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Original Article

Agricultural Livelihoods at Risk: Climate Change Impacts and Resilience Strategies in Eastern Zimbabwe

Lawrence Mango[1,2], Alfred Mapolisa[3], Cosmas Mudzonga[3], Luke Makarichi[1], Kingsley Okpara[4], Techato Kua-anan[1], Melody Muzvidzani[5] & Marshall Mangirichi Magenge[6]*

[1] Prince of Songkla University, Hat Yai, Songkhla, Thailand.
[2] Bindura University of Science Education, P. Bag 1020 Bindura, Zimbabwe.
[3] Zimbabwe Open University, Zimbabwe.
[4] Rivers State University, Nkpolu-Orowurokwu, P. M. B. 5080, Port Harcourt, Nigeria.
[5] Marondera University of Agricultural Sciences and Technology, P. O. Box 35, Marondera, Zimbabwe.
[6] Gwanda State University, P. O. Box 30, Filabusi, Gwanda, Zimbabwe.
[*] Author for Correspondence Email: lawrencemango@gmail.com

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Agricultural Livelihoods, Climate Change, Resilience Strategies, Sustainable Development, Vulnerability.

ABSTRACT

Climate change is expected to exacerbate existing challenges facing smallholder farmers and create novel vulnerabilities, particularly in sub-Saharan Africa. The vulnerability of smallholder farmers is compounded by their reliance on rain-fed agriculture and widespread poverty. The study employed a multi-methodological approach, incorporating questionnaires and observational methods, as well as an extensive literature review, to investigate agricultural livelihoods, climate change impacts on agriculture, and climate resilience adaptation strategies. The study's demographic characteristics revealed a male-dominated sample, with ~60% of respondents having attended school from the secondary to tertiary level and 83% having access to extension services. The study findings indicate that climate change has significantly impacted agricultural livelihoods in eastern Zimbabwe, manifesting as drying of rivers and water scarcity, altered rainfall and temperature patterns, and reduced crop yields and deforestation, resulting in the loss of livestock, and human migration. The results suggest that climate change has diminished agricultural livelihoods, with increased impacts attributed to rising temperatures and reduced rainfall patterns. The study recommends the adoption of climate-resilient strategies, including water harvesting and storage, efficient irrigation schemes, cultivation of drought-tolerant crops and early warning systems. The diversification of on-farm income sources, proper livestock management, education and training, and climate-smart agriculture help mitigate the impacts of climate change on agriculture.

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INTRODUCTION

Climate change poses an imminent and pressing global challenge with far-reaching consequences for sustainable development worldwide. The warming climate system is projected to adversely impact the availability of essential resources, including freshwater, food security, and energy. Climate change influences land cover and associated processes, which in turn affect climate dynamics (Hughes, 2024; Mariappan *et al*., 2023). The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a human-induced alteration of the global atmospheric composition, exacerbating natural climate variability (Kabir n.d.). Climate-related extremes have severe consequences, including ecosystem degradation, food production and water supply disruptions, infrastructure damage, and settlement destruction. Although climate change is a global issue, its impacts are disproportionately felt in developing nations, where millions are pushed into poverty, hindering sustainable development and poverty eradication efforts. Sub-Saharan Africa, home to the least developed countries, is disproportionately vulnerable to climate change impacts despite contributing minimally to planetary warming (Yalew, 2020). Steiner (2019) and Dal (2023) noted that climate change negatively affects African countries' ability to achieve the sustainable development goals (SDGs) and Agenda 2063, impacting gross domestic products (GDPs), national budgets, communities, and rural livelihoods.

Mikulewicz, & Taylor (2020) and St'ahel (2019) posit that the current climate crisis is a sustainable development problem rather than solely a climate change issue. This affects various institutions and productive sectors, including agriculture, forestry, energy, and coastal zones. Livelihoods are shaped by the changing natural environment and are influenced by factors such as soil quality, air and water quality, climatic conditions, and geography. Climate change awareness, impacts, and adaptation mechanisms are limited, particularly in sub-Saharan Africa.

The sustainable development goal of achieving food security and sustainable agriculture is particularly vulnerable. The SDG 13, climate action, aims to address the pressing issue of climate change through a multifaceted approach, encompassing urgent action to mitigate its impacts, integrating climate change measures into national policies and planning, and enhancing education, awareness, and capacity for climate change mitigation, adaptation, and impact reduction (Hussain *et al*., 2024; Yalew, 2020). Furthermore, several other SDGs indirectly address the pervasive impacts of climate change on agricultural development. Agriculture is a significant user of freshwater resources, which can strain local water supplies and impact SDG 6 (Clean water and sanitation). Changes in temperature and precipitation patterns affect agricultural productivity, water availability, and quality, exacerbating the challenges of achieving SDG 6 (Yalew, 2020). Agricultural livelihoods depend on reliable access to water, making SDG 6 crucial for rural communities. Modern energy sources can power irrigation, mechanization, and processing, enhancing agricultural productivity, while agricultural waste can be converted into

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bioenergy, supporting SDG 7 (Affordable and clean energy). Transitioning to clean and renewable energy can reduce greenhouse gas emissions from agriculture. Climate-resilient agricultural practices can enhance employment opportunities and incomes for millions, contributing to SDG 8 (Decent work and economic growth) (Cheng *et al*., 2022). Strengthening agricultural value chains can create jobs and stimulate local economies. Innovations in agricultural infrastructure, such as irrigation systems, storage facilities, and livestock feeding schemes, can enhance resilience to climate change. Industry and innovation can promote sustainable agriculture practices and technologies, reducing environmental impacts, and supporting SDG 9 (Industry, innovation, and infrastructure). Sustainable agricultural practices, including climate-resilient agriculture, can reduce resource waste and emissions through sustainable consumption and production patterns, thereby mitigating climate change and supporting SDG 12 (Responsible consumption and production).

In Zimbabwe, an agro-based country with a large rural population, agriculture is crucial for food security and poverty reduction. Consequently, climate change poses significant risks to agricultural livelihoods, with projected increases in temperature and precipitation variability aggravating the decline in productivity and compromising economic growth, stability, employment, food security, and poverty alleviation efforts (Mariappan *et al*., 2023; Thornton *et al*., 2019). The expansion of marginal lands under changing climatic conditions often renders traditional agricultural systems unsustainable, necessitating adaptive strategies. Poor farmers, without reserves to face climate-related shocks, may adopt adverse coping mechanisms, undermining overall well-being (Steiner, 2019). The long-term change in the earth's climatic system affects the production of maize, a staple crop sensitive to precipitation and temperature changes, and livestock, an essential source of food, income, and capital. In Zimbabwe, climate change has significantly impacted sustainable livelihoods, exacerbating these existing vulnerabilities.

