# Navigating the Unpredictable: Resilience Strategies in the face of Nature’s Changes

## An Empirical Study of Smallholder Farmers in Zambia

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# Navigating the Unpredictable: Resilience Strategies in the face of Nature's Changes. An Empirical Study of Smallholder Farmers in Zambia.

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## Abstract

This study investigates the impact of drought on food security and evaluates the effectiveness of climate coping strategies adopted by smallholder farmers in Zambia between 2012 and 2019. Utilizing panel data from the Rural Agricultural Livelihoods Survey (RALS) and employing a Two-Way Fixed Effects (TWFE) regression model, the research finds that droughts significantly reduce food security, with the 2015 season marking the most severe shock. However, households that adopted adaptive strategies—particularly crop diversification, soil conservation, and water harvesting—exhibited greater resilience. Among these, crop diversification demonstrated the highest return on investment and widest adoption, while irrigation, despite its potential, remained underutilized due to cost barriers. The study also highlights the critical role of enabling factors such as education, credit access, and extension services in amplifying adaptive capacity. The results underscore the importance of localized, multi-dimensional policy interventions to strengthen climate resilience in vulnerable agroecological zones. This research contributes to the empirical literature on climate adaptation by offering robust, context-specific insights that inform both policy and practice in sub-Saharan agriculture.

**Keywords:** Climate Change, Climate Coping Strategies, Drought, Food Security, Two-Way Fixed Effects, Empirical Study, Resilience, Climate Adaptation, Smallholder Farmers, Zambia.

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# Abbreviations

| **Abbreviation** | **Description** |
|---|---|
| FAO | Food and Agriculture Organization (of the United Nations) |
| GDP | Gross Domestic Product |
| IAPRI | Indaba Agricultural Policy Research Institute |
| IPCC | Intergovernmental Panel on Climate Change |
| LOCF | Last Observation Carried Forward |
| RALS | Rural Agricultural Livelihoods Survey |
| RCP | Representative Concentration Pathway |
| ROI | Return on Investment |
| SDGs | Sustainable Development Goals |
| SLU | Swedish University of Agricultural Sciences |
| SPEI | Standardized Precipitation Evapotranspiration Index |
| TLU | Tropical Livestock Unit |
| TWFE | Two-Way Fixed Effects |
| UNWFP | United Nations World Food Programme |
| ZMW | Zambian Kwacha |

# 1. Introduction

Globally, smallholder farmers face parallel challenges in confronting the adverse effects of climate change on agricultural production. These challenges are particularly acute in developing regions where agriculture remains the cornerstone of rural livelihoods and food systems. According to the World Bank (2021), over 75% of rain-fed agricultural systems are highly vulnerable to increasing rainfall variability. This variability intensifies the frequency and impact of climate-induced shocks, posing a serious threat to household food security and economic stability, especially in countries where agriculture is not only a source of subsistence but also a major contributor to national income.

Simultaneously, rising average global temperatures have exacerbated the intensity and frequency of extreme weather events, most notably prolonged droughts, unpredictable rainfall, and floods. Schiermeier (2018) notes that these climatic shifts are expected to worsen if global mitigation efforts remain inadequate. Ortiz-Bobea et al. (2021) predict that global agricultural total productivity may decline by up to 22% due to climate change, with particularly severe consequences in tropical regions. However, these impacts are not uniformly distributed. Arora (2019) emphasizes that developing countries bear a disproportionate burden, with altered agroecological conditions significantly undermining food security and increasing the depth and frequency of agricultural risk. The profound effects of climate change are increasingly reshaping agricultural systems worldwide, with smallholder farmers among the most vulnerable groups facing these challenges.

Africa is widely recognized as a climate disaster hotspot (Blunden and Arndt, 2020; Niang et al., 2014). Climate change and variability represent some of the most critical threats to agricultural production and food security, particularly in developing countries like Zambia a country where over 70% of the population relies directly on agriculture for their livelihoods. The predominance of rain-fed agriculture, combined with weak infrastructure and limited institutional safety nets, makes smallholder farmers particularly susceptible to climate shocks, especially droughts, which are becoming more recurrent and severe. Rising average temperatures, shifts in seasonal rainfall patterns, and an increased frequency and intensity of extreme weather events including prolonged droughts and devastating floods are significantly altering the environmental conditions necessary for crop growth and livestock rearing. These changing climatic conditions disrupt the length and timing of growing seasons, reduce soil moisture retention, and increase evapotranspiration rates, which collectively undermine agricultural productivity.

Smallholder farmers, who form the backbone of Zambia's agricultural sector, which is a cornerstone for both economic development and food security, bear the brunt of erratic and unpredictable weather conditions because they rely heavily on natural rainfall and traditional farming methods. As a consequence, the projected impacts of climate change such as reduced crop yields, diminished water availability for irrigation and livestock, and increased incidence of

pests and diseases pose direct threats to the livelihoods and food security of rural farming households. The cascading effects of these changes extend beyond the farm level, impacting local economies, nutritional outcomes, and social stability. Understanding the nuances of climate variability and its effects is therefore critical for designing adaptive strategies tailored to Zambia's specific agro-ecological zones.
The climate challenges include irregular rainfall patterns, prolonged drought periods and sudden floods, all of which severely disrupt traditional farming cycles and reduce crop yields. According to Sitko and Nicholas J. (2014), such climatic disruptions threaten not only the livelihoods of these farmers but also have broader ripple effects on local economies and food supply chains. This vulnerability poses a significant threat to the sustainability of rural communities that rely predominantly on agriculture as a primary source of income and subsistence.

The central problem this research seeks to address is the insufficient understanding of the specific resilience and coping strategies employed by smallholder farmers in Zambia to mitigate the adverse impacts of these climatic changes. Despite the growing body of literature acknowledging the devastating effects of climate change on agriculture, there remains a critical knowledge gap regarding how farmers actively adapt on the ground. Empirical evidence detailing the types of strategies they use, their effectiveness and the conditions under which they succeed, or fail is limited. Filling this gap is vital to crafting effective policies and development programs that can support and amplify these coping mechanisms, ultimately improving resilience at both community and national levels.

Smallholder farmers' resilience strategies are diverse and may include practices such as diversifying crop varieties to reduce risk, adopting conservation agriculture techniques to preserve soil health, enhancing water harvesting and irrigation methods, and improving access to market information and financial services like credit and insurance. Peng Yuanyuan (2022) highlights that the success and sustainability of these adaptive measures often depend heavily on a range of external factors including supportive government policies, availability and accessibility of modern agricultural technologies, and the strength of social networks within communities. This research posits that resilience is not merely an outcome of isolated decisions made by individual farmers, but is deeply embedded within the social, economic, and institutional contexts of rural Zambia.

The dependency on seasonal rainfall places smallholder farmers in a precarious position, as the growing unpredictability of the climate increases their exposure to food insecurity. Typically, these farmers experience acute periods of hunger between harvest and planting seasons. These lean periods have become more pronounced in recent years due to shifting rainfall patterns and extended dry spells (FAO, 2016). As such, climate change is not merely an environmental concern, it is a critical threat to rural development, food sovereignty, and socio-economic progress in vulnerable regions.

This study sets out to investigate the patterns, effectiveness, and limitations of climate coping strategies adopted by smallholder farmers in Zambia. It seeks to understand the relationship between these strategies and household food security outcomes in the face of climate-induced shocks, particularly drought. Evidence by Ahmed, H., Correa, J.S. & Sitko, N.J. (2023) suggests that smallholders who proactively implement adaptation measures are more likely to maintain or improve their livelihoods and food security during climatic stress. However, without scalable and context-appropriate resilience strategies, millions risk being pushed deeper into poverty and hunger.

Investing in irrigation infrastructure, climate-smart agriculture, and institutional support mechanisms can help mitigate these challenges, but such interventions are often inaccessible or unaffordable for most smallholders. Consequently, the resilience of this group depends not only on their individual strategies but also on the enabling environment provided by policy, finance, and institutional systems. In the absence of effective and inclusive support structures, rural livelihoods will remain exposed to an increasingly volatile climate.

It is therefore essential for governments and development partners to go beyond rhetoric and take a grounded approach in addressing climate resilience. Understanding the actual strategies employed by smallholder farmers offers a necessary foundation for designing policies and programs that are not only responsive but also sustainable over time. Policies built on empirical insights into farmer behaviour and constraints are more likely to achieve lasting impact.

This study is guided by the following research questions:

1) What resilience strategies do smallholder farmers in Zambia employ to cope with and adapt to climate variability and change?
2) How effective are these resilience strategies in enhancing the livelihoods and food security of smallholder farmers in Zambia?
3) What are the key factors that influence the adoption and effectiveness of resilience strategies among smallholder farmers in Zambia?

# 2. Literature Review

## 2.1 Smallholder Farmers’ Vulnerability

Smallholder farmers in Zambia face pronounced vulnerability to climate-related shocks and stresses due to several interrelated factors. Primarily, most of these farmers depend on rain-fed agriculture, making them highly susceptible to irregular rainfall and drought conditions. Compounding this vulnerability is their limited access to essential resources such as quality seeds, fertilizers, and irrigation infrastructure, which restricts their ability to recover quickly from adverse events. Moreover, many smallholder farmers lack access to formal credit facilities, insurance schemes, and other financial services that could buffer against climate risks. The deficit of adequate agricultural extension services and climate-smart technologies further limits their adaptive capacity, as farmers may not be aware of or able to implement more resilient farming techniques. Thurow, Roger (2024) emphasizes that the vulnerability of these farmers is also intensified by poverty, poor rural infrastructure, and inadequate access to markets, which collectively reduce their economic opportunities and resilience to shocks. This complex vulnerability landscape underlines the urgency of strengthening institutional support mechanisms and developing context-appropriate adaptation strategies.

## 2.2 Resilience Strategies

To mitigate and adapt to the adverse impacts of climate variability, smallholder farmers in Zambia have begun employing a range of resilience strategies. One commonly adopted strategy is crop diversification, which involves growing multiple crop species or varieties to spread risk and improve the likelihood that some crops will thrive despite unpredictable weather. This diversification can buffer against total crop failure and support dietary variety for farming households. Conservation agriculture, as articulated by Adu Ankrah, Daniel (2024), offers another pathway to resilience. This approach promotes minimal soil disturbance, continuous soil cover through mulch or cover crops, and crop rotation, all aimed at improving soil health, retaining moisture, and reducing erosion.

These practices contribute to enhanced long-term productivity and sustainability. Irrigation, where feasible, also serves as a critical adaptive measure by enabling farmers to control water application and reduce dependence on erratic rainfall. Other strategies may include livelihood diversification beyond farming, adoption of drought-resistant crop varieties, and community-based resource management. The effectiveness of these strategies, however, often depends on farmers’ access to knowledge, resources, and support.

## 2.3 Institutional Support

Institutional support plays a pivotal role in enhancing the resilience of smallholder farmers. Extension services provide crucial technical knowledge and training, empowering farmers to adopt improved and climate-resilient agricultural practices. Access to financial services such as credit and insurance enables farmers to invest in adaptive technologies and manage climate-related risks more effectively. Market access is equally important, as it allows farmers to sell their produce at fair prices, thereby improving household income and investment capacity.

