SCIENTIA
AGRICULTURAE
BOHEMICA

Article

Perceptions of Drought and Its Effects on Livelihood Diversification among Smallholder Farmers in John Taolo Gaetsewe District Municipality, South Africa

Tlamelo MOEPENG[1], Ayodeji KEHINDE [1,2], Abiodun OGUNDEJI[2]

[1]Department of Agricultural Economics, Faculty of Agriculture, Obafemi Awolowo University, P.M.B. 13, Ile-Ife, Osun State, 220282, Nigeria; kehindeayodeji8@gmail.com;

[2] Disaster Management Training and Education Centre for Africa, Agriculture Building Bloemfontein Campus, University of the Free State, Nelson Mandela Road, Bloemfontein, 9300, South Africa; tlamelomoepeng@gmail.com; ogundejiaa@ufs.ac.za.

*Correspondence: kehindeayodeji8@gmail.com (Nigeria)

Abstract: Drought is a major climate-related threat to smallholder farmers in the arid and semi-arid regions of sub-Saharan Africa, yet localized empirical evidence on its livelihood impacts remains limited. This study examines farmers' perceptions of drought and its socio-economic effects on livelihood diversification in the John Taolo Gaetsewe District Municipality (JTGDM) of South Africa. Using cross-sectional data from 150 households, the analysis combines descriptive statistics and weighted mean scores with a Poisson regression model to assess how drought-related shocks and socio-demographic factors influence the number of income-generating activities per household. Results show that 84% of respondents identified drought as the most severe climatic hazard, with high perception scores for its links to food insecurity (mean = 4.23), malnutrition (mean = 4.12), and wildfire risk (mean = 4.83). Econometric findings indicate that water scarcity reduced livelihood diversification by 22.3% (IRR = 0.777, $p < 0.01$), crop failure by 12.9% (IRR = 0.871, $p < 0.01$), livestock loss by 6.5% (IRR = 0.935, $p < 0.01$), and fire risk by 20.8% (IRR = 0.792, $p < 0.01$). Female-headed households had 23.7% fewer livelihood activities than male-headed households (IRR = 0.763, $p < 0.01$), while education and age were positively associated with diversification ($p < 0.05$). By combining farmers' perceptions with count-data econometric analysis in an under-researched drought-prone district, this study provides context-specific insights into drought–livelihood dynamics. The findings highlight the need for adaptation policies that prioritize water infrastructure, gender-responsive support, and human capital development to strengthen smallholder resilience under increasing climatic stress.

Keywords: Drought, smallholder farmers, perception, vulnerability, climate adaptation, resilience, South Africa

Scientia Agriculturea Bohemica, 57, 2026 (3): 70, 1-35.

DOI: 10.7160/sab.2026.570341

Received for publication on September 04, 2025
Accepted for publication on April 04, 2026

1. Introduction

Drought, defined as a prolonged period of deficient rainfall relative to historical averages, is one of the most severe and complex natural hazards globally (IPCC, 2014). Unlike sudden disasters such as floods or hurricanes, drought develops gradually but causes long-lasting impacts on ecosystems, water resources, agriculture, and human livelihoods. Although commonly linked to arid and semi-arid regions, droughts are increasingly affecting humid and temperate areas due to climate change, land-use change, and deforestation (Ogunleye et al., 2021; Guneralp et al., 2015; Dai, 2011). Over recent decades, drought intensity, duration, and frequency have increased, disrupting food production systems, particularly in rain-fed agricultural regions (Goddard et al., 2003). The economic impacts are substantial. In the United States, average annual drought damages range from $6 to $8 billion, with the 2021 western drought causing over $9 billion in losses (EM-DAT, 2021; Kehinde et al., 2025). In Europe, drought damage has exceeded $100 billion over the past three decades (European Commission [EC], 2019), with countries such as Germany, Hungary, and Ukraine heavily affected (Toreti et al., 2022). The European Environmental Agency reports that the average annual impact of drought doubled between 1976–1990 and 1991–2016 (EEA, 2022). In Asia, recurrent droughts in Iraq, Syria, Iran, and Afghanistan have caused agricultural decline, displacement, and humanitarian crises (EM-DAT, 2021). These patterns show that drought is a global challenge affecting both developed and developing countries, with severe consequences for vulnerable populations.