One of the key vulnerabilities faced by Zimbabwean farmers is the unpredictability of rainfall with drought being more common, leading to crop failure and decreased agricultural productivity. This has a direct effect on farmers' income and food security, as many rely on their crops as their main source of income and sustenance. In addition to its direct impact on agriculture, climate change affects other aspects of sustainable livelihoods. For example, changes in weather patterns can lead to a decrease in water availability, which in turn affects livestock production and access to clean drinking water for communities (Cheng *et al*., 2022). This can further worsen the food insecurity issue and poverty in rural areas. Rising temperatures, changing rainfall patterns, and increased frequency of extreme weather events have affected food security and income, whereas water scarcity and disease prevalence impact human health and livestock productivity (Hashmi *et al*., 2021; Kumar *et al*., 2018). According to Chilunjika, & Gumede (2021), changes in climate are anticipated to worsen water scarcity in the arid regions of sub-Saharan Africa, where smallholder farmers are heavily reliant on limited water resources. This may alter the frequency and magnitude of droughts, reduce crop yields, and increase evapotranspiration rates, ultimately threatening regional food production and human livelihoods. The Paris Agreement stands out by setting a global goal to limit warming to well below 2°C and pursuing efforts to limit it to 1.5°C above pre-industrial levels. By addressing the root causes of climate change, the agreement aims to reduce emissions, promote sustainable development, and enhance resilience, ultimately improving livelihoods and securing a sustainable future for all. This seeks to mitigate the wide-range impacts of climate change, promote global cooperation to support adaptation and resilience efforts and ensure a sustainable agriculture system for future generations.

Despite these challenges, some strategies can help farmers build resilience and adapt to the impacts

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of climate change. The implementation of sustainable agricultural practices, such as conservation agriculture and agroforestry, has helped farmers adapt to changing climatic conditions and improve soil fertility and water retention. Diversifying crops and income sources have helped farmers mitigate the risks associated with climate change in case one crop fails (van Zonneveld *et al*., 2020). Moreover, investing in climate-resilient infrastructure, such as water harvesting systems and sustainable energy sources, helps communities better cope with the impacts of climate change (Salimi, & Asl-Ghamdi 2020). Building capacity through education and training on climate-smart practices and early warning systems are useful adaptive mechanisms for communities to prepare for extreme weather events and reduce their vulnerability. However, assessing vulnerabilities and exploring resilience strategies are crucial in building adaptive capacity and ensuring the sustainable livelihoods of communities in the face of climate change. Consequently, the objectives of this study were to (1) identify the impacts of climate change on agricultural livelihoods and (2) possible climate resilience strategies among smallholder farmers in Nyanga District.

Research Objectives

The research aimed to achieve the following objectives:

- To identify the impacts of climate change on agricultural livelihoods
- To determine agricultural livelihood options for farmers in Nyanga District
- To examine climate resilience strategies among smallholder farmers in Nyanga District

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Ward 8, which includes the Nyautare area of Nyanga District. The district lies in the northern part of Manicaland Province and borders Mozambique (East), Makoni (West), Mutasa (South) and Mudzi and Mutoko to the North (Fig. 1). The ward has a total of 850 households and a population of 3319. The study was carried out in three villages, namely, Katuta, Sadomba and Chibaya. The study area lies in natural farming region III, which is characterized by the occurrence of fairly severe midseason dry spells and is dominated by semi-intensive smallholder farmers. *Zea mays*, commonly referred to as maize, is the predominant agricultural crop cultivated in the district, serving as a staple food source and primary livelihood component for local communities. Additionally, agricultural practices in the region include the cultivation of drought-resistant crops and the implementation of semi-intensive livestock farming systems. The livestock component is characterized by a diverse range of species, primarily *Bos taurus* (cattle) and small ruminants, specifically *Ovis aries* (sheep) and *Capra aegagrus hircus* (goats).

The floristic composition in Nyanga is spatially heterogeneous, with region 3 being characterized by a predominance of *Terminalia sericea* (Silver Terminalia), *Combretum apiculatum* (Red bushwillow), and *Peltophorum africanum* (African yellowwood). Additionally, thorn shrubs and *Adansonia digitata* (baobab) are also prevalent in the area. However, the area is faced with significant environmental challenges, especially land degradation, which results in the annual loss of valuable topsoil through erosion into rivers and streams. The primary drivers of this degradation include illicit mining activities, sand poaching, brick moulding, wildfires, suboptimal agricultural practices, and deforestation. Furthermore, the district is vulnerable to the impacts of climate change, as evidenced by recurring tropical cyclones and increasing average temperatures. In terms of edaphic characteristics, the district encompasses all three primary soil types, namely, *Orthorferrallitic*, *Ferasialitic*, and *Para-ferrallitic* soils.