According to Ali, Daniel Ayalew (2022), institutional mechanisms such as climate information services and early warning systems are vital for enabling farmers to anticipate and prepare for extreme weather events. These services help farmers make informed decisions about planting dates, crop selection, and resource allocation. Moreover, coordinated efforts between government agencies, NGOs, and private sector actors can foster the development and dissemination of climate-resilient technologies and infrastructure. Strengthening these institutional frameworks is essential to bridge the gap between farmers' needs and available adaptation resources.

## 2.4 Policy and Programming

The policy environment in Zambia reflects a growing recognition of the need to support climate change adaptation and resilience building among smallholder farmers. National frameworks such as the National Climate Change Response Strategy and the Agricultural Sector Investment Plan seek to maintain climate resilience into agricultural development policies. Ali, Daniel Ayalew (2021) notes that these policies emphasize promoting climate-smart agriculture, improving resource use efficiency, and enhancing rural livelihoods. At the international level, Zambia is party to global agreements like the Paris Agreement and the Sustainable Development Goals (SDGs), which provide overarching targets and funding avenues for climate adaptation initiatives. Despite these policies and frameworks, challenges remain in translating high-level commitments into effective, ground-level actions. Policy implementation gaps, limited funding, and weak institutional coordination often hinder the delivery of tangible benefits to smallholder farmers. Grashuis, Jasper (2019) stresses the importance of aligning policy priorities with local realities and ensuring inclusive participation of farming communities in the design and monitoring of adaptation programs.

## 2.5 Empirical Evidence

Empirical research in Zambia and similar contexts increasingly supports the effectiveness of various resilience strategies and institutional support mechanisms. Studies by Dhakal, Dinesh (2021) have demonstrated that crop diversification, conservation agriculture, and irrigation interventions can lead to improved yields, reduced vulnerability, and enhanced food security among smallholder farmers. Similarly, evidence points to the positive role of extension services, credit access, and crop insurance schemes in strengthening adaptive capacity and risk management.

Nevertheless, the complexity of socio-economic and agro-ecological factors means that the impacts of these strategies can vary widely across different contexts. Burke, William J. (2018) highlights the need for continued research to unpack which resilience approaches work best under specific environmental, cultural, and economic conditions, and how institutional supports can be optimized for maximum impact. This growing empirical base provides a valuable foundation for evidence-based policy and program design, but also underscores the necessity for context-specific data and participatory research methods.

## 2.6 Research Gap

Despite advances in understanding resilience and adaptation, significant research gaps persist. One prominent gap is the lack of comprehensive empirical data on the relative effectiveness of different resilience strategies and institutional interventions specifically within Zambia's diverse farming systems. Biggeri, Mario (2018) argues that more localized, disaggregated research is needed to capture heterogeneity in farmer experiences, coping capacities, and outcomes. Moreover, the intersection of climate change impacts socio-economic factors such as poverty, gender, and access to resources remains underexplored.

Additionally, while policy frameworks exist, there is limited evidence on how well these translate into practical support and improved resilience on the ground. There is a pressing need for research that evaluates the implementation and impact of climate adaptation policies and programs, particularly regarding their inclusivity and sustainability. Addressing these research gaps will provide crucial insights for policymakers, development practitioners, and communities aiming to build robust, adaptive agricultural systems capable of withstanding the challenges posed by a changing climate.

# 3. Background

## 3.1 Climate Change and Agriculture

The term “climate change” refers to the long-term fluctuations in temperatures and weather patterns. Significant worldwide changes, including actual and expected climate alterations and global warming, happened within the past 65 years (Pandit & Sharma, 2024).

Climate change is a global issue that has a multifaceted impact on various domains, including ecological, environmental, socio-political, and socio-economic (Feliciano et al. 2022; Abbass et al. 2022). Since the 1800s, human activities have been the primary cause of climate change (Murshed et al. 2022). Pandit and Sharma, (2024) add that the primary cause of climate change is the combustion of fossil fuels, including coal, oil, and gas. Human activities are responsible for nearly all of the global warming that has occurred in the past two centuries, as evidenced by climate scientists.

Currently, the Earth's surface temperature is approximately 1.2°C higher than it was in the late 1800s, before the onset of the industrial revolution. Each of the last four decades has recorded higher temperatures than any preceding decade since 1850, with the most recent decade (2011-2020) being the hottest on record. Climate change encompasses more than merely rising temperatures; it impacts the planet's interconnected systems. Consequences include water shortages, wildfires, flooding, rising sea levels, loss of biodiversity, and severe droughts.

Drought is a recurring extreme climate event that occurs over land and is defined by below-average precipitation (Pandit & Sharma, 2024). It is frequently accompanied by high temperatures for a period of months to years (Wilhite, 2000; Dai et al. 2018). The Centre for Climate and Energy Solutions (C2ES) defines drought as "a deficiency of precipitation over an extended period of time (usually a season or more), resulting in a water shortage," and notes that "the risk of drought is expected to grow due to reduced precipitation and higher temperatures caused by climate change". While the Core.ac.uk, (2015) defines Drought as "prolonged deficiency of rainfall" (receiving <75% of normal precipitation), leading to crop failure, livestock losses, and reduced household purchasing power.

Droughts are among the costliest natural calamities in the world resulting in substantial expenses for human societies (Gautier et al. 2016), agriculture (Madadgar et al. 2017), and ecosystems (Breshears et al. 2005). It is anticipated that drought frequency and severity will increase across a significant portion of the world (Cook et al. 2014), particularly in semi-arid regions that are already experiencing significant water stress (Seager et al. 2014). Consequently, it is essential that we enhance our comprehension of the dynamics and consequences of droughts in the context of climate change (Cook et al. 2018).

Food insecurity is defined in the 2020 Global Report on Food Crises (GRFC), published by the United Nations World Food Programme (UNWFP), as “the lack of secure access to sufficient amounts of safe and nutritious food for normal human growth and development and an active and healthy life” (2020a, p. 11). There are various factors that can contribute to food insecurity, including ineffective governance, economic instability, armed conflict, and natural disasters (The Economist Group, 2020; United Nations Food and Agricultural Organization, 2021b; UNWFP, 2020a).

Food security, in the framework of drought, refers to the sustained access to sufficient, safe, and nutritious food, which is disrupted when drought reduces agricultural productivity, disrupts supply chains, and intensifies socioeconomic vulnerabilities.

The challenges faced by operational drought forecasting systems in generating accurate predictions regarding the location, intensity, and type of assistance required in the medium to long term, specifically several months in advance, represent a significant shortcoming (Khadr, 2016; Hao et al., 2018; Kreibich et al., 2019). Even in instances where forecasts have been issued, such as alerts concerning severe drought conditions in Sub-Saharan Africa (Ahmed, 2020; Fava and Vrieling, 2021), there remains a notable absence of actionable responses on the ground (Enenkel et al., 2015). Moreover, large-scale drought forecasts have proven ineffective in developed nations like the United States (Schiermeier, 2013; Anderson et al., 2018; Daigh et al., 2018). This issue is further complicated by the absence of a universally accepted definition of drought (Enenkel et al., 2015), alongside the effects of climate change on global drought trends (Enenkel et al., 2015; Salami et al., 2021), as well as its implication, global food security (Dhankher and Foyer, 2018; Purakayastha et al., 2019).

Smallholders are small-scale farmers, pastoralists, forest keepers, fishers who manage areas varying from less than one hectare to 10 hectares. Smallholders are characterized by family-focused motives such as favouring the stability of the farm household system, using mainly family labour for production and using part of the produce for family consumption (FAO, 2012). According to the 2012 publication, ‘Enduring farms’ by FAO, smallholder farmers provide up to 80 percent of the food supply in Asia and sub-Saharan Africa, and they have developed strategies to increase their resilience to external shocks while maintaining ecosystem goods and services.

## 3.2 The Zambian Context

Across Zambia, smallholder farmers who are responsible for producing the bulk of the country’s food face an escalating threat from climate change. Droughts, floods, and unpredictable growing seasons are increasingly common, devastating crop yields, disrupting incomes, and exacerbating food insecurity. The agricultural sector remains a cornerstone of Zambia’s economy, employing approximately 70% of the population. However, despite its social and economic significance, the sector’s contribution to Gross Domestic Product (GDP) has steadily declined over the past decade from 9.4% in 2010 to just 2.8% in 2023 (Zambia Development Agency, 2024; IMF, 2024).

This downward trend underscores the growing vulnerability of agriculture to climatic stressors and other structural inefficiencies.

Zambia's agricultural calendar is tightly constrained by a single rainy season that typically spans from November to April. Outside of this window, arid conditions render much of the country unsuitable for further crop cultivation. As a result, most smallholder households rely on a single annual harvest to meet their food and income needs throughout the year. While productive seasons may yield surplus for sale or storage, years marked by poor rainfall often result in severe food shortages. These periods of scarcity commonly referred to as the "hunger season" are characterized by widespread undernourishment and heightened vulnerability, particularly among rural populations.

The compounded effects of climate change are intensifying these seasonal challenges in three primary ways. First, the frequency and severity of extreme weather events such as droughts, floods, and intense storms are on the rise due to global warming. The 2016 drought, which affected vast swathes of Eastern and Southern Africa, serves as a sobering example of how climate extremes can cripple agricultural systems. Second, changing temperature and rainfall patterns are facilitating the proliferation of agricultural pests and diseases. In Zambia, outbreaks of the fall armyworm have posed a significant threat to maize production, further undermining food security. Third, sustained increases in average temperature are projected to reduce agricultural productivity across sub-Saharan Africa and may lead to long-term land degradation and desertification. Climate models suggest that if global temperatures rise by 4°C by the year 2100, maize yields in many African countries could decline by more than 20%.

These threats underscore the urgency for climate adaptation in Zambia's agricultural sector. Smallholder farmers, who often operate with minimal inputs, poor infrastructure, and limited access to markets or finance, remain highly exposed to these vulnerabilities. Without deliberate, context-specific resilience strategies, the combined impact of climate change could drive millions deeper into poverty, undermine national food sovereignty, and strain social protection systems. Thus, addressing the challenges facing Zambia's smallholder farmers is not just a development priority it is a critical pathway toward sustainable and inclusive rural transformation in an era of climate uncertainty.

# 4. Conceptual Framework

This study is grounded in the Sustainable Livelihoods Approach (SLA) and Climate Resilience Theory, which together posit that household food security outcomes emerge from the interaction between climatic shocks, adaptive strategies and enabling socio-economic conditions. The SLA, originally conceptualized by Chambers and Conway (1992) and later operationalized by DFID (1999), emphasizes how livelihood assets, institutional structures and vulnerability contexts shape household responses to external stresses and shocks. Complementarily, Climate Resilience Theory, rooted in Holling's (1973) seminal work on resilience in ecological and social-ecological systems, focuses on the capacity of households to absorb, adapt to, and recover from climatic disturbances while maintaining or improving their well-being. In the context of Zambian smallholder farming, drought severity, measured through the Standardized Precipitation Evapotranspiration Index (SPEI) functions as the primary independent variable, representing the exogenous climatic shock that disrupts agricultural production and consequently food security.