In Africa, drought impacts are more severe due to high reliance on rain-fed agriculture and limited adaptive capacity. Recurrent droughts in Kenya, Ethiopia, Somalia, and Sudan have led to crop failure, livestock mortality, food insecurity, and occasional famine (UN-DESA, 2013; Hugo et al., 2021; Olugbenga et al., 2025). The Sahel droughts of the 1980s caused over 500,000 deaths and extensive degradation of pastures and water resources (Kellis, 2008; Traore et al., 2011). Between 2000 and 2011, North Africa experienced four major droughts that reduced livestock herds by more than 80% and pushed millions into poverty (UN-DESA, 2013). Some studies also link prolonged drought and water scarcity to socio-political unrest during the Arab Spring in Syria and parts of North Africa (Gleick, 2014; Kelley et al., 2015). Similar challenges occur in South Africa, where localized drought impacts remain under-researched (Jordaan et al., 2017). The John Taolo Gaetsewe District Municipality (JTGDM) in the Northern Cape has experienced major drought events in 1983–1984, 1991–1992, 2003–2004, and 2015–2019 (Applegreen et al., 2024). These droughts caused severe crop losses, water shortages, and livestock mortality, particularly affecting smallholder farmers who depend on rain-fed agriculture and have limited adaptive resources (World Food Programme [WFP], 2016). Drought has also intensified existing inequalities, especially in informal settlements, where low educational attainment, unemployment, and limited access to early warning systems increase vulnerability (Meza et al., 2021).

This study assesses smallholder farmers' perceptions of drought and examines its socio-economic impacts on livelihood activities in JTGDM. Farmers in this region are highly vulnerable due to dependence on rain-fed agriculture, limited resources, and repeated climatic shocks. The study aims to: (i) examine farmers' awareness and perceptions of drought and its drivers, including rainfall variability, soil degradation, and water scarcity; (ii) analyze adaptation strategies such as crop diversification, water management, and livelihood adjustments; and (iii) evaluate community resilience mechanisms, including social networks, cooperative practices, and local knowledge systems. Addressing these dimensions provides a comprehensive understanding of drought impacts and the strategies rural communities use to sustain resilience. The study adopts a mixed-methods approach combining household surveys with qualitative interviews and focus group discussions. This integration captures farmers' experiences while generating empirical data for policy and planning. Although perception-based drought studies exist, few focus on JTGDM, a region frequently exposed to severe drought yet underrepresented in climate vulnerability research. Moreover, studies using Poisson models to analyze climate vulnerability and livelihood diversification often emphasize quantitative outcomes while overlooking local perspectives. By integrating empirical analysis with farmers' experiential knowledge, this study offers new insights into how drought shapes rural livelihoods and how local adaptation strategies strengthen resilience. The findings contribute to broader debates on climate adaptation, disaster risk reduction, and sustainable rural development in drought-prone areas of Southern Africa (Sivakumar et al., 2014; Meza et al., 2021; Applegreen et al., 2024) and are expected to inform targeted interventions and policies that enhance adaptive capacity among smallholder communities facing recurrent drought.

The rest of this work is organized as follows. The following part discusses the literature review. Section three discusses the study area, data-gathering methods, and estimating procedures. Section four provides detailed explanations of the results. The conclusion and policy implications are addressed in the final section.

