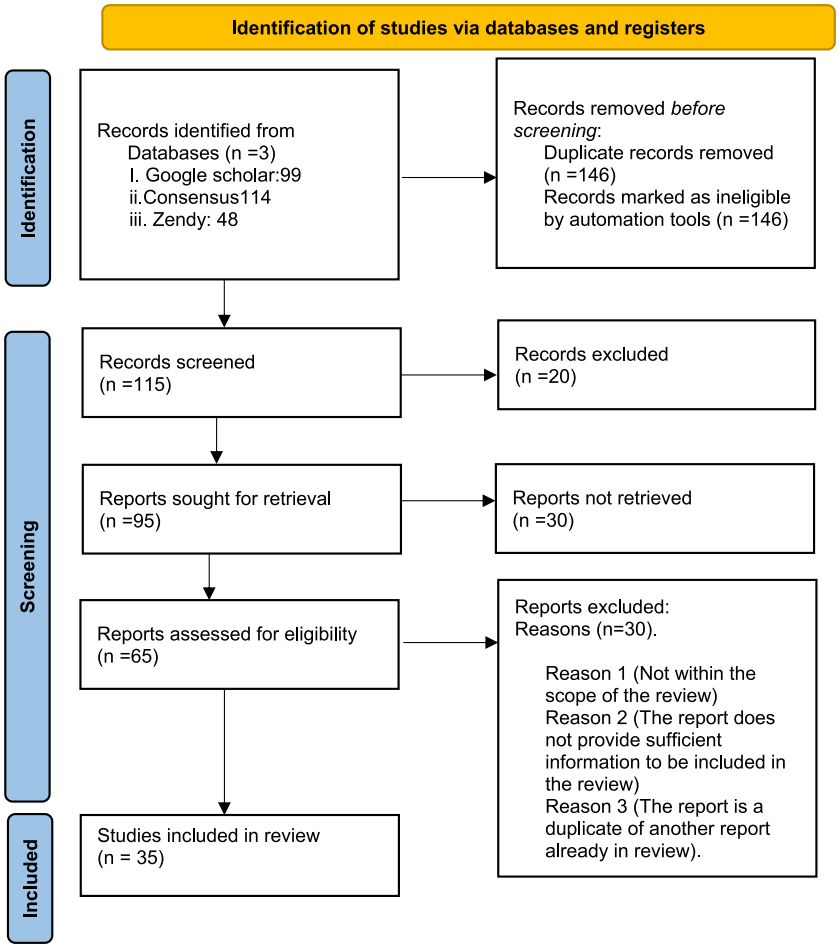

Fig. 1. Flow diagram of the literature screening process.

specifically addressing the impact of climate change on smallholder farmers' livelihoods in South Africa, the number of articles was narrowed down to 35. The selection process involved screening titles and abstracts to identify relevant articles, followed by a full-text review to assess their suitability for inclusion. Articles that did not meet the inclusion criteria were excluded, while those providing valuable insights into the impact of climate change on smallholder farmers in South Africa were included. The selected articles were analyzed to extract relevant information on the challenges faced by smallholder farmers and the strategies they employ to adapt to changing climatic conditions. The findings from these articles were synthesized to provide a comprehensive overview of the subject.

2. Data synthesis

In synthesising the data from the selected journals, key information such as authors, publication years, provinces of study, data sources, methodology types, impacts of climate change, and coping strategies were extracted. Authors and publication years provided insight into the research timeline, while provinces of study offered geographical context. The data sources varied, from primary data collection to secondary sources, enriching the understanding of the research landscape.

The study specifically examined the physical impacts of climate change, such as changes in rainfall patterns and their effects on crops and livestock. However, it also placed significant emphasis on the economic and environmental contexts of the affected communities. Understanding these contexts was crucial, given that many smallholder farmers in South Africa are highly dependent on rain-fed agriculture and often lack the resources and infrastructure needed to adapt to climatic changes.