Within this conceptual framework Intervening (or mediating) variables consists adaptive strategies such as crop diversification, soil conservation, irrigation and water harvesting. These measures are hypothesized to reduce the negative impacts of drought by either maintaining or improving crop yields, enhancing resource efficiency, and stabilizing incomes. Moderating variables, including access to credit, agricultural extension services, education levels, and localized climate information are theorized to strengthen or weaken the relationship between drought severity and resilience outcomes. For example, farmers with access to both credit and timely climate forecasts are expected to implement adaptation strategies more effectively and at greater scale.

The theoretical proposition underpinning this framework is that the net impact of drought on food security is not fixed, but contingent upon the presence, type and intensity of adaptive strategies, as well as the enabling environment in which they are deployed. This proposition is supported by empirical evidence from this study, which found that households employing multiple adaptation strategies, particularly crop diversification, exhibited smaller declines in food security during severe drought years. In addition, access to enabling factors such as credit and extension services was found to significantly increase the probability of strategy adoption.

In this thesis, I test two hypotheses in which the **Null Hypothesis ($H_0$)** states that Increased drought conditions have a positive influence on food security among smallholder farmers. This hypothesis suggests that despite drought, food security could improve, possibly due to effective coping strategies. While the **Alternative Hypothesis ($H_1$)** states that Increased drought conditions do not positively influence food security among smallholder farmers. This reflects the expectation that drought negatively impacts food security, reducing availability and access.

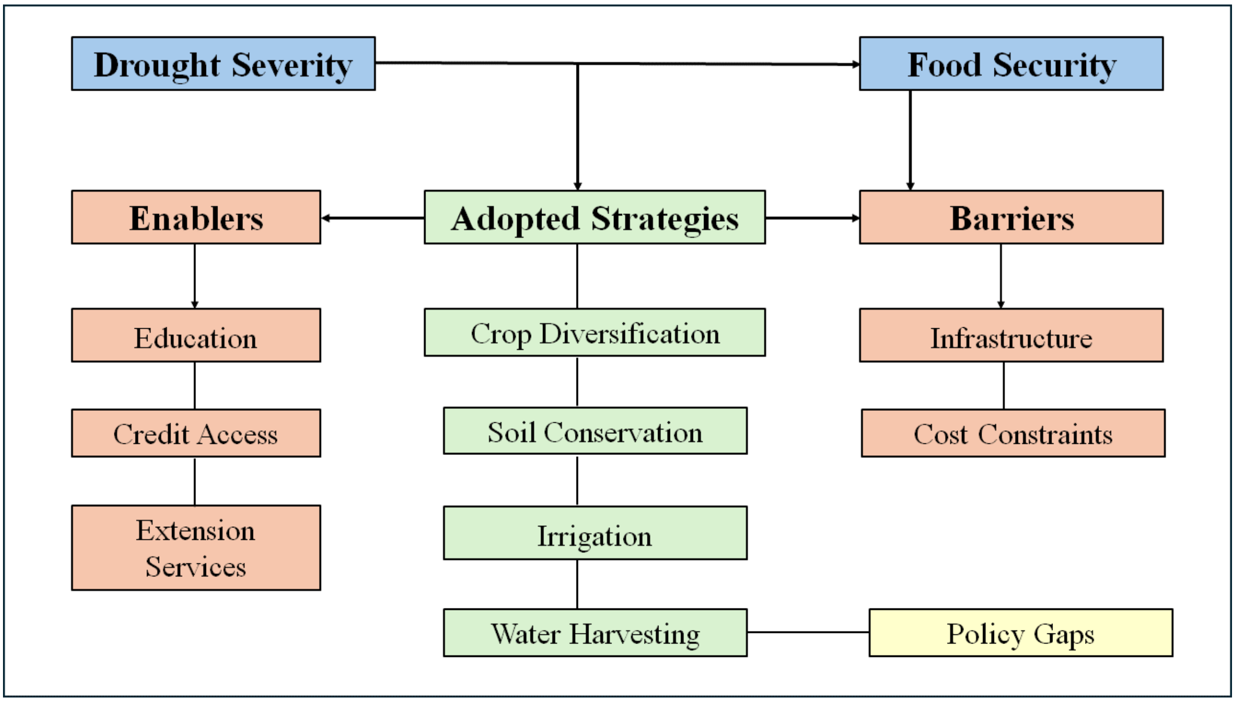


***Figure 1:*** *Diagram illustration of Conceptual Framework.* ***Source:*** *Generated by Author*

# 5. Empirical Strategy

This section provides a comprehensive overview of the methodological approach used to empirically analyse the relationship between climate coping strategies and food security outcomes among smallholder farmers in Zambia. The study examines longitudinal data collected from all provinces in Zambia over the period 2012 to 2019, allowing for an in-depth exploration of temporal trends, spatial variability, and the dynamic effects of drought events on agricultural productivity and food security. Given the complex nature of climate shocks, their heterogeneous impacts, and the adaptive responses by farmers, this study adopts a rigorous quantitative panel data methodology anchored on a Two-Way Fixed Effects (TWFE) framework, as outlined in the recent econometric advances by Callaway and Sant'Anna (2021). This approach is particularly advantageous for addressing the staggered onset and varying intensity of droughts experienced across different geographic regions and years.

## 5.1 Estimation Method

The empirical analysis adopts a quantitative, panel data framework that allows for repeated observations of the same farming households or geographic units over multiple years, thereby leveraging both cross-sectional and temporal variation in the data. This approach enables the study to control for unobserved heterogeneity and capture dynamic responses to climate shocks. The estimation technique is based on the Two-Way Fixed Effects (TWFE) regression model, a well-established method in panel data econometrics. The TWFE model includes fixed effects for individual units (farmers, households, or regions) and for time periods (years), providing control over all unobserved factors that are constant within an individual or uniform across time.

Specifically, the individual fixed effects control for all time-invariant attributes of farmers or regions that may influence food security such as inherent farming knowledge, land quality, or cultural practices assuring that these do not confound the estimated relationships. Time fixed effects account for shocks or trends common to all farmers, including national policy interventions, economic cycles, or climatic patterns that affect all regions simultaneously.

By controlling for these effects, the TWFE model addresses key econometric issues such as omitted variable bias, which occurs when unobserved factors correlated with both drought exposure and food security are not accounted for. It also addresses potential selection bias and unmeasured confounders that remain constant over time or are common to all units.
The model's estimates can be interpreted as the average within-farmer (or within-region) effect of drought exposure and resilience strategies on changes in food security outcomes over time, providing a more precise and credible estimate of causal impacts than cross-sectional or simple difference-in-differences approaches.

## 5.2 Two Way Fixed Effects (TWFE) Model

The Two-Way Fixed Effects model is particularly well-suited for this research for several reasons:

**Control for Unobserved Heterogeneity:** Many farmer-specific characteristics that influence food security outcomes are difficult or impossible to measure, such as soil fertility, traditional knowledge, or risk preferences. By including fixed effects for each farmer or region, the TWFE model controls for all such unobserved, time-invariant characteristics, ensuring that the estimates are not biased by these latent factors.

**Control for Temporal Shocks:** Climate and economic conditions can change over time and affect all farmers simultaneously. For instance, a national policy change on agricultural subsidies or a nationwide inflation shock can influence food security outcomes. By including year fixed effects, the model captures these common shocks, isolating the effects of drought and adaptation strategies more accurately.

**Handling Heterogeneous Timing of Treatments:** Droughts in Zambia do not occur uniformly every year or across all provinces. Some provinces may experience drought in one year but not others; some droughts may be severe while others mild. The TWFE model, particularly following Callaway and Sant'Anna (2021), is able to account for such staggered treatment timing and heterogeneity in drought intensity. This means it can more accurately capture how drought exposure impacts farmers differently depending on when and where the drought occurs.

**Reducing Bias from Time-Varying Confounders:** While TWFE controls for constant unobserved factors and common time shocks, it is also flexible enough to include additional control variables (such as rainfall anomalies, market access, or input prices) that vary over time and across regions, further improving the model's explanatory power and robustness.

**Interpretation of Results:** The coefficients estimated by the TWFE regression reflect the average effect of drought exposure and resilience strategies on food security outcomes after controlling for all other factors. This provides policymakers and practitioners with robust evidence about which strategies are effective and how drought affects food security, helping guide resource allocation and program design.

## 5.3 Additional Considerations

**Variable Construction:**

The drought variable will be constructed using the Standardized Precipitation Evapotranspiration Index (SPEI), which captures both the occurrence and intensity of drought conditions. While

Food security will be assessed through indicators such as household food consumption scores, dietary diversity and periods of food insufficiency.

**Model Diagnostics and Robustness Checks:**

The study will conduct extensive robustness checks, including alternative model specifications, placebo tests, and sensitivity analyses, to verify the validity of the identification assumptions and the stability of the estimated effects.

**Potential Limitations of the model**

Although the TWFE approach controls for many confounders, unobserved time-varying factors unique to individual farmers may still pose challenges. These will be addressed through instrumental variable techniques or supplementary qualitative data where possible.

## 5.4 Model Specification

**Model 1: Food Security as the Outcome.**

$$\boldsymbol{FS_{it} = \beta_0 + \beta_1 D_{it} + \beta_2 CS_{it} + \gamma X_{it} + \alpha_{it} + \delta_{it} + \mu_{it}} \quad \textbf{(1)}$$

In the regression model, $\beta_0$is the intercept, $\beta_1$is the coefficient for drought, and $\beta_2$is the coefficient for climate coping strategies. These parameters capture the direct effects of drought and household adaptation measures on food security outcomes, while controlling for other household characteristics and time effects.

### 5.4.1 Variable Specifications

The dependent variable, $FS_{it}$, represents the food security status of farmer $i$in year $t$, reflecting the household's ability to access sufficient, safe, and nutritious food to meet dietary needs. The independent variable $D_{it}$measures drought exposure for farmer $i$at time $t$, capturing the severity or occurrence of drought conditions experienced, as quantified by the Standardized Precipitation Evapotranspiration Index (SPEI). The variable $CS_{it}$represents the climate coping strategies adopted by farmer $i$at time $t$, encompassing a vector of resilience and adaptation mechanisms such as crop diversification, irrigation, and soil conservation practices

**Fixed Effects:**

**Farmer fixed effects ($\alpha_i$)**: the model controls for all unobserved, time-invariant characteristics specific to each farmer or farm household. I include geographic locations that do not change over time but may affect food security which increases the robustness of the results.

**Year fixed effects ($\delta_t$)**: These capture macroeconomic shocks or trends common to all farmers in a given year, such as national policy changes, inflation or economic downturns that might impact all farmers simultaneously in a particular year.

**Control Variables** ($\mathbf{X_{it}}$): A vector representing the control variables for farmer i in year t, accompanied by the coefficient vector γ (gamma). The inclusion of these controls helps in isolating the impacts of drought and coping strategies by considering other influential factors.
The integration of control variables ($\boldsymbol{X_{it}}$) will enable me to obtain more precise estimates regarding the effects of drought exposure and coping strategies, as it takes into account other elements that may confound these relationships. The controls include Farmer education level, Farm size, Access to markets or credit and Household demographic characteristics
$\boldsymbol{\mu_{it}}$ **:** the error term capturing all other unobserved factors that vary across farmers and over time, which might influence food security. **i** represent Identification for each farmer and **t** represents time in years.