2. Literature review

Drought, a recurring climatic phenomenon, has received increasing scholarly attention due to its significant impacts on water resources, food systems, and rural livelihoods. Often described as a "creeping disaster" because of its slow onset and delayed recognition (Wilhite & Glantz, 1985), drought occurs in several forms—meteorological, agricultural, hydrological, and socio-economic—each affecting agricultural systems differently (Dai, 2011). Globally, the rising intensity and frequency of drought are closely linked to anthropogenic climate change, land degradation, and unsustainable water management (IPCC, 2014; Mishra & Singh, 2010). Sub-Saharan Africa, where agriculture largely depends on rainfall, is particularly vulnerable due to limited adaptive capacity, weak infrastructure, and restricted access to climate information (Niang et al., 2014). In this context, drought functions not only as an environmental stressor but also as a socio-economic driver that deepens poverty and inequality (Adger et al., 2003; Eriksen et al., 2005). Smallholder farmers are among the most vulnerable to drought impacts. Many operate in marginal agroecological zones with limited access to irrigation, credit, crop insurance, and extension services, which reduces their resilience to climate variability (Deressa et al., 2009; Morton, 2007). Drought reduces soil moisture, delays planting, increases crop failure, and leads to livestock mortality, undermining food security and household income (Lobell et al., 2008; Thornton et al., 2009). In South Africa, drought has disproportionately affected communal and small-scale farmers compared to commercial producers, largely due to differences in asset ownership, institutional support, and access to technology (Jordaan et al., 2017; Mpandeli et al., 2020). For example, the 2015–2019 El Niño-induced drought severely reduced agricultural production in the Northern Cape, Eastern Cape, and Free State provinces, contributing to higher food prices, unemployment, and rural migration (Meza et al., 2021; DAFF, 2016).

Farmers' perceptions of drought risk strongly influence their adaptation behavior. Evidence from Ethiopia, Kenya, and Nigeria shows that farmers' experiences—such as perceived rainfall decline, frequent crop failures, or rising temperatures—shape their willingness to adopt coping and adaptation strategies (Adeagbo et al., 2025; Tessema et al., 2013; Below et al., 2012; Mertz et al., 2009). These perceptions are influenced by socio-economic factors including education, age, gender, access to climate information, and participation in local organizations (Nhemachena & Hassan, 2007; Bryan et al., 2009). In South Africa, studies by Bahta et al. (2016) and Botai et al. (2017) show that many rural farmers recognize changes in climate patterns but often lack the institutional support needed to respond effectively. This highlights the importance of integrating local perceptions with scientific climate information when designing drought management strategies. Adaptation to drought typically involves both short-term coping measures and long-term resilience strategies. Short-term responses include migration, livestock sales, reduced food consumption, and reliance on social networks, while long-term strategies involve adopting drought-tolerant crops, conservation agriculture, water harvesting technologies, and livelihood diversification (Cooper et al., 2008; Thomas et al., 2007; Gbetibouo, 2009). However, the adoption of these strategies is often constrained by poverty, limited infrastructure, restricted access to credit, and weak extension systems (Asfaw et al., 2019; Smit & Wandel, 2006). In the Northern Cape, some farmers have adopted practices such as community grazing schemes, indigenous weather forecasting, and rotational water use, although the sustainability of these approaches remains uncertain without stronger institutional support (Applegreen et al., 2024).

Despite these insights, localized empirical studies on drought experiences remain limited, particularly in historically marginalized districts such as the John Taolo Gaetsewe District Municipality (JTGDM). Much of the existing research focuses on national or provincial trends or on major drought events in economically dominant provinces such as the Western Cape or Gauteng (WFP, 2016; DEA, 2017). As a result, there is limited understanding of how smallholder farmers in JTGDM perceive and respond to recurrent droughts. This gap restricts the development of context-specific adaptation policies and disaster risk reduction strategies. Moreover, widely used climate vulnerability indices often fail to capture the socio-cultural and economic realities of rural communities in arid and semi-arid South Africa (Ziervogel and Zermoglio, 2009). This study addresses this gap by providing an empirical, bottom-up analysis of drought impacts and responses among smallholder farmers in JTGDM. By combining qualitative narratives with quantitative analysis, it offers a comprehensive understanding of the lived experiences of drought in a region characterized by climatic vulnerability and socio-economic constraints. In doing so, the study contributes to broader discussions on climate adaptation, disaster risk reduction, and sustainable agricultural development in Africa, emphasizing the importance of community-based resilience strategies (Adger, 2006; FAO, 2021).