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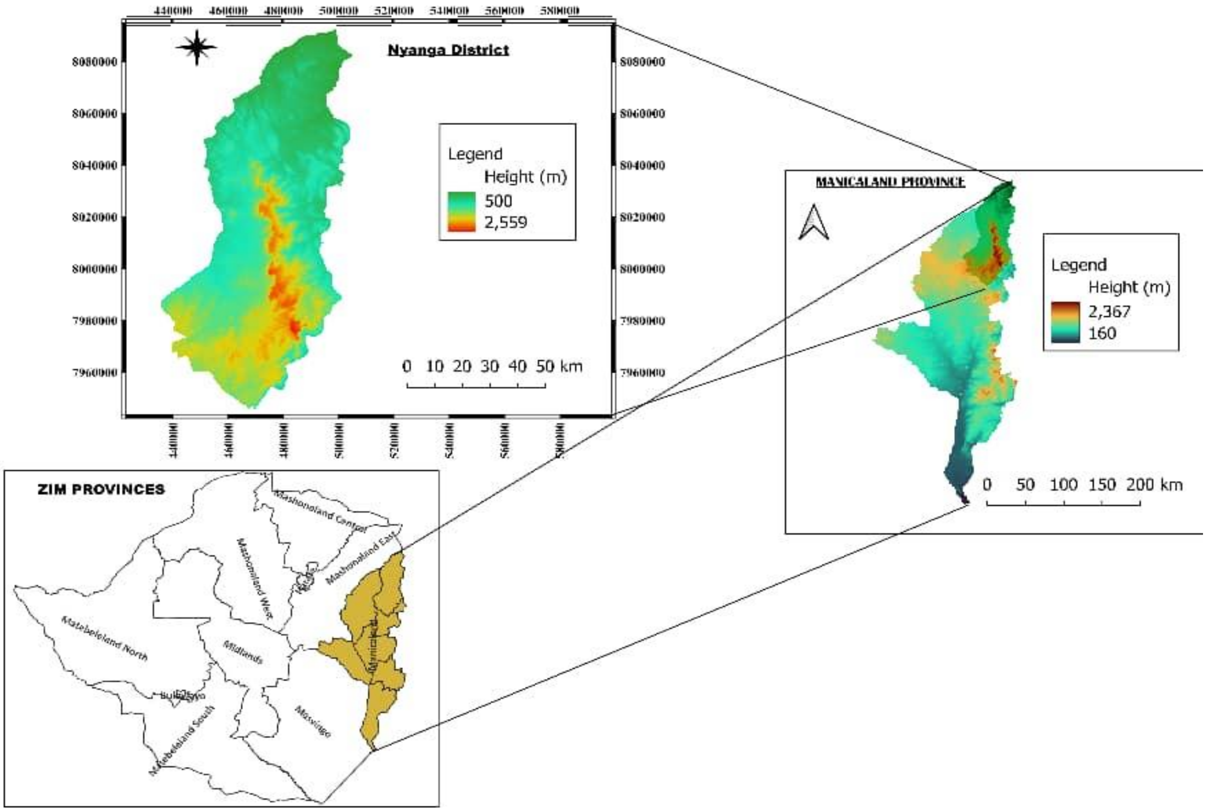
Figure 1: Study Area, Nyanga District in Manicaland Province



Research Design

This study employed a descriptive-exploratory research design, aiming to provide a comprehensive and systematic description of climate change impacts. The exploratory component sought to investigate the research questions without purporting definitive solutions to the existing problem. This design is particularly suited to contexts characterized by high levels of uncertainty and limited understanding of the issue at hand. The descriptive research design was complemented by qualitative research methods, with the incorporation of quantitative elements through the administration of a questionnaire. A multi-methodological framework was adopted for primary data collection, incorporating both quantitative (questionnaire-based) and qualitative (observational) approaches. The instruments employed were rigorously selected to align with the research questions and objectives, thereby ensuring a robust and nuanced understanding of the research phenomenon. Qualitative research facilitated the collection and analysis of non-numerical data, in-depth understanding of concepts, opinions, and experiences related to climate change-related challenges and resilience strategies for sustainable rural livelihoods in Nyanga District.

Data Collection Procedures

Before commencing the study, the researchers obtained informed consent from local leaders, who addressed potential ethical concerns. Formal permission to conduct the research was granted by the local authorities. A comprehensive research program was designed, outlining the methodology and procedures for data collection. The study was conducted over two weeks, leveraging the geographic proximity of respondents within the same area. The questionnaires were administered in person, with researchers visiting respondents at their homesteads in each village. To minimize bias in data collection, pre-mapping of the study area and pretesting of the questionnaire (pilot-tested with 10 household heads from a non-sampled village) were conducted.

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Data Collection Tools

Questionnaires

A standardized questionnaire was employed as a research instrument to collect primary data from household heads. This questionnaire comprised a structured set of open-ended and closed-ended items designed to elicit specific information regarding climate change impacts and adaptation strategies from respondents. For clarity and precision, the questions were concise, unambiguous, and straightforward. The questionnaire was organized into three thematic sections: section A captured general demographic information, section B focused on research-specific thematic areas, and section C solicited respondents' recommendations. As a widely used data collection tool in survey research, questionnaires play a crucial role in gathering accurate and relevant information from household heads. Its standardized format facilitated efficient administration across all respondents, ensuring consistency and reliability in the data collected.

Observations

Visual data collection tools, including digital cameras and photographic equipment, were utilized to capture observational evidence of climate change in the form of photographs. This methodological approach enabled the collection of data without reliance on self-report measures, instead leveraging the researcher's sensory perceptions, specifically sight, to document phenomena. Through unstructured observational techniques, researchers have recorded visual evidence of climate change impacts, including water resource dimensions, grazing land conditions, livestock health, and anthropogenic activities such as deforestation. Photographic records served as empirical evidence to support observational findings. This approach allowed for the systematic documentation of visual data, providing a robust and objective record of climatic conditions.

Secondary Data

To contextualize the analysis and reporting, a range of secondary data sources were utilized, offering a cost-effective and efficient means of gathering information. The researchers used articles from peer-reviewed journals, online databases, and official records to supplement primary data collection. Additionally, rainfall data for the past five years was obtained from the Nyanga Meteorological Office, which is located at the Nyanga Experimental Station. This dataset was employed to investigate trends in temperature and precipitation patterns, specifically to determine whether the region is experiencing increased aridity or temperature fluctuations. By integrating these secondary data sources, this study aimed to elucidate the impacts of climate change on sustainable rural livelihoods in the Nyanga district, providing a more comprehensive understanding of the phenomenon.

Sampling Procedures and Sample Population

A probability sampling design was employed to select participants for the questionnaire survey. Specifically, a simple random sampling (SRS) technique was utilized to ensure a representative and unbiased sample selection. This method involved randomly selecting participants from a comprehensive list of eligible household heads within the designated villages, thereby minimizing selection bias and ensuring the generalizability of findings to the broader population. A 30% sample population was employed for this study (Table 1).

Table 1: Sampling Frame for the Respondents

Village Name	Total Households	Sample population
Katuta	96	29
Chibaya	91	27
Sadomba	71	21
	258	**77**

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Data Presentation and Analysis Procedures

The analysis and presentation of the data entailed a descriptive examination of the findings, accompanied by an exploratory investigation of the implications of climate change. The data were organized and presented under logical themes, and the statistical package for social sciences (SPSS) software package was used to analyze the impacts of climate change and resilience strategies. The analyzed data were subsequently presented clearly and concisely, utilizing tables, images, and bar graphs to illustrate key findings. Particular attention was given to ensuring that the observations were explicitly linked to the research arguments, thereby maintaining a coherent and logical narrative.