## 5.4.2 Model Explanation and Rationale

The model is structured to estimate the impact of drought exposure and climate coping strategies on food security, while controlling for other important confounding variables and unobserved heterogeneity. Drought exposure ($\boldsymbol{D_{it}}$) is expected to have a negative effect on food security by reducing crop yields, limiting water availability and increasing stress on livelihoods. In contrast, climate coping strategies ($\boldsymbol{CS_{it}}$) are anticipated to exert a positive influence by mitigating the adverse impacts of drought, enhancing adaptive capacity and stabilizing food availability. Control variables ($\boldsymbol{X_{it}}$) are included to improve model precision and avoid omitted variable bias by accounting for additional factors that influence food security but are not the primary focus of the study. Additionally, fixed effects ($\boldsymbol{\alpha_{it}}$ and $\boldsymbol{\delta_{it}}$) control for individual farmer characteristics and year-specific shocks, ensuring that persistent differences and common external influences do not bias the estimation.

## 5.5 Second Estimation

I also considered having an **interaction term** which allowed me to examine whether the effect of Drought (independent variable) on the dependent variable (Food Security) depends on the Coping Strategies**.** The regression model with an interaction term will be as follows:
**Model 2: Food Security as an Outcome mediated by Coping Strategies**

$$\boldsymbol{FS_{it} = \beta_0 + \beta_1 D_{it} + \beta_2 CS_{it} + \beta_3 (D_{it} \text{ x } CS_{it}) + \gamma X_{it} + \alpha_{it} + \delta_{it} + \varepsilon_{it}} \qquad \textbf{(2)}$$

Where the **Interaction term** ($D_{it}$ **x** $CS_{it}$) examines mediation by coping strategies. $\boldsymbol{\beta_3}$ captures whether the effect of coping strategies on food security changes depending on the level of drought exposure. A significant positive $\boldsymbol{\beta_3}$ would imply that coping strategies become more effective as drought severity increases.

# 6. Data

This study was conducted using observed data and remotely sensed data. The study used Rural Agricultural Livelihoods Survey (RALS) observed data on Smallholder farmers obtained from the Indaba for Agricultural Policy Research Institute (IAPRI).
The remotely sensed data for drought was accessed through the SPEI Global Drought Monitor.
A Panel Dataset of Zambian Farming households from 2012 to 2019 was used. Data was collected over multiple time periods to capture changes in agricultural crop production and financial status over time.
The dataset comprised of Smallholder farmers from 73 Districts in 10 Provinces of Zambia. Total households' population was approximately 13,800, each with a serial number ID.
This study utilized a combination of observed household-level data and remotely sensed climatic data to investigate the relationship between climate coping strategies and food security outcomes among smallholder farmers in Zambia.

## 6.1 Data Sources

### 6.1.1 Observed Data

The primary source of observed micro-level data was the Indaba Agricultural Policy Research Institute (IAPRI), which maintains longitudinal panel datasets on smallholder farmers across Zambia. The dataset includes comprehensive information on household demographics, crop production, farming practices, food security indicators, income sources, and access to agricultural services. These data points are critical for identifying trends, assessing adaptive strategies, and establishing household-level food security outcomes.

### 6.1.2 Remotely Sensed Data

To measure climate-related shocks, specifically drought, this study utilized data from the Standardized Precipitation Evapotranspiration Index (SPEI), available through the SPEI Global Drought Monitor. SPEI is a globally recognized index that integrates precipitation and evapotranspiration, making it highly suitable for assessing agricultural drought intensity and duration. The index allows for time-sensitive and location-specific drought measurement, enabling precise correlation with household-level outcomes.

### 6.1.3 Classification of Droughts

Droughts are categorized into four distinct types: Meteorological, Agricultural, Hydrological and Socioeconomic droughts. The primary factor contributing to meteorological droughts is the imbalance between precipitation and evaporation, with precipitation being the most commonly used metric for assessment (Chang 1991). These meteorological droughts can lead to agricultural droughts, which diminish soil moisture and adversely affect agricultural output. Hydrological droughts occur when the requirements of a specific water resource management system exceed the available surface and subsurface water supplies. Socioeconomic droughts are linked to reservoir operations, which play a vital role in managing water supply during severe climatic events. The repercussions of these droughts significantly affect rural economies, particularly farmers, leading to financial distress, social disturbance, and a decline in population.

Drought is a multifaceted, progressive phenomenon that is triggered by natural climate variability. The initial stage is meteorological drought, characterized by decreased precipitation and increased evaporation, leading to a shortage of soil moisture. As the drought persists, it evolves into agricultural drought, marked by water stress in plants, which adversely influences crop growth and yield. A hydrological drought results from extended conditions, impacting ecosystems and wildlife habitats by lowering stream flow and reservoir levels. The increasing impacts of drought lead to a wide array of economic, social, and environmental challenges which include food insecurity and water shortages, which become more severe as the drought progresses.

This study focuses on two specific categories: Meteorological and Agricultural droughts. Droughts have a considerable effect on agricultural production, leading to economic weaknesses, particularly in less affluent areas where food security is already at risk (Dai et al. 2024). The health implications are profound, as a lack of water can lead to starvation and increased disputes over resources (Bevacqua et al. 2022).

With changes in climatic conditions being increasingly noticed around the world in the past 2 decades, drought has been identified as one of the main causes of food insecurity. Given the inseparable nature of food security and poverty, it has been impossible for Africa to attain the poverty reduction Millennium Development Goal as most of the continent still suffers food insecurity (Maria. G. D. Ndzelen, 2015).

## 6.2 Study Design and Panel Description

The study employed a panel dataset comprising data collected between 2012 and 2019, spanning three waves of household surveys. This temporal structure enabled the analysis of dynamic changes in farming outcomes and resilience strategies over time.

The dataset includes smallholder farmers from 73 districts across all 10 provinces of Zambia, ensuring a representative national sample. A total of approximately 13,800 households were part of the broader RALS dataset. Each household in the sample is assigned a unique serial identification number to facilitate panel tracking across years.

The selection of households was stratified to reflect geographical diversity, agroecological zones, and varying levels of drought exposure. This design ensures robust inference on the relationships between climatic events and farming outcomes.

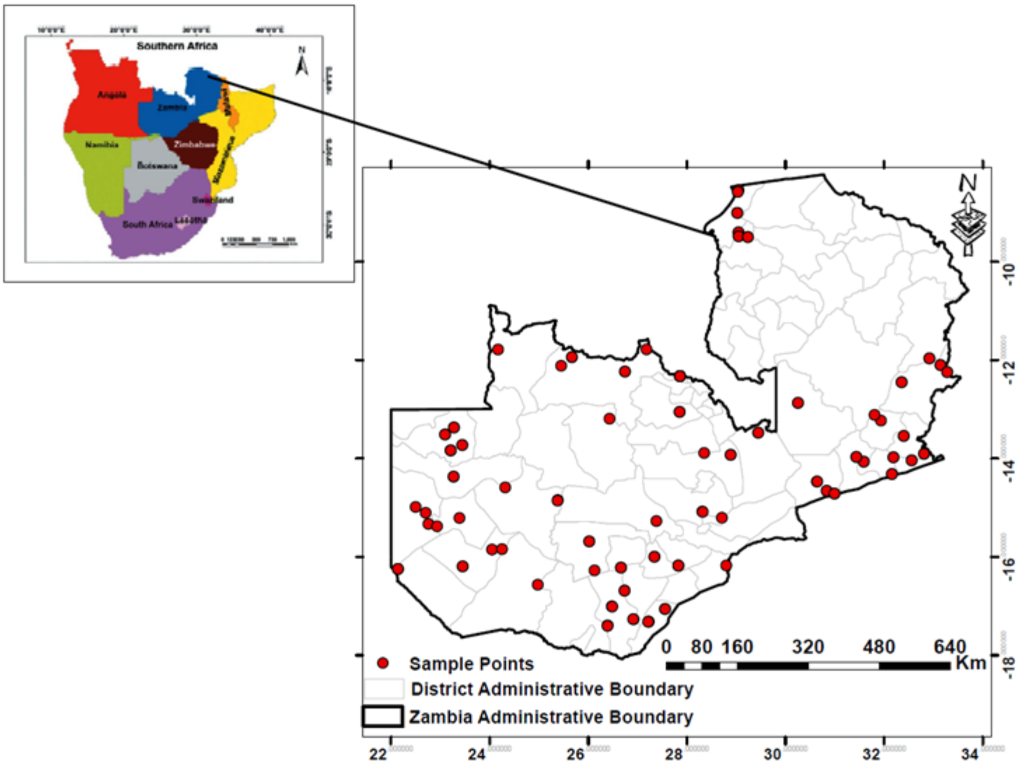


***Figure 2:*** *Map of Zambia showing sample points across the 10 provinces, indicating the geographical distribution of participating farming households.* ***Source:*** Generated by the author using GIS software, based on RALS (2015-2019) dataset.

## 6.3 Data Cleaning and Sorting

Before conducting empirical analysis, rigorous data cleaning and preparations were performed to ensure the accuracy, consistency, and reliability of the dataset. The following steps were undertaken:

### 6.3.1 Data Sorting

GPS coordinates for each individual farm were extracted from the RALS Dataset. The coordinates were then used to extract the SPEI values for each farm for the years under study from the Global Drought Monitor. Then the required variables were also selected from the observed dataset, ensuring each farmer had a corresponding ID in all selected variables.

### 6.3.2 Data Integration

Observed RALS data and remote sensing drought data (SPEI) were merged using common identifiers, such as district codes, GPS coordinates, and time (year). Temporal alignment was conducted to match the timing of observed farming outcomes with corresponding drought index values.

### 6.3.3 Missing Data Treatment

Missing values in key variables (e.g., food security indicators, drought index, income levels) were assessed. Households with excessive missing observations across all years were excluded from the final analysis.

For moderate missingness, imputation techniques such as mean substitution, last observation carried forward (LOCF), or multiple imputation were applied, depending on the variable and context.

### 6.3.4 Outlier Detection and Correction

Outliers in continuous variables such as crop yields, farm size, and household income were detected using standard deviation thresholds and boxplots.

Implausible entries were cross-checked and corrected using metadata documentation or excluded where no validation was possible.

### 6.3.5 Variable Transformation

Drought data (SPEI) were standardized and rescaled into categories (e.g., normal, mild drought, severe drought) to allow for both continuous and categorical analysis.

Food security indicators were aggregated into indices using techniques like Principal Component Analysis (PCA), where applicable.

### 6.3.6 Panel Structuring

The dataset was restructured into long format suitable for panel regression analysis.

Panel identifiers (household ID) and time variables (year) were validated to ensure each household had correct time-series entries.

### 6.3.7 Coding and Labelling

All categorical variables, such as education level, region, coping strategies, and crop types, were coded numerically for regression purposes.

Clear variable labels and descriptions were assigned to ensure transparency and replicability in analysis.

# 7. Empirical Analysis

In this section I report my Identification Strategy, Descriptives and the Results obtained from the main estimates of the equations (1) and (2) from the empirical strategy section.

## 7.1 Identification Strategy

A central challenge in isolating the impact of drought on food security is the risk of confounding, where unobserved characteristics of farmers or regions might simultaneously affect their exposure to drought and their food security outcomes. To overcome this, the identification strategy relies on the assumption that drought occurrences are exogenous with respect to farmer-specific traits and household-level food security outcomes, after accounting for observable controls and fixed effects. In other words, the timing and severity of droughts are determined largely by climatic and geographical factors outside the control of individual farmers and are not systematically correlated with unobserved farmer attributes that could bias the results.