This study is guided by a conceptual framework that combines climate vulnerability and adaptation theories with the Sustainable Livelihoods Framework (SLF) to examine drought impacts on smallholder farmers in the John Taolo Gaetsewe District Municipality (JTGDM). The framework assumes that farmers' responses to drought are shaped by their exposure to climatic risks, their perceptions of these risks, and the resources and institutional support available for adaptation.

Drought is conceptualized as a multifaceted hazard characterized by prolonged rainfall deficits, high evapotranspiration, and declining soil moisture, which reduce crop productivity, threaten livestock, and deplete water resources (Wilhite & Glantz, 1985; IPCC, 2014). These effects are especially severe in arid and semi-arid areas such as JTGDM, where livelihoods depend heavily on rain-fed agriculture and water access is limited. Farmers' vulnerability is understood through three interrelated components: exposure, sensitivity, and adaptive capacity. Exposure denotes the extent to which households experience drought, sensitivity reflects the degree to which agricultural systems are affected, and adaptive capacity refers to the resources and strategies households can mobilize to cope and recover (Adger, 2006; Smit & Wandel, 2006). In JTGDM, limited financial capital, weak extension services, poor infrastructure, and inadequate institutional support increase sensitivity and constrain adaptive capacity (Bahta et al., 2016; Mpandeli et al., 2020).

Farmers' perceptions of drought and climate variability are central to the framework. Perceptions influence how risks are interpreted, prioritized, and addressed through adaptation strategies (Mertz et al., 2009; Bryan et al., 2009). For example, experience of prolonged dry seasons may prompt adoption of drought-tolerant crops or livelihood diversification. Perceptions are shaped by socio-demographic factors such as education, age, gender, farming experience, access to weather information, and prior drought exposure (Tesso et al., 2012; Gbetibouo, 2009). The SLF further informs the analysis by identifying five types of capital that shape adaptive capacity: natural (land, water), physical (tools, infrastructure), financial (income, savings), human (knowledge, labor), and social (networks, group membership) (DFID, 1999). Limited access to these assets in JTGDM constrains households' ability to implement adaptation strategies and recover from drought-related losses. Institutional and policies also shape resilience. Government interventions, such as social grants, drought relief programs, and agricultural support, can enhance adaptive capacity, while weak or inadequate institutions can exacerbate vulnerability (Cooper et al., 2008; Adger, 2003). Thus, institutional context may facilitate or constrain farmers' adaptive responses.

3. **Materials and Methods**

3.1 Research design

This study employed a quantitative research design to examine drought perceptions and impacts on smallholder farmers in the John Taolo Gaetsewe District Municipality (JTGDM). A research design provides a structured plan for collecting, measuring, and analyzing data to answer research questions effectively. Among the three primary approaches—qualitative, quantitative, and mixed methods—the quantitative approach was deemed most suitable. Quantitative research involves systematic collection and analysis of numerical data to identify patterns, test hypotheses, and determine relationships among variables, enabling generalizable conclusions from representative samples. This makes it particularly appropriate for assessing perceptions and socio-economic impacts (Leedy & Ormrod, 2015; Ayanwale et al., 2024). While efficient and structured, quantitative research relies on closed-ended instruments, which may limit the depth of participants' experiences (Glass et al., 1996). In contrast, qualitative methods explore lived experiences in detail but are time-consuming and less practical for larger or diverse populations. Given the study's focus on measuring drought perceptions and impacts, a quantitative approach was selected.

The study was guided by an interpretivist philosophical orientation, recognizing that reality is socially constructed through individual experiences and interactions. Although interpretivism is often associated with qualitative research, it informed the development of context-specific survey questions to capture farmers' perceptions within their socio-economic and environmental settings. The target population consisted of smallholder farming households in JTGDM rather than the general population. According to the 2016 Census, the district has approximately 242,264 residents, but only households actively engaged in smallholder agriculture formed the sampling frame. Lists of registered and locally identified smallholder farmers were obtained from agricultural extension offices and community leaders across the district's three local municipalities—Ga-Segonyana, Gamagara, and Joe Morolong.