RESULTS AND DISCUSSIONS

Demographic Data

The demographic analysis revealed a significant gender disparity, with males accounting for 61.05% of the respondents and females accounting for 38.95% (Table 2). The educational background of the respondents showed a diverse distribution, with 42% having completed secondary education, 31.17% with primary education, 11.69% holding a diploma, 9.08% with no formal education, 5.2% possessing a degree, and 1.3% with a postgraduate degree (Table 2). With respect to awareness of climate change and climate-resilient agricultural strategies, 58.44% of males and 41.56% of females demonstrated awareness. Notably, respondents with secondary education presented the highest level of awareness (31.86%), followed by those with primary education and no formal education. Conversely, individuals with postgraduate degrees presented the lowest level of awareness, likely because of their underrepresentation in the sample. A significant proportion (83.12%) of the respondents reported accessing extension services from various sources, including agricultural extension officers; non-governmental organizations (NGOs), such as Community Training Organization Development (CTOD) and Simukai; and seed breeders. Additionally, agricultural field days conducted by extension officers provided education on climate change, further contributing to awareness.

Harvey *et al*. (2018) reported a significant gender disparity in their Central American study, with males comprising 78.4% of the participants, characterized by low educational attainment. The finding of our study is corroborated by Merrey *et al*. (2018) in a Nepalese study, suggesting a pervasive patriarchal influence, where males traditionally hold land ownership rights and occupy positions of authority as household heads. The educational profile of the participants in the study aligns with that of Mutekwa *et al*. (2009), who reported 53% primary education, 29% secondary education, and 7% no formal education. However, this contradicts findings indicating higher educational attainment among farmers, with 45% secondary school education, 21.30% tertiary education, and 18.96% primary education, alongside 13% without formal education. Notably, farmers receiving information from extension agents demonstrated an increased likelihood of adapting to climate change impacts, which is supported by the literature highlighting the positive effects of extension services on adaptation mechanisms (Asfaw *et al*., 2019; Khanal *et al*., 2018). This finding has also been confirmed by the Zimbabwe Vulnerability Assessment Committee (ZIMVAC), in its 2021 Rural Livelihoods Assessment Report (RLAR) that approximately 97% of the rural households in Nyanga have, to some extent, received extension visits and training from extension officers (Risk, 2021). Conversely, 17% of the farmers lacked access to extension services, underscoring the need for these services to facilitate effective climate adaptation in the studied district. In contrast, Nyang'au *et al*. (2021) reported lower male dominance (40.8%) and higher female participation (59.2%) in a Kenyan study, highlighting regional variations in gender dynamics. High educational attainment is hypothesized to significantly influence the adoption of climate-resilient strategies, mitigating climate variability and change impacts (Amir *et al*., 2020; Kumar *et al*., 2018).

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Table 2: Demographic Information of the Respondents

Characteristic		Proportion of population			Resilience strategies		
		Aware of climate change (%)			(%)		
		Male	Female	CP	Male	Female	CP
Respondents by gender		61.05	38.95	**100**	58.44	41.56	**100**
Level of education	Never been to school	3.90	5.18	**9.08**	11.69	13.59	**25.28**
	Primary	19.48	11.69	**31.17**	15.58	10.39	**25.97**
	Secondary	24.68	16.88	**41.56**	19.48	12.38	**31.86**
	Diploma	7.79	3.90	**11.69**	6.49	2.60	**9.09**
	Degree	3.90	1.30	**5.20**	3.90	2.60	**6.50**
	Postgraduate degree	1.30	0.0	**1.30**	1.3	0.0	**1.30**
Extension advice	Accessed extension	50.65	32.47	**83.12**	46.75	27.27	74.02
	No access to extension	10.39	6.49	**16.88**	15.58	10.39	25.97

CP: cumulative percentage

The State of Rivers in the Study Area

The timing of the study coincided with the post-harvest season, which made crop fields unobservable. However, observations were made regarding the hydrological features of Ward 8, Nyanga District. Notably, other perennial streams ceased flowing, as exemplified by the Nyautare River (Fig. 2a), which remained dry despite receiving adequate rainfall during the 2020/21 agricultural season. At the time of the study, only the Nyabombwe River (Fig. 2b) maintained a flow, although it was greatly threatened by upstream siltation from stream bank cultivation. This river serves as a water source for the piped water supply in some sections of Ward 8 under the administration of the Zimbabwe National Water Authority (ZINWA) and supports the Nyabombwe irrigation scheme, which encompasses 200 hectares. However, not all ward residents benefited from this irrigation scheme, leading to households in the Sadomba A and B villages resorting to upstream stream bank cultivation.

A recent study by Pokhrel *et al*. (2021) revealed a significant decline in terrestrial water storage (TWS) across various regions, particularly in the southern hemisphere, potentially leading to increased drought frequency and severity. This finding is corroborated by numerous studies documenting decreasing hydrological stream flow in rivers, including Lake Chad (Mahmood *et al*., 2019), West and Central Africa (Sidibe *et al*., 2020), the Mara River basin (Ayuyo, 2021), the Pra river basin (Acheampong, 2021), and the Limpopo River basin (Makhanya, 2021). The projected decrease in precipitation in sub-Saharan Africa can be attributed to climate change, among other factors, leading to reduced annual rainfall, compromised river flow and groundwater resources, and exacerbated water scarcity and vulnerability (Nairizi, 2017). Nyanga district is experiencing severe water scarcity due to drought-induced river depletion and surface water decline, resulting in limited access to potable water for human and livestock consumption. Respondents reported a significant decline in groundwater levels, necessitating deeper well digging to access water, further exacerbating hydrological stress in the region. According to Siddha, & Sahu (2022), the drying of rivers in tropical regions can be attributed to climate change and siltation, worsening the vulnerability of impoverished rural farmers struggling to maintain their livelihoods from horticultural projects. The detrimental impacts on agricultural productivity have resulted in significantly diminished farming livelihoods, leading to widespread poverty and, in some cases, forced migration to urban centres and transnational relocation (Hoffmann *et al*., 2022). Increased rural poverty and displacement underscores the need for targeted interventions and adaptive strategies to support climate-resilient agriculture and sustainable livelihoods in vulnerable communities.