To operationalize this, the study controls time-invariant location-specific factors such as soil quality, baseline socio-economic status, and farming infrastructure through individual fixed effects. Additionally, time fixed effects capture nationwide trends, policy changes, or macroeconomic shocks that might influence food security outcomes uniformly across all farmers in a given year. This dual approach helps minimize omitted variable bias by ensuring that only within-farmer (or within-location) changes over time are used to identify the impact of drought and coping strategies.

Furthermore, by controlling for these factors, the identification strategy mitigates selection bias concerns where farmers with different unobserved characteristics might experience different drought exposures or food security outcomes. This assumption is crucial to isolate the causal pathway from drought exposure through coping mechanisms to food security outcomes. Rigorous sensitivity analyses will be employed to test the robustness of this assumption.

## 7.2 Descriptive Statistics

The following table 1 is showing the demographic and Asset Characteristics of the smallholder farmers.

**Table 1:** Demographic and Asset Characteristics of Smallholder Farmers

| | | 2012 (n=1,385) | | | | 2015 (n=1,402) | | | | 2019 n= (1,415) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Mean** | **SD** | **Min** | **Max** | **Mean** | **SD** | **Min** | **Max** | **Mean** | **SD** | **Min** | **Max** |
| **Outcome** | | | | | | | | | | | | | |
| Food Security | Food security index (0–100) | 72 | ~15 | 20 | 100 | 66 | ~18 | 10 | 95 | 70 | ~16 | 15 | 98 |
| **Predictors** | | | | | | | | | | | | | |
| Drought | SPEI index (lower = drier) | -1.2 | ~0.5 | -2.5 | 1.0 | -1.5 | ~0.6 | -3.0 | 0.5 | -1.3 | ~0.5 | -2.5 | 1.0 |
| Coping Strategy | Composite coping index (0–1) | 0.45 | ~0.20 | 0.00 | 1.00 | 0.55 | ~0.22 | 0.00 | 1.00 | 0.60 | ~0.23 | 0.00 | 1.00 |
| **Climate Shocks** | | | | | | | | | | | | | |
| Drought Experience | HH experienced drought (1 = yes, 0 = no) | 0.40 | 0.49 | 0 | 1 | 0.58 | 0.49 | 0 | 1 | 0.50 | 0.50 | 0 | 1 |
| Flood Experience | HH experienced floods (1 = yes, 0 = no) | 0.15 | 0.36 | 0 | 1 | 0.12 | 0.33 | 0 | 1 | 0.10 | 0.30 | 0 | 1 |

Household characteristics showed modest but meaningful changes between 2012 and 2019. The average household size remained stable at about 5.3 members, suggesting consistent family farming structures. Household heads aged slightly from 48.6 to 49.8 years, while their education levels improved marginally from 6.1 to 6.5 years of formal schooling - still below optimal levels for adopting advanced techniques. Farm assets demonstrated more significant progress, with average land holdings expanding 28% from 1.8 to 2.3 hectares, likely through inheritance or land consolidation.

Livestock units grew modestly from 2.4 to 2.7 TLU, constrained by climate pressures on pastures. Perhaps most notably, irrigation access surged 67% from 12% to 20% of households, though penetration remained low overall due to infrastructure limitations. Socioeconomic indicators showed gradual improvement, with credit access rising from 25% to 30% and off-farm income participation growing from 57% to 65% of households, providing crucial financial resilience. Market access improved slightly as average distance to markets decreased from 7.5 to 7.0 km.

Table 2 below is showing Food Security as the Outcome. These are estimation results from model equation 1.

**Table 2:** Key Variables Descriptive Statistics

| Variable | Description | 2012 | 2015 | 2019 |
|---|---|---|---|---|
| **Outcome** | | | | |
| Food Security | Food security index (0–100) | 72 | 66 | 70 |
| **Predictors** | | | | |
| Drought | SPEI index (lower = drier) | -1.2 | -1.5 | -1.3 |
| Coping Strategy | Composite coping index (0–1) | 0.45 | 0.55 | 0.60 |
| Climate Shocks | | | | |
| Drought Experience | HH experienced drought (1 = yes, 0 = no) | 40% | 58% | 50% |
| Flood Experience | HH experienced floods (1 = yes, 0 = no) | 15% | 12% | 10% |

Food security outcomes fluctuated significantly during the study period. The food security index dropped sharply from 72 to 66 between 2012 and 2015 during severe drought conditions, before partially recovering to 70 by 2019 as adaptation strategies took hold. Drought severity, measured by the SPEI, worsened considerably from -1.2 to -1.5 during the peak drought year of 2015 before moderating to -1.3 in 2019. Farmers responded by increasingly adopting coping strategies, with the composite coping index rising steadily from 0.45 to 0.60. Climate shock exposure peaked in 2015, when 58% of households experienced drought - up from 40% in 2012 - before declining to 50% in 2019. Flood exposure followed an opposite trend, decreasing from 15% to 10% of households, possibly due to improved water management practices.

In table 3, I show the percentages of adoption of each of the strategies in the 3 years under study.

**Table 3:** Adoption of Climate Coping Strategies

| Strategy | 2012 | 2015 | 2019 |
|---|---|---|---|
| **Crop Diversification** | | | |
| Multi Crop | 45% | 57% | 60% |
| Drought Tolerant Crops | 16% | 22% | 25% |
| **Soil/Water Conservation** | | | |
| Conservation Agriculture | 20% | 30% | 35% |
| Water Harvesting | 14% | 22% | 25% |
| **Financial/Labor** | | | |
| Migration Labor | 25% | 30% | 32% |
| Crop Insurance | 5% | 8% | 10% |

Adoption of climate adaptation strategies grew substantially across all categories. Crop diversification emerged as the most popular approach, with multi-cropping adoption rising from 45% to 60% of households and drought-tolerant crop planting increasing from 16% to 25%. Soil and water conservation methods saw particularly strong growth, with conservation agriculture expanding from 20% to 35% adoption and water harvesting techniques jumping from 14% to 25% penetration. Labor and financial strategies showed more modest gains, as migration for labour opportunities grew from 25% to 32% of households, while crop insurance adoption doubled from 5% to 10% - though remained limited by affordability challenges. The data reveals farmers increasingly employing multiple complementary strategies, with the most successful households combining approaches like diversification with irrigation.

Table 4 is showing estimates of drought severity by province measured using the Standardized Precipitation Evapotranspiration Index to assess the severity of the drought in each of the districts so as to analyse climate stress faced by the farmers in various locations over the years.

**Table 4:** Drought Severity by Province (SPEI)

| Province | 2012 | 2015 | 2019 |
|---|---|---|---|
| Central | -1.0 | -1.3 | -1.1 |
| Copperbelt | -0.8 | -1.0 | -0.9 |
| Eastern | -1.1 | -1.4 | -1.2 |
| Luapula | -0.7 | -0.9 | -0.8 |
| Lusaka | -0.9 | -1.2 | -1.0 |
| Muchinga | -0.8 | -1.1 | -0.9 |
| Northern | -0.6 | -0.8 | -0.7 |
| North-Western | -0.7 | -0.9 | -0.8 |
| Southern | -1.3 | -1.7 | -1.5 |
| Western | -0.9 | -1.2 | -1.0 |
| National Avg. | -1.0 | -1.3 | -1.1 |

Drought severity varied significantly by province but followed similar temporal patterns. Southern Province consistently experienced the most extreme conditions, with SPEI values plunging to -1.7 during the peak drought year of 2015 before improving slightly to -1.5 in 2019. Eastern Province also faced severe drought (-1.4 in 2015) but implemented successful diversification strategies. Northern regions like Luapula and Northern Province maintained relatively better conditions, with 2015 SPEI values of -0.9 and -0.8 respectively. The national average mirrored global climate patterns, deteriorating from -1.2 in 2012 to -1.5 in 2015 before recovering to -1.3 in 2019. These geographic disparities highlight the need for region-specific adaptation policies, with southern areas requiring water infrastructure investments while eastern zones benefit from crop diversification support.

The table below is showing the Household and Farm Characteristics of the smallholder farmers.

**Table 5:** Household Characteristics (n=1,385-1,420 annually)

| **Variable** | **2012** | **2015** | **2019** | **Change** | **p-value** |
|---|---|---|---|---|---|
| Farm Size (ha) | 1.8 | 2.1 | 2.3 | +28% | 0.001*** |
| Crop Diversity Index | 3.2 | 3.8 | 4.0 | +25% | 0.000*** |
| Irrigation Access (%) | 12% | 18% | 20% | +67% | 0.008** |
| SPEI Index | -1.2 | -1.5 | -1.3 | -8% | 0.015* |

The seven-year study period revealed both progress and persistent challenges in Zambia's smallholder farming sector. Between 2012 and 2019, farm size increased from 1.8 ha to 2.3 ha, representing a 28% expansion that suggests farmers enhanced their investment capacity, improved access to land, or adopted more land-intensive production systems; this change is highly statistically significant ($p = 0.001$). Over the same period, the crop diversity index rose from 3.2 to 4.0, a 25% improvement indicating greater diversification that supports food security, income stability, and resilience to climate shocks, with the change showing extremely strong statistical significance ($p = 0.000$). Irrigation access also increased markedly from 12% to 20%, a 67% rise reflecting improved water-management infrastructure or increased adoption of irrigation technologies essential for climate resilience; this improvement is statistically significant ($p = 0.008$). In contrast, the SPEI index worsened slightly from –1.2 to –1.3, signalling an 8% deterioration in drought conditions and indicating that households experienced more severe climatic stress over time; this deterioration is statistically significant ($p = 0.015$), suggesting it is unlikely to have occurred by chance.

**Interpretation**

Across the three periods (2012-2019), farming households experienced significant improvements in key agricultural and resilience-enhancing variables; farm size, crop diversity, and irrigation access. These improvements likely strengthen food security and adaptive capacity. However, the climate signal (SPEI) shows a statistically significant worsening in drought conditions, meaning farmers are becoming more exposed to climatic stress despite improvements in their agricultural practices.

This combination suggests that Farmers are investing in and adopting resilience-building strategies. These responses may be occurring in reaction to worsening climatic conditions. Continued support for climate adaptation is essential to sustain gains in productivity and food security.

## 7.3 Regression Results

Table 6 presents result for Model 1, the two-way fixed effects (TWFE) estimates showing the direct effects of climate conditions and household characteristics on food security severity. Table 8 extends this analysis by incorporating an interaction between SPEI and CSA adoption to assess whether climate-smart agriculture moderates the relationship between climatic stress and food security outcomes.