The research also highlighted the socio-economic challenges faced by these farmers, including poverty and limited access to markets, which further reduce their resilience to climate-induced shocks. By synthesising the findings, the study identified common themes and disparities in coping strategies, such as crop diversification and water conservation practices. The analysis underscored the resilience of smallholder farmers but also pointed to the necessity for targeted interventions that consider both the economic and environmental contexts of these communities.

Overall, this methodology provided valuable insights into the complex and dynamic relationship between climate change and the livelihoods of smallholder farmers in South Africa, emphasizing the need for holistic approaches in developing effective interventions.

3. Results

3.1. Research progress on impact of climate change on smallholder farmers in South Africa

The results of the 35 studies analyzed comprised 13 mixed-methods studies, 9 qualitative studies, and 13 quantitative studies (Fig. 2). This reflects the researchers' recognition of the value of integrating these approaches to better understand the complex and multifaceted issue of climate change and its impact on smallholder farmers. Using both qualitative and quantitative approaches allows researchers to gain a more holistic understanding of the issue and to triangulate data from different sources [56]. Additionally, the combination of these methodologies facilitates a more holistic understanding of the research problem, as it allows for the exploration of both the statistical significance of findings and the underlying meanings behind them [56–58].

One reason for this trend towards mixed-methods research is the increasing availability of both primary and secondary data sources. Primary data can be collected through surveys, interviews, and focus groups [59]. On the other hand, secondary data sources can be found in existing databases, government reports, and scholarly publications [59]. By combining these different types of data, researchers can get a more comprehensive understanding of the issue [60,61]. The increasing use of mixed-methods research in the field of climate change and food security may also be due to the growing recognition of the value of both qualitative and quantitative approaches in addressing complex issues. This trend is supported by research conducted by Ref. [51], which highlights the expected substantial reduction in crop yields in South Africa due to climate change, emphasizing the need for comprehensive research approaches to address food security challenges.

Fig. 3 illustrates the trends of studies on the impact of climate change on the livelihoods of smallholder farmers in South Africa

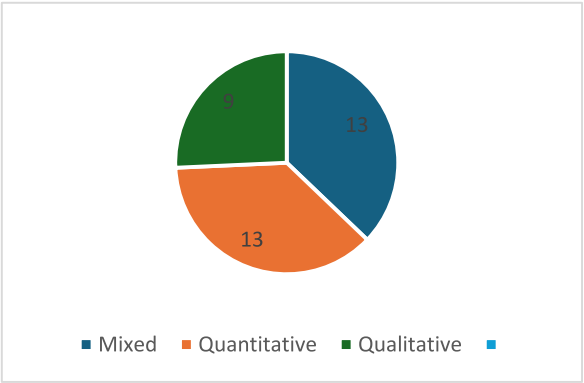

Fig. 2. Methodology and data sources of the included literatures.

between 2015 and 2023. The data reveals a marked increase in research output beginning in 2017, with three articles published that year. This rise is likely due to the growing awareness of the challenges faced by smallholder farmers as a result of climate variability and change, as highlighted in various studies that document their vulnerability to climatic shocks and dependence on rain-fed agriculture [33], [62], [63]. During 2018 and 2019, the number of publications stabilized at two per year, indicating a phase of consolidation in research focusing on adaptation strategies and the socio-economic impacts of climate change on smallholder livelihoods [64,65].

In 2020, the number of publications rose significantly, with six articles released, reflecting renewed urgency in addressing the impacts of climate change on agricultural practices and food security [66,67]. This upward trend continued into 2021, reaching a peak with eight articles published, highlighting the growing academic interest in climate-smart agricultural practices and the adaptive strategies employed by smallholder farmers in response to climatic challenges [68,69]. The steady publication rate of six articles each in 2022 and 2023 indicates a sustained focus on exploring the intersection of climate change and smallholder farming, with ongoing discussions about effective adaptation measures and the socio-economic resilience of these communities [70].

Overall, these publication trends reflect a burgeoning body of literature that underscores the critical need for targeted research and policy interventions to support smallholder farmers in South Africa as they navigate the complexities of climate change [71].