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Figure 2a: The State of the Nyautare River 2b Nyabombwe River

Livestock and Grazing Land

Researchers' observations revealed a significant decline in grazing land due to the increased demand for agricultural land, leading to a scarcity of suitable grazing areas. The predominant veld type in the region is more conducive to browsing than grazing, necessitating cattle to exploit alternative foraging sources. Notably, cattle were observed grazing in harvested maize fields (Fig. 3a), as well as in limited wetland, and mountainous areas on severely grazed dwarfed forage. In response to the scarcity of animal feed, cattle owners have adopted the practice of stockpiling maize stalks at their kraals for livestock sustenance during the driest periods of the season (Fig. 3b). The present study revealed that climate change and variability significantly impact livestock and grazing land in dry tropical regions such as Nyanga, Zimbabwe.

Rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events collectively impact pasture quality and quantity. This may lead to reduced forage availability and quality due to temperature and rainfall-induced changes in grassland productivity (Lee *et al.*, 2017). Additionally, changes in precipitation and increased evaporation resulting from warmer temperatures affect water availability for livestock. Climate stress reduces livestock growth rates, milk production, and fertility and alters the distribution and prevalence of livestock diseases and pests (Das, 2018; Mondal, & Reddy 2018).

Furthermore, increased temperatures and altered precipitation patterns can lead to soil erosion, reduced soil fertility, and increased weed invasion, causing grazing land degradation. Land fragmentation due to agriculture, coupled with climate change, has resulted in reduced land for livestock forage, forcing farmers to stockpile maize stover for livestock feed during the driest months of the year (Cholo *et al*., 2019; Escarcha *et al*., 2018). Resilience strategies for livestock management in arid tropical regions include diversifying livestock breeds and species to adapt to changing conditions. Implementing conservation agriculture practices helps to reduce soil erosion, promote agroforestry, improve soil fertility, increase biodiversity, and improve disease surveillance and management practices. This can also support extension services to farmers, encouraging sustainable rotational grazing practices to maintain pasture health and developing early warning systems for climate-related hazards to enable proactive decision-making (Das, 2018; Cholo *et al*., 2019).

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Figure 3a: Cattle Grazing in a Harvested Maize Field 3b Maize Stalks Staked for Future Cattle Feed

Deforestation in Smallholder Communities

In this study, observational evidence indicated widespread deforestation in the area; driven by various purposes, including fuelwood collection, land fragmentation, hut and kraal construction, and the use of trees as fencing material for fields and gardens (Fig. 4). Deforestation in sub-Saharan Africa has significant impacts on climate change, including the loss of carbon sequestration, as forests absorb CO_2 and deforestation releases stored carbon, contributing to increased atmospheric CO_2 levels. Additionally, deforestation disrupts water cycles, as forests play a crucial role in regulating them, leading to changes in precipitation patterns and reduced water availability. The study findings are congruent with those of Azare *et al*. (2020) in the Sudano–Sahelian region of Nigeria, Girard *et al*. (2021) in sub-Saharan Africa, and Maeda *et al*. (2021) in Amazonian deforestation, highlighting a consistent pattern of deforestation-induced environmental degradation. Deforestation precipitates soil degradation by disrupting the soil-holding capacity of tree roots, leading to erosion, decreased fertility, and increased greenhouse gas emissions (Kumar *et al*., 2022). Furthermore, deforestation triggers the release of stored carbon and creates conditions conducive to increased emissions from activities such as agriculture and urbanization (Azare *et al*., 2020). Deforestation also results in biodiversity loss, as forests harbour diverse species, and their clearance can lead to extinction and reduced ecosystem resilience. This exposes communities to heightened vulnerability to climate-related disasters, including floods and droughts. Additionally, deforestation alters local climates by modifying temperature and precipitation patterns. The economic costs of deforestation are substantial and include the loss of sustainable forest-and-non timber products and opportunities for ecotourism.

Figure 4: A Field Fence of Thorny Tree Branches

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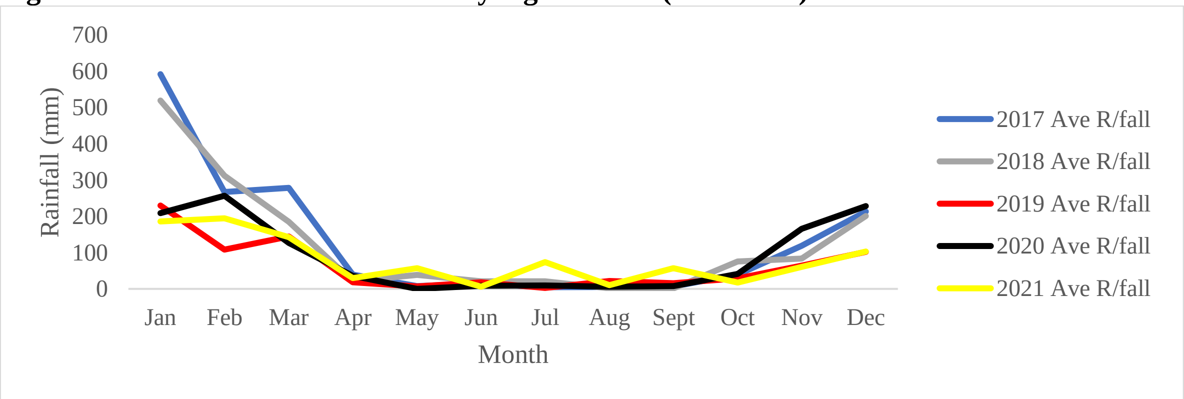
Mean Rainfall Pattern for Nyanga District (2017-2021)

An analysis of climatological data from the Meteorological Weather Station at Nyanga Experimental Station (Fig. 5) from 2017-2021 revealed notable concurrences from long-term averages. Specifically, annual rainfall exhibited a decreasing trend, whereas the number of rainy days per month showed a decreasing trend. Notably, the annual rainfall totals for 2017, 2018, 2019, 2020 and 2021 were 1586.72 mm, 1480.20 mm, 759.80 mm, 1094.60 mm and 938.20 mm, respectively. On average, the number of days with rainfall declined from 11.66 to 8.86 from 2017 to 2021. Inter-annual variability in the rainfall distribution was also observed, with distinct dry periods identified each year. The dry spell conditions were rampant between January and February, with a more pronounced dry spell in 2019 during the period of January to March. These dry spell conditions were common among the years under study, resulting in limited annual rainfall for all the years.