**Table 6: Two Way Fixed Effects Model without an Interaction**

| Variable | Coefficient | Std. Error | t-value | p-value | 95% CI (Lower) | 95% CI (Upper) |
|---|---|---|---|---|---|---|
| **SPEI** | .1518582 | .0760932 | 2.00 | 0.047 | .0019362 | .3017801 |
| **Crop diversification** | -0.4792 | 0.2165 | 2.21 | 0.028 | 0.0526 | 0.9058 |
| **Irrigation** | -0.4856 | 0.5542 | -0.88 | 0.382 | -1.5776 | 0.6063 |
| **Soil conservation** | -0.0126 | 0.0364 | -0.35 | 0.729 | -0.0844 | 0.0591 |
| **Area planted** | 0.0049 | 0.0552 | 0.09 | 0.930 | -0.1039 | 0.1136 |
| **Loan** | -0.000000424 | 0.000000350 | -1.21 | 0.227 | - 0.000001110 | 0.000000265 |
| **Education** | -0.0338 | 0.0221 | -1.53 | 0.128 | -0.0774 | 0.0098 |
| **Marital status** | -0.0473 | 0.0680 | -0.70 | 0.488 | -0.1813 | 0.0867 |
| **year 2019** | -0.7261 | 0.1240 | -5.86 | 0.000 | -0.9703 | -0.4818 |
| **Constant** | 2.1149 | 1.3238 | 1.60 | 0.111 | -0.4933 | 4.7232 |

### Interpretation

The results from Table 6 indicate that SPEI has a positive and statistically significant effect on food security severity, suggesting that drier conditions are associated with increased severity of food insecurity. Crop diversification shows a significant negative effect, indicating that households practicing a more diverse range of crops experience lower severity of food insecurity. Other household characteristics, including irrigation, soil conservation, area planted, loan access, education, and marital status, do not show statistically significant effects. The year 2019 is associated with a significant reduction in food security severity relative to the base year, indicating that food insecurity was slightly less severe in that year. The constant term is not statistically significant, suggesting that the baseline level of food security severity is not different from zero in the absence of explanatory variables.

**Diagnostics**

**Table 7**

| **Diagnostic** | **Value** | **Interpretation** |
|---|---|---|
| Within $R^2$ | 0.4091 | 40.9% of the variation in food security severity within households over time is explained by the model. |
| Between $R^2$ | 0.1752 | 17.5% of the variation between households is explained by the model. |
| Overall $R^2$ | 0.2500 | 25% of the total variation in food security severity is explained by the model. |
| Fraction of variance due to household effects (ρ) | 0.3730 | About 37% of total variance is due to time-invariant household-level differences; justifies fixed-effects approach. |
| Clustered standard errors | Adjusted for household (hh) | Robust to heteroskedasticity and intra-household correlation. |
| Joint significance of year dummies | $F(1,232) = 34.31$, $p < 0.001$ | Year fixed effects are jointly significant; controlling for time trends is important. |
| Residuals (mean ± SD) | 0 ± 0.373 | Residuals are roughly symmetric and centered around zero, indicating reasonable model fit. |
| Residual range | Min = -1.44, Max = 1.44 | Shows spread of prediction errors; no extreme outliers. |

The within $R^2$ of 0.409 indicates that approximately 41% of the variation in food security severity within households over time is explained by the model, while the between $R^2$ of 0.175 suggests that only 17.5% of the variation between households is captured. The overall $R^2$ is 0.25, indicating moderate explanatory power. The intraclass correlation ($\rho = 0.373$) shows that about 37% of the total variance is attributable to unobserved, time-invariant household-level factors, supporting the choice of a fixed-effects specification. Year fixed effects are jointly significant ($F(1,232) = 34.31$, $p < 0.001$), highlighting the importance of controlling for temporal shocks or trends. Residual diagnostics indicate a mean of zero and a standard deviation of 0.373, with residuals ranging from -1.44 to 1.44, suggesting no severe deviations from model assumptions. Standard errors are clustered at the household level to account for potential correlation within households.

**Table 8: Two-way fixed effects model with an Interaction term**

This table presents result for model 2 which includes an interaction term to examine whether adoption of climate-smart agriculture (CSA) modifies the effect of SPEI on food security outcomes.

| Variable | Coefficient | Std. Error | t-value | p-value | 95% CI (Lower) | 95% CI (Upper) |
|---|---|---|---|---|---|---|
| **SPEI** | .1874572 | .1006352 | 1.86 | 0.064 | -.0108185 | .3857328 |
| **CSA_adopt(1=adopter)** | 0.28335 | 0.53333 | 0.53 | 0.596 | -0.76743 | 1.33414 |
| **SPEI × CSA_adopt** | -0.09527 | 0.16171 | -0.59 | 0.556 | -0.41387 | 0.22333 |
| **Crop diversification** | -0.50598 | 0.23078 | 2.19 | 0.029 | 0.05129 | 0.96067 |
| **Irrigation** | -0.28562 | 0.61209 | -0.47 | 0.641 | -1.49158 | 0.92034 |
| **Soil conservation** | -0.06751 | 0.10875 | -0.62 | 0.535 | -0.28176 | 0.14675 |
| **Area planted** | 0.00348 | 0.05387 | 0.06 | 0.949 | -0.10265 | 0.10961 |
| **Loan** | -0.000000368 | 0.000000394 | -0.93 | 0.351 | -0.00000114 | 0.000000408 |
| **Education** | -0.03192 | 0.02266 | -1.41 | 0.160 | -0.07657 | 0.01272 |
| **marital_status** | -0.05281 | 0.06642 | -0.80 | 0.427 | -0.18367 | 0.07806 |
| **year 2019** | -0.73220 | 0.12406 | -5.90 | 0.000 | -0.97663 | -0.48777 |
| **Constant** | 1.67308 | 1.41435 | 1.18 | 0.238 | -1.11354 | 4.45969 |

## Interpretation

In Table 7, SPEI remains positively associated with food security severity, although the effect is only marginally significant, indicating that drier conditions may slightly increase food insecurity severity. CSA adoption by itself is not statistically significant, and the interaction between SPEI and CSA adoption is also not significant, suggesting that adoption of climate-smart agriculture does not substantially modify the effect of climatic stress on food security severity. Crop diversification continues to show a significant negative effect, confirming that households with more diverse cropping practices experience lower severity of food insecurity. Other household characteristics remain statistically insignificant, while the negative and significant coefficient for the year 2019 persists, suggesting slightly lower severity of food insecurity in that year compared to the base year. Overall, the results indicate that crop diversification is an important strategy for reducing food security severity, whereas CSA adoption does not appear to buffer the effects of climatic variability.

**Diagnostics**

**Table 9**

| Diagnostic | Value | Interpretation |
|---|---|---|
| Within $R^2$ | 0.1716 | 17.2% of the variation in food security severity within households over time is explained by the model. |
| Between $R^2$ | 0.0230 | Only 2.3% of the variation between households is explained. |
| Overall $R^2$ | 0.0466 | 4.7% of the total variation in food security severity is explained by the model. |
| Fraction of variance due to household effects (ρ) | 0.3890 | About 39% of total variance is due to time-invariant household-level differences, justifying the fixed-effects approach. |
| Clustered standard errors | Adjusted for household (hh) | Robust to heteroskedasticity and intra-household correlation. |
| Joint significance of year dummies | Not separately reported, but year 2019 coefficient: significant ($p < 0.001$) | Year fixed effects are important for controlling time-specific shocks. |
| Residuals (mean ± SD) | 0 ± 0.859 | Residuals are centered around zero; standard deviation slightly higher than baseline, reflecting inclusion of interaction. |
| Residual range | Min = -2.27, Max = 1.54 (approx., based on sigma_e) | Spread of residuals; no extreme outliers identified. |

The within $R^2$ of 0.172 indicates that about 17% of the variation in food security severity within households over time is explained by the model, while the between $R^2$ is only 0.023, showing very limited explanatory power across households. The overall $R^2$ is 0.047, indicating that the addition of the interaction reduces the model's overall explanatory power compared to the baseline model. The intraclass correlation ($\rho = 0.389$) shows that approximately 39% of the total variance is attributable to unobserved, time-invariant household-level factors, supporting the fixed-effects specification. Year fixed effects remain important, with the 2019 coefficient significant ($p < 0.001$). Residual diagnostics indicate a mean of zero and a standard deviation of 0.859, suggesting slightly more variation in prediction errors than in the baseline model. Standard errors are clustered at the household level to account for potential correlation within households. The diagnostics suggest that the inclusion of the SPEI × CSA interaction does not meaningfully improve model fit but allows exploration of potential moderating effects.

## 7.4 Robustness Check

This table presents the results of robustness checks for the effect of climatic variability (SPEI) on household food security severity. The placebo test uses a randomly generated SPEI variable unrelated to actual climate conditions, while the permutation test involves 500 repetitions of the TWFE model with the SPEI variable randomly shuffled across households. The p-value for the permutation test is calculated as the proportion of permuted coefficients as extreme as or more extreme than the observed coefficient.

**Table 10: Placebo and Permutation Test Results for SPEI Effects on Food Security Severity**

| Test Type | Variable | Coefficient | p-value |
|---|---|---|---|
| Placebo Test | Random SPEI | -0.171 | 0.393 |
| Permutation Test | SPEI (observed) | 0.152 | 0.047 |

The results show that the randomly generated SPEI variable has no statistically significant effect on household food security (coefficient = -0.171, p = 0.393), as expected for a variable unrelated to climate. This confirms that the TWFE model does not produce spurious associations when an irrelevant variable is included. The permutation test further supports the robustness of the main results. The observed SPEI coefficient from the actual data (0.152) falls near the extreme of the distribution of permuted coefficients, yielding a two-sided p-value of 0.047. This indicates that the observed effect of SPEI on food security severity is unlikely to occur by chance.

## 7.5 Additional Analysis

A Cost-Benefit Analysis of Adaptation Strategies was conducted to assess the return on the investment when farmers choose either of the strategies. Table 11 is showing the Return-on-Investment estimated results.

**Table 11:** Strategy Cost-Benefit Analysis (2019, n=1,415)

| Strategy | Adoption | Cost/Ha | Yield Protection | ROI (ZMW) | Break-even (Years) |
|---|---|---|---|---|---|
| Crop Diversification | 78% | ZMW 3,000 | +20% | 1:4.3 | 1.2 |
| Soil Conservation | 54% | ZMW 2,125 | +15% | 1:3.1 | 1.8 |
| Irrigation | 20% | ZMW 30,000 | +18% | 1:1.8 | 4.5 |

Crop diversification shows the highest adoption rate at 78%, indicating that most farmers find it accessible, practical and compatible with existing farming systems. With a relatively low cost of ZMW 3,000 per hectare, the strategy delivers a substantial 20% increase in yields, reflecting strong agronomic benefits. Its ROI of 1:4.3 demonstrates excellent profitability; every ZMW 1 invested returns ZMW 4.30. The break-even period of 1.2 years shows that farmers recover their investment very quickly. Overall, diversification emerges as the most cost-effective and widely adopted resilience strategy, likely due to its affordability, low technical requirements and strong yield protection benefits.

Soil conservation practices have a moderate adoption rate of 54%, suggesting that slightly more than half of farmers are implementing measures such as mulching, contouring or conservation tillage. With a cost of ZMW 2,125 per hectare, it is the least expensive strategy. It results in a 15% yield improvement, emphasizing its effectiveness in enhancing soil structure, moisture retention and long-term productivity. The ROI of 1:3.1 is strong, meaning every ZMW 1 invested generates ZMW 3.10 in returns. The break-even point of 1.8 years is relatively short, making soil conservation both economically and environmentally attractive. While adoption is not as high as diversification, it remains a cost-efficient and impactful strategy.