Fig. 4 illustrates the distribution of published articles across various provinces in South Africa. Research on climate change in South Africa highlights a significant geographical distribution of published articles, with Limpopo Province standing out as a major focal point (Fig. 4). Limpopo has the highest number of climate change-related publications, totaling eight, indicating the province's heightened concern with climate issues [72–74]. This is supported by studies showing that Limpopo has been severely impacted by climate change, experiencing both droughts and floods, which have led local communities to actively engage in climate adaptation strategies [75,76].

As illustrated in Fig. 4, the Northern Cape follows with six articles, reflecting significant attention to climate change in this region as well [69]. Research suggests that the Northern Cape is also facing challenges related to climate variability, particularly in agriculture, which has drawn increased interest from researchers [69].

In addition to Limpopo and the Northern Cape, both the Eastern Cape and KwaZulu Natal each have five articles, indicating a moderate level of engagement with climate change topics in these provinces [30,55,77]. The Eastern Cape, in particular, has been noted for its vulnerability to climate-induced natural disasters, prompting research into coping strategies among rural households [78]. The Free State has four articles, suggesting a similar interest level to KwaZulu Natal, though slightly lower [49]. Meanwhile, North-West Province, with three articles, indicates a lesser focus on climate change compared to the other provinces, potentially reflecting varying levels of climate impact awareness and research activity [79] (See Fig. 4). Lastly, Mpumalanga, with only two articles, shows the least reported engagement on climate change topics among the provinces mentioned, which might indicate either fewer research initiatives or a lower perceived impact of climate change in that region.

3.2. *Impact of climate change on smallholder farmers livelihood in South Africa*

The literature review has identified distinct climate conditions prevalent in the studied contexts, primarily comprising drought, mixed climate variables and increased temperature. Among these, drought accounts for 57 % of the documented cases, while mixed climate variables are reported in 40 % of the instances representing combinations of various climatic phenomena (Fig. 5). The remaining 3 % are characterized by an increase in temperature. These mixed variables may include a blend of drought, elevated temperatures, reduced rainfall, occurrences of heat waves, instances of flooding, and periods of prolonged dry spells.

Drought, characterized by prolonged dry spells and reduced rainfall, is a critical concern, especially given that approximately 60 % of the country's water demand is directed towards agriculture, which predominantly relies on rain-fed systems [80]. The susceptibility of South Africa to drought is exacerbated by the increasing frequency of extreme weather events, including heat waves and flooding, which are becoming more prevalent due to climate change [81]. Drought can lead to crop failure and loss of income, while increased temperatures can cause heat stress and affect crop growth. Mixed climate variables can be especially difficult to manage, as farmers may not know which conditions to prepare for. Given the challenges of managing mixed climate variables, It's important for farmers to have access to reliable weather information, as well as early warning systems that can provide timely alerts about upcoming conditions. Additionally, it's important for farmers to diversify their crops and livelihoods, to minimize the risks of crop failure and economic loss. For example, farmers can grow crops that are more resilient to drought or temperature extremes, or they can diversify into

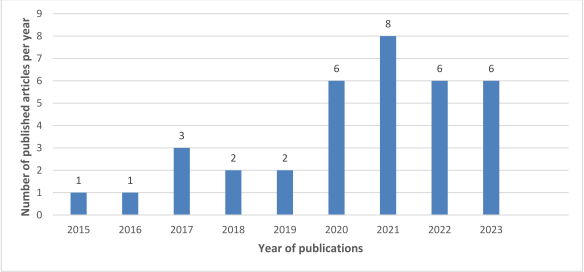

Fig. 3. Number of published articles per year.

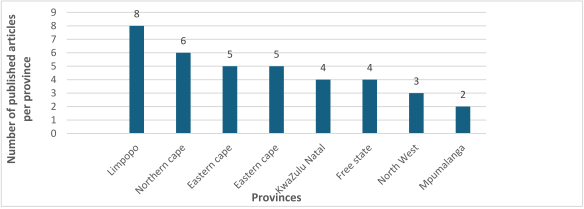

Fig. 4. Number of published articles per province.