A sample of 150 farmers was determined using the Raosoft sample size calculator at a 95% confidence level and an 8% margin of error (Creative Research Systems, 2023). Fifty farmers were selected per municipality using a stratified sampling approach to ensure representation across municipalities with differing population sizes and agricultural intensity. Within each stratum, simple random sampling selected respondents from the identified lists, while purposive sampling ensured inclusion of actively farming households. Data were collected via structured, closed-ended questionnaires administered in person. Participation was voluntary, and informed consent was obtained from all respondents. Ethical standards were strictly observed, and all responses were treated confidentially for academic purposes.

3.2 Description of the study area

The John Taolo Gaetsewe District Municipality (JTGDM), formerly Kgalagadi, is one of five districts in South Africa's Northern Cape province. (Figure 1). Geographically, it lies between latitude 27°S and longitude 23°E, bordering Dr Ruth Segomotsi Mompati District to the northeast, Frances Baard District to the south, ZF Mgcawu District to the southwest, and Botswana to the northwest (IDP, 2020). Administratively, it comprises three local municipalities: Ga-Segonyana, Gamagara, and Joe Morolong. JTGDM is situated in a semi-arid region with low and erratic rainfall, ranging from about 500 mm annually in the southeast to 200 mm in the northwest (van Weele, 2011), levels insufficient for sustainable dryland cropping. Rainfall is concentrated in short, intense summer downpours, particularly in February, when temperatures and evaporation are highest (IDP, 2020). Annual temperatures range from 8°C to 28°C, with averages between 16°C and 20°C. High summer temperatures exacerbate evaporation, intensifying drought risks and reducing effective soil moisture (van Weele, 2011). The terrain is mostly flat, interrupted by a north–south ridge system and the Kuruman Hills. Soils are sandy, ranging from shallow and poorly developed to deeper profiles with weak horizons, supporting vegetation highly sensitive to disturbance (Low, 2000; Rebelo, 1996). The district lies within the Orange River Basin, with the Kuruman and Gamagara Rivers as main watercourses. The Kuruman River shifts from northward to westward, eventually joining the Molopo and Orange Rivers (van Weele, 2011). Vegetation is predominantly Savanna Biome, with tree cover ranging from Shrubveld to Bushveld and Woodland. Key species such as *Acacia erioloba*, *Acacia haematoxylon*, and *Boscia albitrunca* are protected under the National Forests Act (1998), though *Acacia erioloba* is still commonly harvested for firewood and charcoal (JTGDM SDF, 2011; SANBI, 2015).

According to the 2016 Census, the district had 242,264 residents, about 20.3% of the Northern Cape population. Population growth has been modest in Ga-Segonyana and Gamagara, while Joe Morolong saw a 25% decline between 1996 and 2016 due to outmigration. Population density varies, with Ga-Segonyana at 15.54 people/km² and Joe Morolong at 3.75 people/km². Setswana is the dominant language, followed by Afrikaans, reflecting the district's ethnic diversity. Economically, the district depends on agriculture and mining. Over 80% of residents rely on livestock farming, including cattle, goats, sheep, and games. Mining activities, historically focused on asbestos, now centre on iron ore and manganese, with the Sishen Iron Ore Mine among the world's largest. The district also has tourism potential, particularly for winter game hunting.