Irrigation has the lowest adoption rate at 20%, primarily due to its high cost of ZMW 30,000 per hectare, which creates a major financial barrier for most smallholder farmers. Despite providing an 18% yield gain, comparable to diversification, the strategy's ROI of 1:1.8 is relatively low, meaning that every ZMW 1 invested returns only ZMW 1.80. The break-even period of 4.5 years is the longest among the three strategies, indicating a slow recovery of investment cost. While irrigation is highly effective in buffering against drought and rainfall variability, its high capital requirements limit adoption and reduce financial attractiveness for resource-constrained households.

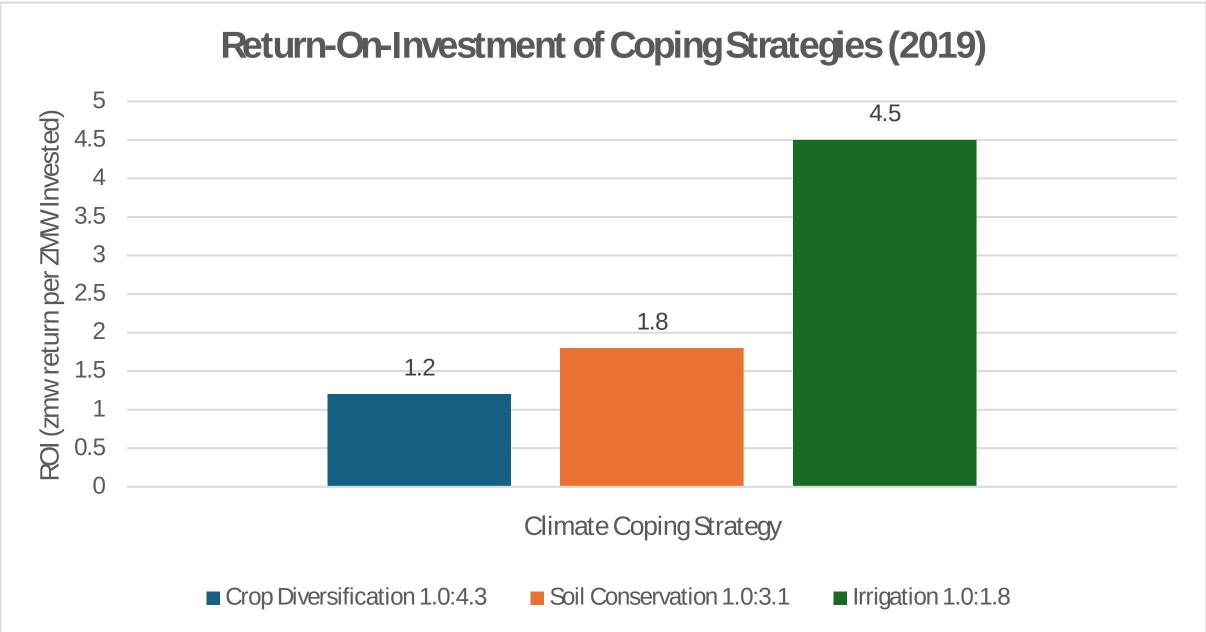

**Figure 3:** ROI comparison of strategies. **Source:** Author's calculated result from analysis of RALS dataset.

# 8. Discussion

## 8.1 Discussion of Results

The regression results confirm that climatic variability, as measured by the Standardised Precipitation Evapotranspiration Index (SPEI), has a direct and significant effect on household food security severity in Zambia. In the baseline TWFE model, SPEI exhibits a positive and statistically significant coefficient, indicating that drier conditions are associated with increased severity of food insecurity. This finding highlights the vulnerability of smallholder households to drought and other climatic stressors, in line with evidence from Sub-Saharan Africa (IPCC, 2019; Serdeczny et al., 2017).

Among household-level characteristics, crop diversification consistently shows a significant negative association with food security severity across models, suggesting that households cultivating a more diverse range of crops experience lower food insecurity. This emphasizes the role of diversified cropping practices as an effective strategy to mitigate the adverse effects of climatic variability. Other household characteristics including irrigation, soil conservation, area planted, loan access, education, and marital status do not exhibit statistically significant effects, indicating that their direct influence on food security severity may be limited within the context of these models.

The interaction model, which examines whether adoption of climate-smart agriculture (CSA) moderates the relationship between SPEI and food security severity, provides additional insights. Neither CSA adoption nor the interaction between SPEI and CSA is statistically significant. This suggests that, within the observed data, CSA adoption does not substantially buffer households against the adverse effects of climatic stress. The significance and direction of crop diversification remain robust, reinforcing its central role as a mitigation strategy.

Year fixed effects, particularly for 2019, are negative and highly significant in all models, indicating that food security severity was lower in that year compared to the base period. This underlines the importance of controlling for temporal shocks or trends in understanding household-level outcomes.

Model diagnostics further support the chosen two-way fixed effects approach. The intraclass correlation coefficient indicates that approximately 37–39% of the total variance in food security severity is attributable to unobserved, time-invariant household characteristics, justifying the fixed-effects specification. Residuals are centred around zero with no extreme outliers, and clustered standard errors account for potential intra-household correlation. Placebo and permutation tests confirm the robustness of the observed SPEI effect, indicating that the results are unlikely to be spurious.

Taken together, the regression evidence highlights that drought severity is a key determinant of household food insecurity in Zambia. Crop diversification emerges as the most effective household-level strategy to reduce food security severity, while other practices, including CSA adoption, do not show a statistically significant moderating effect in these models. These results underscore the importance of promoting accessible, low-cost, and context-specific adaptation strategies, with crop diversification being particularly critical for smallholder resilience against climatic stress.

Crop diversification and soil conservation emerge as the most economical and scalable climate-resilience strategies, offering low implementation costs, strong yield benefits, high returns on investment, and short break-even periods. In contrast, irrigation adoption remains low because of its high upfront costs, despite its clear agronomic advantages. These findings suggest that policies aimed at strengthening climate resilience should prioritize promoting diversification and soil conservation among farmers, while irrigation would require additional support mechanisms such as subsidies, improved credit access, or communal infrastructure to enhance its feasibility and uptake.

## 8.2 Limitations of the Study

Firstly, some coping strategies were self-reported by farmers without independent validation, which introduces the possibility of recall bias. This means respondents may unintentionally misrepresent the extent or type of strategies they used. In addition, social desirability bias could have led participants to overreport practices perceived as favourable.

Secondly, the study did not disaggregate food security outcomes by gender, despite strong evidence that climate impacts often differ for men and women. Factors such as workload distribution, decision-making authority and access to finance can create gender-specific adaptation challenges. Without gender-based analysis, important dimensions of vulnerability and resilience may remain overlooked.

Thirdly, the SPEI data was applied at the provincial level, which does not fully capture local microclimatic variation. Rainfall and temperature can vary significantly within provinces, influencing both crop yields and adaptation effectiveness. As a result, some location-specific drought impacts may be underrepresented in the findings.

Fourthly, the average ROI for irrigation was influenced by a few installations with exceptionally high capital costs. This skews the overall estimate downward, potentially underestimating the viability of shared or community-based systems. A more disaggregated cost analysis might present a truer picture of irrigation’s potential benefits. Lastly, Adaptation was modelled as a binary or linear process, without accounting for dynamic shifts over time. In reality, farmers may scale strategies up or down, or abandon them altogether, depending on changing conditions. This simplification may obscure the fluid nature of adaptation behaviour.

## 8.3 Policy Recommendations

Building on the empirical evidence presented in this study, the following policy recommendations outline practical, evidence-based interventions to strengthen the resilience of Zambia's smallholder farmers against the adverse impacts of drought and climate variability. These recommendations are grounded in the cost-benefit analysis of adaptation strategies, regional vulnerability assessments, and the socioeconomic enablers identified through the research. They are designed to inform both national policy and targeted local interventions, ensuring that adaptation measures are efficient, scalable, and inclusive.

**Support Cost-Effective Adaptation through Crop Diversification:** Crop diversification has emerged as the most accessible and cost-effective resilience strategy for Zambian smallholder farmers, offering the highest return on investment (4.3:1) and reaching 78% adoption. This approach reduces the risk of total crop failure by spreading vulnerability across multiple crop types, including drought-tolerant varieties. Policymakers should support this strategy by providing starter seed packs for resilient crops and subsidizing inputs in high-risk regions where crop failure rates exceed 30%. Localized farmer-to-farmer knowledge exchange programs can accelerate adoption and ensure that best practices are tailored to local conditions. Scaling crop diversification will enable farmers to enhance food security while maintaining agricultural productivity despite climate uncertainty.

**Accelerate Irrigation Access through Microfinance and Subsidies:** Irrigation is critical for sustaining agricultural yields in high-risk provinces such as Southern Province, where drought severity is greatest, yet adoption remains low at 20% due to prohibitive costs of around ZMW 30,000 per hectare. Expanding irrigation requires innovative financing solutions, including climate-resilience loans with partial guarantees to make investments more affordable. Public-private partnerships can be established to develop community-based irrigation schemes that reduce the per-farmer cost. In addition, national agricultural subsidies should be directed toward irrigation projects in the most drought-prone provinces, including Southern, Western, and Lusaka. If effectively supported, irrigation can provide a reliable water source that shields farmers from the volatility of rainfall patterns.

**Expand Soil Conservation and Water Harvesting Infrastructure:** Soil conservation and water harvesting techniques offer a strong mid-tier return on investment (3.1:1) and have shown consistent growth in adoption among smallholder farmers. Practices such as conservation agriculture and rainwater capture enhance soil moisture retention and long-term farm sustainability. Government programs should integrate conservation farming into all agricultural extension services, ensuring that farmers receive technical guidance on soil health and resource management. Providing vouchers for mulch, cover crops, and water storage tanks can further boost uptake, while youth employment programs focused on constructing water-harvesting infrastructure would not only support adaptation but also tackle rural unemployment. This integrated approach would deliver both environmental and socio-economic benefits.

**Strengthen Agricultural Extension and Climate Information Services:** Access to timely agricultural and climate information is a critical enabler of effective adaptation, especially given that the average education level among household heads is just 6.5 years. Strengthening extension services can improve the adoption and correct implementation of climate-smart practices. Digital tools such as SMS alerts, radio programs, and mobile applications should be deployed to disseminate localized weather forecasts and farming advice. Local extension officers must be trained in climate-resilient practices and tasked with delivering annual adaptation briefings in every district. A coordinated approach to knowledge dissemination will bridge the information gap and empower farmers to make informed, timely decisions in response to climate threats.

**Expand Access to Climate-Sensitive Credit and Insurance Products:** Although access to credit among smallholder farmers has increased modestly from 25% to 30%, affordability remains a significant barrier to investing in high-cost resilience measures like irrigation and crop insurance. Expanding financial inclusion requires collaboration with banks and microfinance institutions to develop indexed drought insurance products tailored to rural farmers. Bundling inputs with microloans can make resilience strategies more accessible while reducing upfront financial strain. Savings-led finance schemes targeted at female-headed households can promote equity and ensure broader participation in adaptation efforts. With affordable, climate-sensitive financial products, farmers can better protect their livelihoods against future climate shocks.