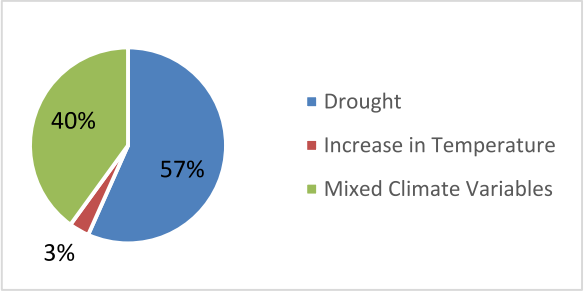

Fig. 5. Climatic conditions identified in the selected literatures.

other activities, such as livestock production or off-farm income.

The spatial distribution of drought in South Africa reveals distinct patterns, with certain regions, particularly in the Eastern and Northwestern provinces, experiencing more severe drought conditions [82]. This spatial variability is closely linked to the broader climatic zones of the country, which include savanna, grassland, and fynbos ecosystems [82]. Furthermore, the impacts of drought are not uniform; they vary significantly across different agricultural practices and regions, leading to substantial economic losses and food insecurity [65]. For instance, the national livestock herd has seen a decline of approximately 15 % due to drought impacts, highlighting the severe implications for rural livelihoods [65].

In addition to drought, elevated temperatures and heat waves contribute to the overall climatic stress faced by agricultural systems in South Africa. The year 2016 was recorded as the hottest year since 1860, with extreme temperature events intensifying the effects of drought [81]. This combination of high temperatures and reduced precipitation creates a challenging environment for crop production, leading to decreased yields and increased agricultural vulnerability [83]. It's important to increase access to climate-smart agricultural practices, such as drought-tolerant crop varieties, rainwater harvesting, and soil conservation techniques. The main reason is that these practices can help smallholder farmers to adapt to changing climate conditions while maintaining or even increasing their productivity. For example, drought-tolerant crop varieties can allow farmers to continue growing crops even during periods of drought [84]. Rainwater harvesting can help farmers to make use of available water resources more efficiently, while soil conservation techniques can improve the fertility and resilience of the soil [85].

There are a few methods that can be applied for livestock farmers to adapt to climate change. One example is the use of heat-tolerant breeds of livestock, which can be more resilient to increasing temperatures [86,87]. The introduction of heat-tolerant livestock breeds is one approach to help smallholder farmers adapt to climate change, there are also other innovative solutions being explored. These traits include improved thermoregulation, feed efficiency, and disease resistance, which are critical for maintaining livestock health in increasingly hot environments [88,89].

Researchers should look at ways to optimize livestock grazing patterns and reduce heat stress through shade and water provision. In addition, livestock farmers should start using weather forecasting and early warning systems to help them make decisions about when to move their animals to different locations or provide them with additional feed or water. These practices can help to reduce the farmers' vulnerability to extreme weather events and make them more resilient in the long term.

The identified climatic conditions have far-reaching consequences, spanning a range of impacts that extend beyond mere loss of livestock and crops. They manifest in various forms, such as diminished animal health and productivity, heightened levels of poverty among farming communities, and the progressive degradation of land resources. These impacts permeate multiple spheres of influence, encompassing not only the agricultural sector but also broader economic and environmental domains. Through systematic categorization, these effects are classified into distinct areas, including impacts on livestock, crops, economy, and the environment, as illustrated in the accompanying flowchart (Fig. 6).