The findings of the present study align with observations reported by other scholars, who noted a perceived decline in rainfall over a comparable period. These results are consistent with those of Esayas *et al*. (2019), in southern Ethiopia, Biasutti (2019) in the African Sahel, and Ibrahim *et al*. (2014), in Burkina Faso. A similar study by Harvey *et al*. (2018) revealed that 95% of smallholder farmers observed impacts of climate change on crop yields, pest and disease incidence, and income generation due to rising temperatures, unpredictable rainfall, and extreme weather events. Harvey *et al*. (2018) reported that temperature changes (96.1%), lower annual rainfall (68.6%), and greater uncertainty (22.8%) are consistent with the present study. Similarly, Gadissa *et al*. (2019) projected average precipitation decreases of 7.97% and 2.55% under the Regional Climate Models (RCMs) RCP4.5 and RCP8.5, respectively, in the Central Rift Valley Basin, Ethiopia. Farmers who rely on seasonal rainfall and those heavily dependent on rain-fed agriculture for food security are particularly vulnerable to climate change.

Figure 5: Mean Rainfall Pattern for Nyanga District (2017-2021)



Mean Temperature Pattern for Nyanga District (2017-2021)

A statistically significant warming trend was observed over the 5-year study period (2017-2021), which coincided with the rainfall pattern (Fig. 6). The temperature metrics, including the minimum, average and maximum values, gradually yet steadily increased. The annual mean temperatures for the corresponding years were 21.94°C (2017), 21.84°C (2018), 22.73°C (2019), 23.0°C (2020), and 21.14°C (2021). Seasonal temperature variability was evident, with increased temperatures recorded during the austral summer (August-December) and early autumn (January-March), followed by a decline from April-July, marking the temperature recession period. Notably, all the winter periods (May-August) were characterized by low temperatures, with a moderate increase in winter temperatures observed over the study period.

The findings of this study are consistent with those of Ochieng *et al*. (2017), who reported that 74.9%

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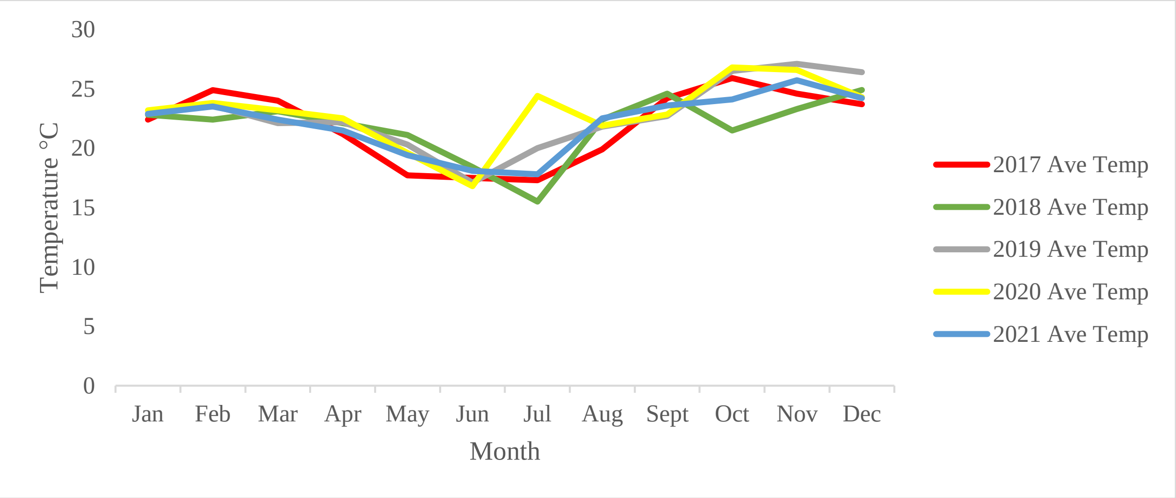
of respondents in various Kenyan zones perceived increased temperatures. Similar trends were observed in Moscow (Mikhaylov *et al*., 2020), with a pronounced increase in hot days throughout the tropics, particularly in the southern hemisphere (Van Ruijven *et al*., 2019). Temperature variability has increased by approximately 15% per degree of global warming in Amazonia and southern Africa and up to 10%°C^{-1} in Sahel, India, and Southeast Asia (Bathiany *et al*., 2018). Gadissa *et al*. (2019) projected temperature increases of 1.9°C and 2.7°C under RCP4.5 and RCP8.5, respectively, which were likely attributed to deforestation and other anthropogenic factors. In contrast, Nilawar, & Waikar (2019) reported an increasing trend in precipitation and patterns in India. However, in seasonally arid and tropical regions, rising temperatures can have both positive and negative impacts on crop and livestock productivity. Higher temperatures often negatively impact yields, whereas changes in rainfall can affect both crop quality and quantity, leading to food shortages and increased prices in some regions (Kumar *et al*., 2022). According to Girard *et al*. (2021), increased temperatures, coupled with erratic rainfall patterns and intensified droughts, have resulted in widespread crop failure and reduced livestock productivity, worsening water scarcity and compromising crop yields and livestock growth and development.

Figure 6: Mean Temperature Pattern for Nyanga District (2017-2021)



Means of Agricultural Livelihoods

The findings indicate that crop production constituted 21.12% of the respondents' livelihoods strategies, with maize production contributing 8.5%, small grain production (encompassing sorghum and millet) accounting for 6.2%, and vegetable production (including leafy greens and tomatoes) comprising 6.5%. Livestock production represented 14.29% of the respondents' livelihoods, with cattle production (for beef or dairy) contributing 5.0%, goat production (for meat or milk) accounting for 3.5%, poultry production (including chickens and eggs) comprising 2.5%, rabbit production accounting for 1.1% and pig production (for pork) making up 2.1% (Table 3). Agroforestry accounts for 9.32% of the respondents' livelihoods and involves the intentional integration of trees into farming systems to enhance ecological interactions and biodiversity, and benefits from fruits and wood. Aquaculture represented 8.06% of the respondents' livelihoods, with fish harvesting from rivers and dams contributing 5.5% and other aquatic organisms (including prawns and frogs) comprising 2.5%. Irrigation-based farming accounts for 16.77% of the respondents' livelihoods, utilizing controlled water application to optimize crop growth under limited rainfall circumstances. Agricultural entrepreneurship constituted 14.29% of the respondents' livelihoods, involving the initiation and management of agriculture-related businesses, such as farm equipment sales or repairs,

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agricultural consulting or advisory services, and value-added product development (including peanut butter, mealie meal and honey etc.). Employment as a farm labourer accounted for 8.7% of the respondents' livelihoods, entailing tasks such as planting, maintaining, and harvesting crops, as well as feeding, breeding, and caring for livestock. Finally, other business ventures represent 7.45% of the respondents' livelihoods, encompassing nonfarm enterprises such as trade (retail or wholesale), services (including transportation and shopkeeping), and manufacturing (including textiles and crafts).