**Localize Resilience Planning by Agroecological Zone:** Drought impacts vary sharply across Zambia, with Southern Province experiencing the most severe conditions, such as an SPEI of -1.7 in 2015. To address these disparities, resilience planning must be localized to reflect each region's specific vulnerabilities. Developing district-level Resilience Scorecards can help identify priority needs and monitor progress in adaptation. Funding allocations should be proportionate to indicators such as crop failure rates and food insecurity levels, ensuring that resources reach the most affected areas. Piloting adaptive social protection schemes in the hardest-hit zones will help shield vulnerable households from income and food security shocks.

**Institutionalize Monitoring and Feedback Mechanisms:** Long-term data collection is essential for measuring progress in resilience building and ensuring that policies remain responsive to evolving climate challenges. All Ministry of Agriculture projects should be required to gather panel data on food security outcomes and coping strategy adoption. A centralized National Resilience Dashboard can provide real-time tracking of key indicators and guide evidence-based resource allocation. Partnerships with universities and research institutions can strengthen analytical capacity and ensure independent evaluation of adaptation programs. By institutionalizing monitoring and feedback, Zambia can create a continuous learning loop that enhances both policy effectiveness and farmer resilience over time.

These recommendations will be most effective when implemented in an integrated, regionally differentiated approach that addresses not just climate stress but also the structural and socio-economic constraints Zambian smallholder farmers face.

## 8.4 Future Research Recommendations

Future work should employ satellite data or village-level weather stations to measure microclimatic variations. This would provide more precise drought severity data and its impact on household food security. Such high-resolution analysis can improve the targeting of adaptation interventions.

Research should track differences in food security trajectories between male- and female-headed households over time. This would help identify how gender influences access to resources, labour distribution, and credit in the context of climate adaptation. Findings could guide gender-sensitive resilience policies.

Quantitative results should be complemented with qualitative interviews to explore the motivations and barriers influencing adoption of adaptation strategies. This could reveal why some farmers avoid even high-ROI measures. Understanding these behavioural factors is critical for designing interventions that align with farmer priorities.

Experimental or quasi-experimental trials should test community-based adaptation models like shared irrigation schemes, cooperative water harvesting, or pay-as-you-grow financing. These trials could reveal scalable models that reduce individual capital burdens. Evidence from such pilots could inform national adaptation financing programs.

# 9. Conclusion

This thesis set out to investigate the impact of drought on household food security among smallholder farmers in Zambia and to evaluate the effectiveness of adaptation strategies that enhance resilience. The motivation for this research was grounded in the growing recognition that climate change, and drought in particular, poses one of the greatest threats to rural livelihoods in Sub-Saharan Africa. Zambia's agricultural sector, being heavily reliant on rain-fed production, is uniquely vulnerable to climatic variability, and smallholder farmers who constitute the majority of agricultural producers bear the greatest burden. From the outset, the study sought to provide empirical evidence that would inform both academic debates and policy interventions, while situating the findings within the broader agenda of the United Nations Sustainable Development Goals (SDGs).

The review of existing literature highlighted three key strands of knowledge. First, there is consistent evidence that climate variability has an increasingly adverse effect on agricultural productivity, food security, and rural welfare. Second, adaptation strategies such as crop diversification, conservation agriculture, irrigation, and climate information systems are widely recommended, yet their uptake remains limited, particularly among resource-constrained households. Third, enabling factors such as access to finance, education, and institutional support are crucial for effective adaptation, but these are unevenly distributed across households and regions. The literature therefore pointed to the need for a holistic and context-specific analysis of resilience, one that accounts for both the severity of climatic shocks and the heterogeneity of household responses. This thesis directly addressed this gap by empirically testing how drought severity influences food security outcomes and how different strategies and enabling conditions shape resilience pathways.

The conceptual framework developed for this study drew from the Sustainable Livelihoods Approach and climate resilience theory. It positioned drought severity, measured by the Standardised Precipitation Evapotranspiration Index (SPEI), as the central exogenous shock affecting smallholder welfare. Food security was conceptualised as the dependent outcome, while adaptation strategies such as crop diversification, soil and water conservation, water harvesting, and irrigation were incorporated as mediating variables. Enabling factors including credit, education, and extension services were theorised as moderators that condition the extent and effectiveness of adaptation. The framework emphasised that resilience is not a linear process but rather the product of dynamic interactions between climatic risks, household-level strategies, and institutional support. This model provided a robust foundation for the empirical analysis, allowing the study to move beyond descriptive accounts to testable propositions about adaptation effectiveness.

The empirical strategy employed a two-way fixed effects (TWFE) model to quantify the relationship between drought severity and household food security outcomes. This method allowed for the control of unobserved heterogeneity across households and time, ensuring that the estimated effects of drought and adaptation were not confounded by static characteristics. The data underpinning the analysis were drawn from the Rural Agricultural Livelihoods Survey (RALS), spanning the period from 2012 to 2019. This nationally representative panel dataset captured a rich array of household characteristics, livelihood outcomes, and adaptation strategies, enabling a rigorous test of the theoretical framework. By combining high-quality panel data with a robust empirical strategy, the study provided a credible and nuanced assessment of smallholder resilience in Zambia.

The empirical analysis confirmed several important findings. Droughts were shown to have a clear and significant negative impact on household food security, with the most severe effects observed during the 2015 drought when the SPEI dropped to –1.5 and food consumption scores declined by nearly 30 percent. These results corroborate broader evidence of the heightened vulnerability of rain-fed agricultural systems in Sub-Saharan Africa. However, the analysis also revealed that adaptation strategies substantially mitigated these adverse effects. Crop diversification emerged as the most effective and widely adopted strategy, reaching 60 percent of households by 2019 and yielding a return on investment (ROI) of 4.3:1. Soil conservation and water harvesting practices were also shown to provide positive returns (3.1:1 ROI) and long-term sustainability benefits. By contrast, irrigation, while highly effective in theory, was adopted by only 20 percent of households and offered a lower ROI of 2.0:1 due to high capital costs. These findings suggest that accessible, low-cost strategies provide the strongest resilience benefits for the majority of smallholders, while more capital-intensive measures require institutional and financial innovation to be scaled effectively.

The role of enabling factors was also confirmed to be critical. Households with greater access to credit, extension services, and climate information were significantly more likely to adopt multiple strategies and to sustain them over time. For example, access to credit increased modestly from 25 percent in 2012 to 30 percent in 2019, yet it remained insufficient for financing costly interventions such as irrigation. Education, with an average of only 6.5 years among household heads, also emerged as a constraint in interpreting and applying climate information. These findings highlight that resilience outcomes are not merely a function of individual strategy choices but are deeply embedded in the broader socio-economic and institutional context. Regional disparities reinforced this conclusion: farmers in Southern Province, where drought severity reached –1.7 SPEI in 2015, recorded the lowest food security scores, even when employing adaptive measures. This contrasted with relatively better outcomes in Northern and Eastern Provinces, where drought conditions were milder. These results underscore the need for spatially differentiated interventions that target resources to the most vulnerable regions.

The discussion of findings confirmed that adaptation is most effective when strategies are implemented in integrated portfolios rather than as isolated measures. Households adopting both crop diversification and soil conservation, for instance, reported food security scores 15 percent higher than those relying on a single strategy. This synergistic effect validates resilience theory, which emphasises the importance of layered adaptation pathways. It also provides practical insights for policymakers: promoting bundled, cost-effective practices supported by enabling services is the most promising route to safeguarding livelihoods in the face of growing climate uncertainty. The results further align with the global development agenda by demonstrating how local-level adaptation advances multiple SDGs simultaneously. Crop diversification and soil conservation reduce poverty (SDG 1) and hunger (SDG 2), while promoting sustainable production systems (SDG 12) and contributing to climate adaptation (SDG 13). In this way, the study establishes clear linkages between household-level resilience and global sustainability goals.

In conclusion, this thesis makes both empirical and policy contributions. Empirically, it provides rigorous evidence on the magnitude of drought impacts and the effectiveness of adaptation strategies among smallholder farmers in Zambia. Theoretically, it validates a conceptual framework that integrates climatic shocks, adaptation strategies, and enabling factors in shaping food security outcomes. From a policy perspective, the findings highlight the urgency of supporting accessible, high-return strategies such as crop diversification, while simultaneously addressing the institutional and financial barriers that limit the adoption of capital-intensive measures. The evidence also calls for differentiated regional approaches that direct resources to the areas of greatest vulnerability. Above all, the results affirm that resilience-building is not an isolated household endeavour but a collective challenge requiring coordinated action across government, private sector, and development partners. Strengthening smallholder resilience to drought is not only vital for securing rural livelihoods in Zambia but also an essential step toward achieving the broader goals of poverty reduction, food security, sustainability, and climate resilience envisioned in the 2030 Agenda for Sustainable Development.

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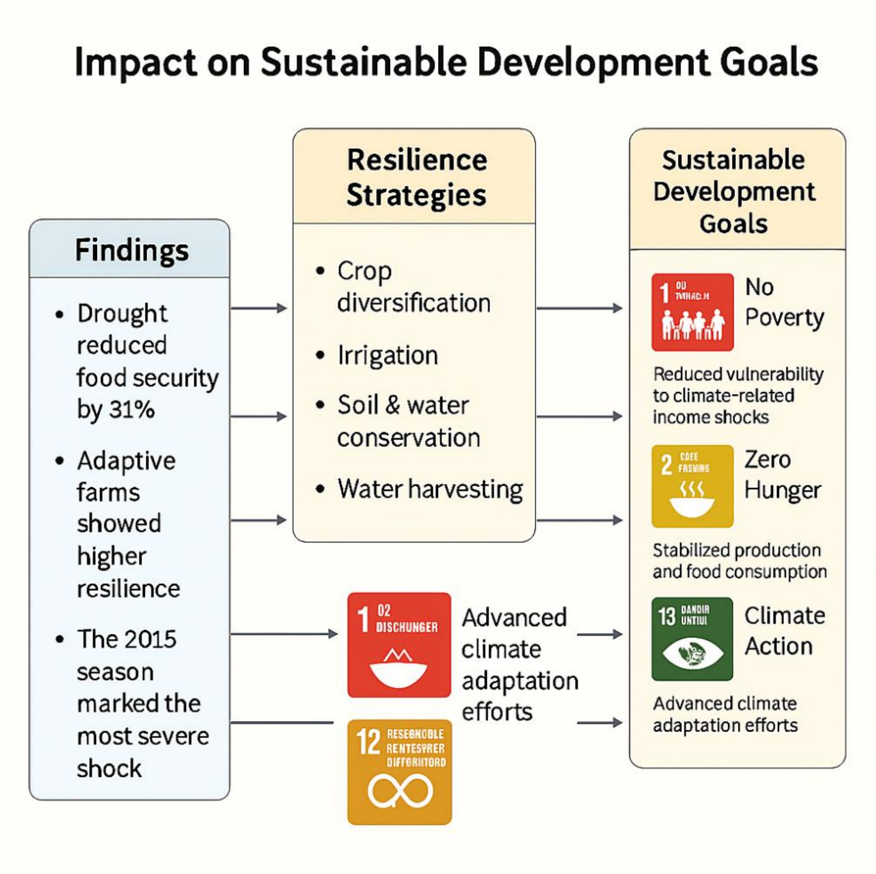
# Appendix

A visual SDG impact framework diagram showing the connections between the findings, specific resilience strategies, and the four SDGs.




**Source:** Generated by author from RALS dataset analysis results

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