The impact of climate change on livestock health and productivity, has several interconnected effects. For example, heat stress can reduce feed intake and nutrient absorption, leading to reduced weight gain and poor health [90]. Similarly, a lack of access to water can reduce livestock productivity and animal fertility [55,90,91]. During periods of drought, the availability of both feed and water diminishes, leading to compounded stress on livestock and increased economic losses for farmers [55,92]. Moreover, a changing climate can increase the incidence of diseases and further impact livestock health [55], [93]. These effects can have a direct impact on

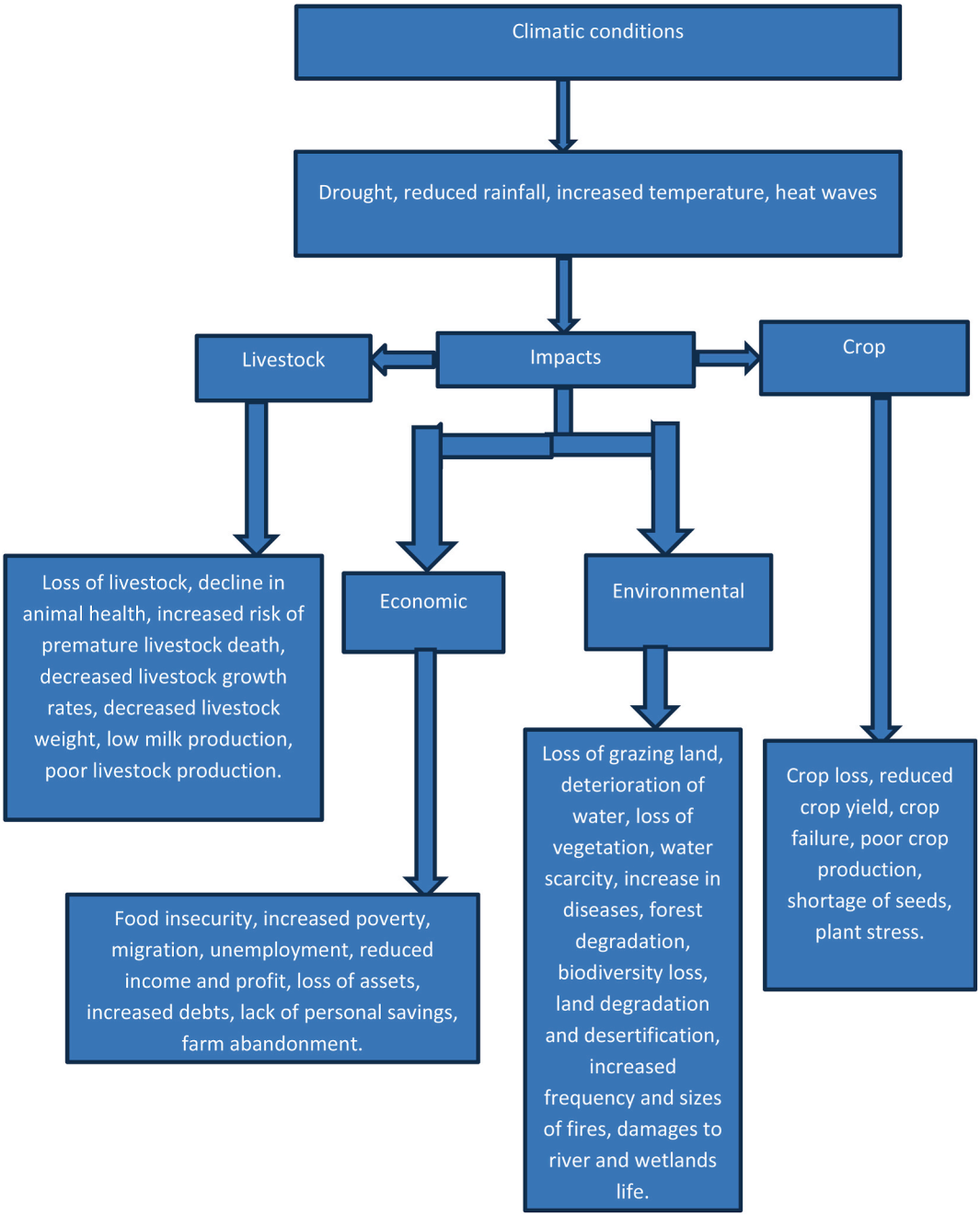

Fig. 6. Flow chart of the impacts of climate change on smallholder farmers in South Africa from the reviewed studies.

the livelihoods of farmers, leading to economic hardship and food insecurity. One innovative solution that can be proposed to address these issues is the use of precision livestock farming (PLF). PLF involves the use of technology, such as sensors and digital monitoring, to track and manage the health and productivity of livestock. This allows for the early detection of health issues, the identification of animals at risk of disease, and the optimization of feeding and water management practices.