Funk *et al*. (2020) suggested that implementing various adaptation strategies, including information and communication technology, crop and farm diversification, social networking through cooperatives, and soil and water conservation measures, can provide sustainable solutions for farmers in the face of climate change. Climate change impacts livestock production, particularly egg and meat production, by altering feed intake and increasing energy requirements to mitigate heat stress caused by increased temperatures (Soumya *et al*., 2022). Moreover, climate change adversely affects livestock production through competition for natural resources, decreased quantity and quality of feeds, compromised food security, increased livestock diseases, heat stress, and biodiversity loss. Changes in temperature, rainfall, and severe weather events are projected to reduce crop yields in many developing countries, particularly in sub-Saharan Africa. A study by Paudel *et al*. (2022) revealed that the primary motivations for adopting agroforestry practices in Nepal were livelihood improvement, income generation, and food production. The findings of this study revealed the importance of implementing climate-resilient agricultural practices to mitigate the impacts of climate change on agricultural productivity and enhance food security.

Table 3: Means of Agricultural Livelihoods

Livelihood means	Percentage
Crop production (maize, small grains, vegetables)	21.12
Livestock production (cattle, goats, poultry, pigs)	14.29
Agroforestry	9.32
Aquaculture (fish harvesting)	8.06
Irrigation-based farming	16.77
Agricultural entrepreneurship	14.29
Farm laborer	8.7
Other business ventures	7.45

Impacts of Climate Change on Agricultural Livelihoods

Results of this study reveal that the most prevalent perceived impact of climate change in the Nyanga district was water scarcity and the drying up of rivers, as shown by 14.36% of the respondents. Deforestation (12.31%) was the second most significant impact, as illustrated in Fig. 7. Decreased crop yields (11.79%) ranked third, followed by shifted growing seasons (10.77%), loss of livestock (9.74%), and human migration and conflicts, which shared identical percentages (9.23%). Postharvest losses and temperature increases were reported as the eighth and ninth most significant impacts, respectively, whereas increased pests and diseases (6.15%) were perceived as the least impactful among the respondents. This ranking of climate change impacts suggests that water scarcity and land degradation are the foremost concerns in the Nyanga district, underscoring the need for targeted interventions to mitigate these effects. Crops and their corresponding pests are directly and indirectly affected by climate change. Climate change has significant implications in tropical regions, impacting various aspects of the environment, agriculture, and human livelihoods and leading to a range of devastating effects.

Changes in precipitation patterns and increased evaporation due to warmer temperatures can cause

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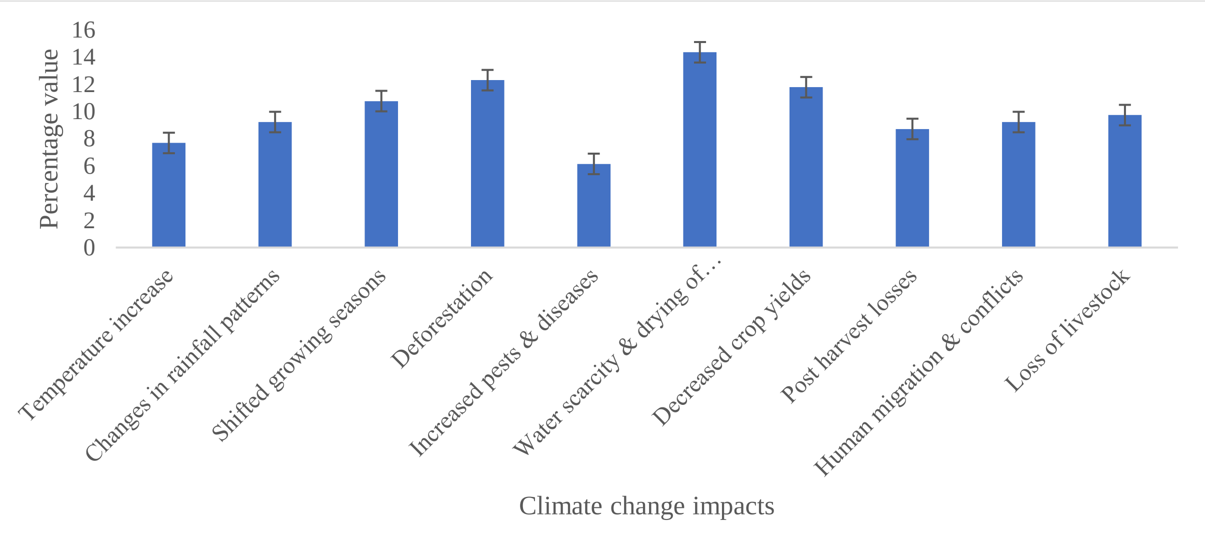
rivers' water to significantly decrease, whereas rising temperatures and altered rainfall patterns affect forest ecosystems, resulting in increased tree mortality and decreased forest cover (Fadina, & Barjolle, 2018; Mekonnen *et al.*, 2021). As a result, climate change drives migration as people seek better living conditions, escape drought, floods, or reduce livelihood opportunities. Changes in temperature and humidity increase the likelihood of crop spoilage and damage during growth stages and storage (Salimi, & Al-Ghamdi 2020). Furthermore, this alters the distribution and prevalence of pests and diseases affecting crops and livestock, leading to increased infestations and epidemics, creating a cascade of interconnected consequences that threaten the foundation of tropical ecosystems and human communities (Phani *et al*. 2024).