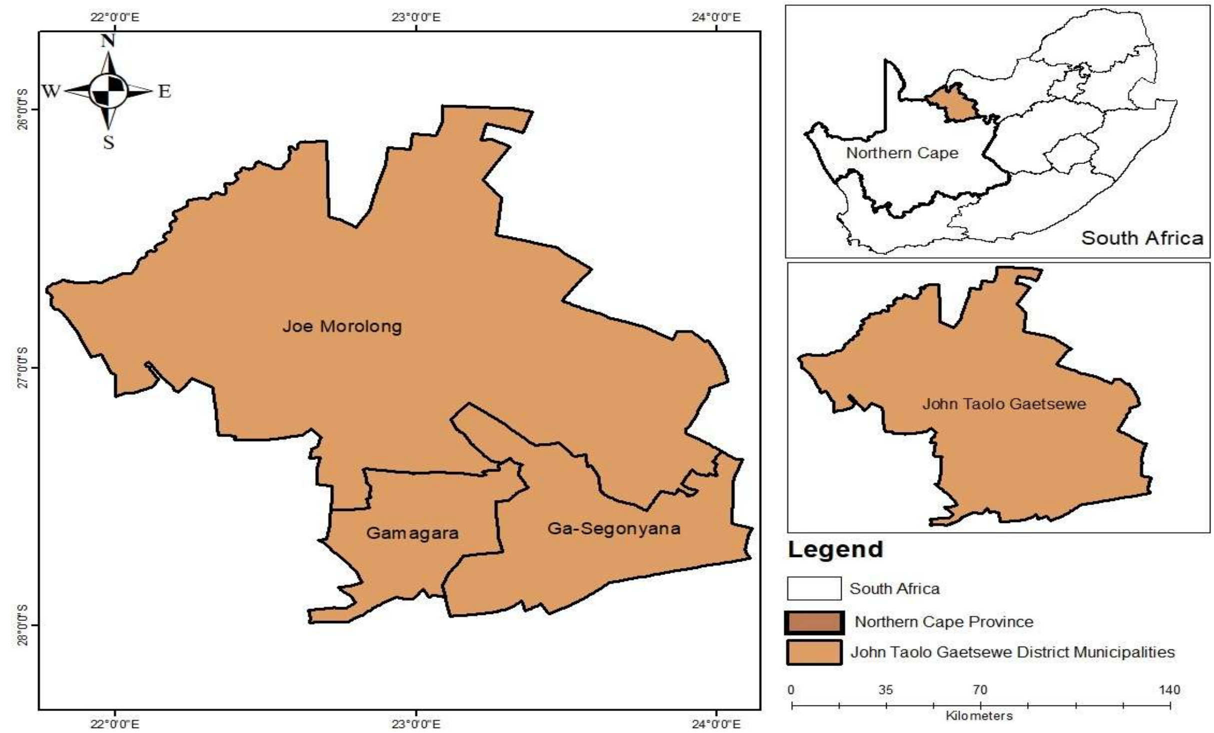

Figure 1. Locational map of John Taolo Gaetsewe District Municipality (JTGDM)

Source: Author's work (2023)

3.3. Sampling Procedure

In empirical research, the population refers to the complete group about which inferences are drawn, whereas the sample constitutes a subset selected to represent that population (Elfil and Negida, 2017). In this study, the target population comprises residents of the John Taolo Gaetsewe District Municipality (JTGDM) in South Africa, which had an estimated population of 242,264 individuals according to the 2016 national census. Given the study's focus on agricultural livelihoods, the effective study population was limited to smallholder farming households within the district. To ensure representativeness and minimise selection bias, a probability-based sampling strategy was adopted. Specifically, simple random sampling was employed within each of the district's three local municipalities—Ga-Segonyana, Gamagara, and Joe Morolong. Lists of smallholder farmers obtained through local agricultural offices and extension agents served as the sampling frame. From these lists, respondents were randomly selected, ensuring that each eligible farming household had an equal and known probability of inclusion. This approach enhances the external validity and generalisability of the study findings across the district. The sample size was determined using the Raosoft sample size calculator developed by Creative Research Systems. A 95% confidence level ($Z = 1.96$), an 8% margin of error, and a conservative population proportion ($p = 0.5$) were specified. The choice of $p = 0.5$ maximises variance and yields the largest required sample size, making it appropriate in the absence of prior information on population characteristics.