The impact of climate change on crops is multifaceted and complex. The observed consequences include the loss of crops due to extreme weather events [94]. In addition, the reduced quality and quantity of crops due to changing weather patterns and temperature fluctuations can have a significant impact on food security [95]. Moreover, a shortage of seeds can occur due to the failure of crops to produce viable seeds as the result of climate change [96]. Furthermore, plant stress due to the changing climate can result in reduced photosynthesis and decreased nutrient uptake, leading to reduced crop yields [97]. There are a number of innovative solutions that can be implemented to mitigate the impact of climate change on crop productivity. The use of drought-tolerant and heat-tolerant crop

varieties can help to maintain productivity even under changing conditions. Additionally, the use of irrigation, particularly in the form of drip irrigation, can help to maintain productivity in the face of reduced rainfall. Furthermore, the adoption of conservation agriculture practices, such as no-till farming and the use of cover crops, can improve soil health and help to mitigate the effects of climate change.

The economic impacts of climate change in South Africa are diverse and have far-reaching consequences for the country's economy and population. The most notable economic impact is food insecurity, which has been exacerbated by climate change through the reduced availability and increased cost of food [98]. As a result, poverty has increased, particularly in rural areas, leading to increased migration to urban areas in search of work [99,100]. This has increased unemployment and resulted in reduced income and profit for many households [99]. In addition, the loss of agricultural assets, such as livestock and land, and increased debts have further contributed to poverty [99]. There are several potential solutions to the economic impacts of climate change in South Africa. One is to

Table 1
Coping strategies adopted by South Africa smallholder farmers to adapt to climate change.