Figure 7: Impacts of Climate Change on Agricultural Livelihoods



Climate Resilience Strategies in Agriculture

The results of this study indicate that the most frequently cited climate-resilient strategy in the district is water harvesting and storage, which is endorsed by 24.14% of the respondents. This is followed by efficient irrigation schemes (13.30%), the growing of drought-tolerant crops (10.34%), and early warning systems (8.87%). The diversification of on-farm income sources (8.37%) and alternative water sources (7.88%) were also identified as key strategies, ranking fifth and sixth, respectively (Figure 8). Proper livestock management, education and training, and climate-smart agriculture were each cited by 7.39% of the respondents, indicating a tie in perceived importance. Improved watershed management was the least frequently cited strategy (4.9%), suggesting a potential area for targeted interventions.

The findings of the present study highlight the importance of water management and agricultural practices in building climate resilience in the district. This study aligns with the findings of Mekonnen *et al*. (2021) and Alhassan *et al*. (2019), who reported that a significant proportion of farmers are integrating climate-resilient strategies into their farm management practices. This may include the adoption of improved crop varieties and livestock production, as well as crop diversification. Similar observations were made by Mohammed *et al*. (2021), who noted that livelihood diversification has become an essential adaptation strategy for farmers. The study also reveals that climate change-related migration to nearby and distant towns, both within and outside the country, is increasing, leading to dependence on remittances to supplement agricultural incomes and address food shortages. The other prevalent adaptation strategies among farmers include planting drought-tolerant varieties and adjusting planting dates. These findings are consistent with those of Maja, & Ayano (2021), who reported that farmers are migrating to other parts of the country,

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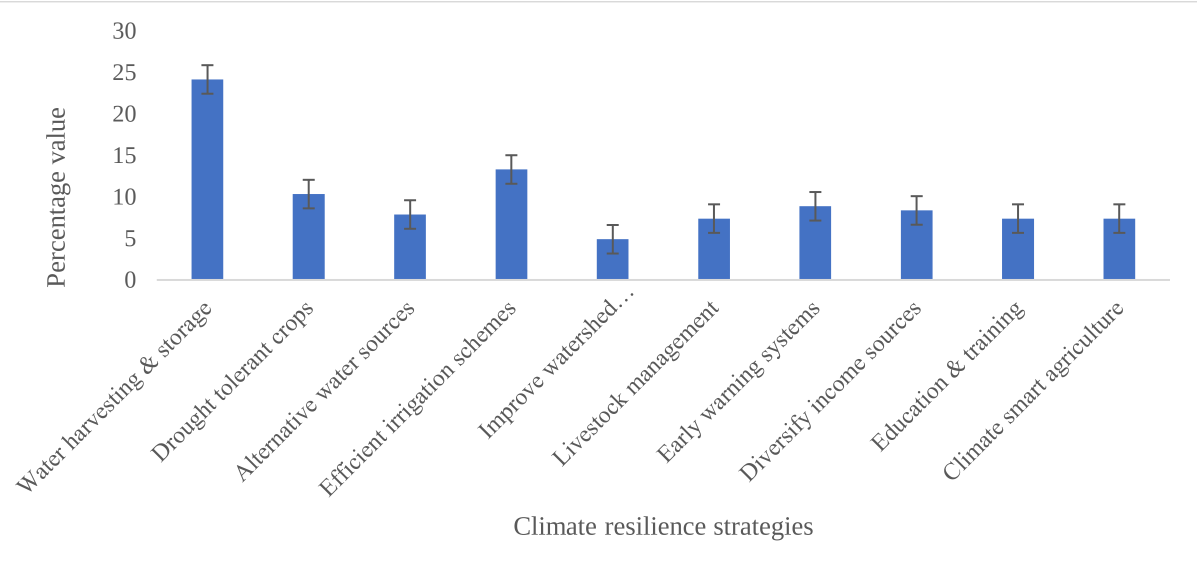
as well as to low-income countries and overseas, in search of improved income opportunities.

A study by Ali, & Erenstein (2017) in Pakistan revealed that the primary adaptation practices used by farmers included adjusting sowing times (22%), using drought-tolerant varieties (15%), and shifting to new crops (25%). The results of this study indicate that younger farmers and those with higher levels of education are more likely to adopt adaptation practices, as are wealthier farmers who cultivate larger land areas and have joint families. The number of adaptation practices used was positively correlated with education, male household head, land size, household size, extension services and wealth. These findings align with studies by Harvey *et al*. (2018) and Antwi-Agyei, & Nyantakyi-Frimpong (2021), who reported that smallholder farmers implemented various adaptation practices, including agroforestry, restoration activities, agroecological practices, intensification, and the adoption of new crop varieties and technologies. The results of this study suggest that the adoption of climate change adaptation strategies significantly enhances sustainable agricultural livelihoods. The positive impacts of adaptation on crop and livestock productivity are consistent with the findings of Khanal *et al*. (2018) in Nepal, Diallo *et al*. (2020) in southern Mali, and Kalimba, & Culas (2020) in sub-Saharan Africa. The key adaptation strategies adopted by the farmers in this study are consistent with those reported in studies by Kichamu *et al.* (2018) in Eastern Kenya, Araro *et al*. (2020) in Southern Ethiopia, and Fadina, & Barjolle (2018) in South Benin.

Figure 8: Climate Resilience Strategies in Agriculture



CONCLUSION

The sub-Saharan region, including Zimbabwe, is highly vulnerable to climate change impacts, which are expected to intensify over time. The results of this study showed that strategies that enhance adaptive capacity and strengthen climate resilience should be implemented to target smallholder farmers, who are the most vulnerable. Traditional agricultural adaptation strategies, such as water harvesting and storage, efficient irrigation schemes (open furrow), and the cultivation of drought-tolerant crops, were found to be effective in dry regions. However, constraints to implementation, including limited knowledge, expertise, and climate change-related data, as well as inadequate institutional frameworks, should be addressed with keen insight. Proactive adaptation, human capital development through education and training, and extension services could improve smallholder farmers' coping with climate change. Moreover, promoting sustainable agricultural practices and climate-resilient agriculture is crucial for preventing food insecurity and supporting recovery efforts. Effective social safety nets

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enhanced agricultural livelihoods, subsequently promoting food security, sustainable development, and human well-being. Therefore, a comprehensive approach that addresses these challenges and leverages opportunities for climate resilience is essential for building food security and sustainable agricultural development in Zimbabwe.

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Conflict of interest: The authors declare that they have no conflicts of interest/competing interests.

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