Themes	Coping Strategies	Authors
Water-efficient Farming Practices	Selecting crops that require less water or cultivating drought-resistant varieties	Mpandeli et al. (2015), Ruwanza et al. (2022), Shikwambana et al. (2022)
	Adapting agronomic and farming practices to optimize water usage and soil health	Mpandeli et al. (2015), Popoola et al. (2018), Mdoda et al. (2020), Olabanji et al. (2021), Matlou et al. (2021), Nkosi et al. (2023)
	Choosing mature or early-maturing crop varieties to mitigate risks associated with water scarcity	Mpandeli et al. (2015), Ruwanza et al. (2022), Shikwambana et al. (2022)
	Using drought-resistant seeds and implementing crop rotation to enhance resilience to drought conditions	Oduniyi (2018), Mdoda et al. (2020), Shikwambana et al. (2022)
	Employing techniques such as using crop residue for soil cover and planting cover crops to conserve moisture and improve soil fertility	Nkosi et al. (2023)
	Adjusting planting depths and utilizing irrigation techniques to optimize water distribution and usage	Mdoda et al. (2015), Olabanji et al. (2021), Ruwanza et al. (2022), Nkosi et al. (2023)
Livestock Management	Changing grazing routes	Popoola et al. (2018), Hunter and Cronin (2021)
	Increasing grazing distances	Popoola et al. (2018)
	Changing livestock herd size	Hunter and Cronin (2020)
	Destocking	Maluleke and Mokwena (2017), Popoola et al. (2019a), Popoola et al. (2019b), Ruwanza et al. (2022), (Zhou et al., 2022), Bahta (2020), Bahta, (2022), Bahta and Myeki (2023), Rasch et al. (2016). Ojo et al. (2021).
	Supplementary livestock feeding	Lamega et al. (2021); Letsoalo et al. (2023),
	Wildlife ranching	Otieno et al. (2023)
	Genetic diversity	Molotsi et al. (2017).
	Wetting and forced ventilation	Ogundeji et al. (2021)
	Abandonment of livestock, change of grazing patterns, change of fodder	Talanow et al. (2021)
	Drilling boreholes, tree planting and shade planting.	Pili (2020).
Livelihood Diversification	Eating less food a day and reducing portion sizes to stretch available resources and Changing diet to incorporate more affordable or locally available food options	Ubisi et al. (2017), Hawkins et al. (2022)
	Borrowing money or receiving food parcels from relatives to meet immediate needs	Ubisi et al. (2017), Ruwanza et al. (2022), Hawkins et al. (2022)
	Purchasing cheaper, less nutritious, and more starch-based foods to manage expenses	Hawkins et al. (2022)
	Taking children out of school to work or seeking additional employment opportunities to increase income	Ruwanza et al. (2022), Hawkins et al. (2022)
	Begging and getting cash loans as short-term solutions to financial challenges	
	Creating food reserves and buying supplementary foods	Hawkins et al. (2022)
Environmental Sustainability and Resilience	Harvesting water from rain and other sources	Popoola et al. (2018), Popoola et al. (2019a), Myeni and Moeletsi (2020), Fanadzo et al. (2021), Olabanji et al. (2021)
	Practicing a mixed cropping system	Popoola et al. (2018), Mdoda et al. (2020), Olabanji et al. (2021), Ruwanza et al. (2022)
	Crop diversification	Popoola et al. (2019), Mdoda et al. (2020), Ruwanza et al. (2022), Shikwambana et al. (2022)
	Increasing land under production	Hunter et al. (2020), Mdoda et al. (2020)
	Changing crop type and Irrigation	Mdoda et al. (2020), Myeni and Moeletsi (2020), Olabanji et al. (2021), Ruwanza et al. (2022), Nkosi et al. (2023)
	Studying weather conditions over time to predict weather accurately.	Popoola et al. (2018)
	Altering planting dates to suit weather conditions	Oduniyi (2018), Mdoda et al. (2020), Olabanji et al. (2021), Ruwanza et al. (2022), Shikwambana et al. (2022)
	Mulching	Thinda et al. (2020)
	Planting native plant varieties	Kom et al. (2023)

invest in agricultural insurance, which would help to mitigate the economic losses caused by crop failures or livestock losses due to climate change. Another is to invest in climate-smart agricultural practices, such as rainwater harvesting and the use of drought-resistant crops, which can help to improve food production and increase income for farmers. Additionally, policies and programs aimed at reducing poverty and promoting economic growth in rural areas could help to alleviate the economic impacts of climate change.

The environmental impacts of climate change have significant consequences for smallholder farmers in South Africa. Loss of grazing land and deterioration of water reduce the availability of natural resources, which in turn reduces food production and income [101]. While heavy rainfall and flooding are projected to increase in certain areas of South Africa, dry conditions, such as in the western interior and the northern parts of the west coast, can lead to drought with negative impacts on food security and nutrition [102]. The loss of vegetation and water scarcity make it more difficult for farmers to grow crops and raise livestock. Increased diseases and forest degradation pose health risks to both humans and animals, and land degradation and desertification lead to a loss of productivity and arable land. Furthermore, the increased frequency and severity of wildfires pose a threat to crops, infrastructure, and people.

The increased frequency and severity of wildfires have several negative consequences. The fires can destroy crops and other vegetation, reducing food production and income for farmers [95]. In addition, they can damage or destroy houses, roads, and other infrastructure, costing money to repair or replace. The health risks associated with wildfires can be significant, including smoke inhalation, burns, and injuries. In extreme cases, wildfires can even cause fatalities. All of these impacts can have a devastating effect on smallholder farmers, making it even more difficult for them to make a living. There are several measures that can be taken to reduce the consequences of wildfires. One is to create fire breaks, which are strips of land that have been cleared of vegetation to prevent the spread of fires. Another is to conduct controlled burns, which are intentionally set fires that are used to clear away dead vegetation and reduce the risk of larger, uncontrolled fires. Additionally, education and outreach programs can help to raise awareness about fire safety and prevention. Finally, investing in firefighting equipment and training can help to minimize the damage caused by wildfires.

3.3. Adaptation measures employed by smallholder farmers in response to climate change

Table 1 illustrates the coping strategies adopted by South Africa smallholder farmers to climate change. The coping strategies identified in the literature reflect the resourcefulness and adaptability of smallholder farmers in response to the challenges posed by climate change. These strategies encompass a multifaceted approach, addressing various aspects of agricultural, economic, and environmental resilience. From implementing water-efficient farming practices to adjusting livestock management strategies, farmers are proactively seeking solutions to mitigate the impacts of changing climatic conditions. Additionally, economic adaptations, such as altering dietary habits and seeking alternative sources of income, demonstrate the innovative measures undertaken to sustain livelihoods in the face of adversity. Furthermore, environmental adaptations, including water harvesting and land management practices, underscore the importance of sustainable resource utilisation in building resilience to climate change. Overall, these coping strategies highlight the dynamic and comprehensive nature of smallholder farming communities' response to climate-related challenges.

Based on the results, it is crucial to uplift these coping strategies through various approaches. Firstly, the Department of Agriculture, Forestry and Fishery should support smallholder farmers through the provision of resources, such as improved seeds, extension services, and technical assistance. Secondly, there is a need to support smallholder farmers with climate-resilient agricultural technologies and services, such as micro-loans and weather insurance.

4. Conclusion and recommendation

In discussing strategies to bolster the resilience of smallholder farmers to climate change impacts in South Africa, several key recommendations emerge.

One critical suggestion is the development of socio-economic and economic risk tolerance indices tailored to the needs of subsistence and commercial maize farmers [103]. These indices can serve as valuable tools for assessing farmers' vulnerability and economic risk tolerance to climate change impacts, providing policymakers, agriculturalists, and businesses with insights for designing targeted interventions and support programs.

Furthermore, enhancing support structures for smallholder farmers is crucial. This includes promoting the formation of representative farmer structures and strengthening institutional mechanisms to facilitate greater stakeholder involvement in provincial and local agriculture [43]. By leveraging government support and prioritising innovative strategies, smallholder farmers can better navigate the impacts of climate variability.

Improving extension services emerges as another critical recommendation. Strengthening the relationship between smallholder farmers and extension officers through training and resource provision for climate change adaptation is vital [48]. Government interventions should focus on enhancing extension services, ensuring fair allocation of resources, and restoring alternative water sources to support sustainable crop production and livelihoods.

Promoting Climate-Smart Agriculture is also highlighted as a key strategy. Encouraging the adoption of adaptive farming practices such as crop diversification and integrated farm activities can bolster farm income and resilience [104]. Providing education and training through extension agents to enhance farmers' climate change awareness, as well as implementing disaster insurance and subsidies for farmers, are important components of this recommendation.

Investing in infrastructure is crucial for building resilience to climate change impacts. Allocating resources for adaptation measures such as intensified irrigation, water harvesting, and improved storage capacity for crops and water is essential [87], [105]. Prioritising

long-term infrastructure projects, such as dam and borehole construction, can mitigate the impacts of climatic shocks and enhance resilience in the agricultural sector.

By implementing these recommendations, South Africa can strengthen its climate change response policies and systems, empower smallholder farmers, and build resilience in the face of climate variability and change.

Future studies on the impact of climate change on the livelihoods of smallholder farmers should consider meta-analysis. A meta-analysis could provide a more holistic understanding of the factors that influence the livelihoods of smallholder farmers in South Africa, including socioeconomic factors, governance systems, and land tenure arrangements. This would help to identify areas of improvement for policies and programs aimed at supporting smallholder farmers.

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Ethical approval and consent to participate are not applicable to this study.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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