The initial sample size was calculated as:

$$n = \frac{(1.96)^2.0.5(1-0.5)}{(0.08)^2} = \frac{3.816.025}{0.0064} = \frac{0.9604}{0.0064} = 150.06 \quad (1)$$

Given the relatively large population size, adjustment for the finite population correction (FPC) yielded a negligible change:

$$n_{adj} = \frac{150.06}{1+\left(\frac{150.06-1}{242,264}\right)} \approx 150.00 \quad (2)$$

Thus, a total sample of 150 respondents was deemed statistically adequate and sufficiently powered to detect meaningful relationships at conventional significance levels. The sample was proportionately allocated across the three municipalities to ensure balanced geographical representation, with 50 questionnaires administered in each municipality. The selection of 150 respondents for this study is both statistically and methodologically justified. First, the sample size was determined using a standard sample size estimation procedure based on a 95% confidence level and an 8% margin of error, with a conservative population proportion (p = 0.5). This approach is widely adopted in social science and agricultural economics research, particularly when prior information on population variance is limited, as it yields the maximum required sample size and ensures adequate precision of estimates. Second, given the large population of smallholder farmers in the John Taolo Gaetsewe District Municipality (242,264 individuals), a sample of 150 respondents is sufficient to produce reliable and generalisable estimates. The finite population correction (FPC) factor has a negligible effect when the population size is large relative to the sample, further confirming the adequacy of the chosen sample size.

From an econometric standpoint, the sample size of 150 households provides sufficient statistical power for the Poisson regression used in this study. Guidelines for count-data models recommend at least 10–15 observations per estimated parameter to ensure stable coefficient estimates and avoid overfitting. With a parsimonious model specification, this study meets that criterion, allowing reliable estimation of the relationships between drought impacts and household-level variables. Comparable or smaller sample sizes have been successfully applied in prior agricultural and livelihood studies using Poisson or similar count models, particularly in rural and resource-limited settings, making the sample appropriate for this analysis. Data was collected via a structured questionnaire capturing socio-demographics, drought experiences, livelihood activities, and adaptation strategies. The dependent variable—drought impact—was operationalized as a count of livelihood disruptions per household, including crop failure, livestock loss, water scarcity, and income reduction. The Poisson regression model was selected for its suitability with discrete, non-negative count data, and allows direct interpretation of incidence rate ratios. Independent variables were constructed based on theoretical and empirical relevance, encompassing household characteristics, resource access, and exposure to climatic stressors. To reduce omitted variable bias, the model controlled for key socio-economic and institutional factors linked to livelihood vulnerability. Although the cross-sectional design limits causal inference, potential endogeneity was mitigated through the inclusion of relevant controls and exogenous household and environmental characteristics. These methodological choices strengthen the reliability and credibility of empirical findings.

3.4. Analytical framework

Quantitative data were analysed using descriptive and inferential statistical methods. The Statistical Package for the Social Sciences (SPSS) was used to generate descriptive statistics of respondents' socio-demographic characteristics. A weighted mean score analysis assessed smallholder farmers' perceptions of drought impacts. For inferential analysis, Poisson regression was employed to examine the influence of drought on livelihood diversification. This model is appropriate for counting data, capturing the frequency of events, and is widely used to evaluate the relationship between a dependent variable and multiple independent variables, such as crop failure or soil degradation (Elhai et al., 2008; Mazumder, 2024). By applying Poisson regression, the study estimated how drought severity affects the number of household income streams. The results provide evidence-based insights that can inform policy interventions to reduce smallholder farmers' socio-economic vulnerabilities to climate-induced shocks such as drought.

3.4.1. Poisson Regression Model Specification

This study employs a standard Poisson regression model with a log-link function to examine the determinants of livelihood diversification among smallholder farmers in the JTGDM. The dependent variable is the count of income-generating activities (streams of income) adopted by each household. The Poisson model is appropriate given the discrete, non-negative integer nature of the outcome variable and its widespread use in modeling event frequencies in applied economic analysis (Cameron & Trivedi, 2005). A key advantage of the Poisson specification is that it directly models the number of income streams without imposing restrictive assumptions about substitution or complementarities among livelihood activities. Unlike binary or index-based approaches that require arbitrary aggregation, the Poisson framework treats each observed count as a meaningful outcome, making it particularly suitable for rural livelihood diversification analysis. This approach is consistent with earlier studies on income diversification in agricultural settings (Isgin et al., 2008; Pamuk et al., 2014).

Formally, the probability that farmer i adopts $y_i$income-generating activities is assumed to follow a Poisson distribution:

$$P(Y_i = y_i) = \frac{e^{-\lambda}\lambda_i^{y_i}}{y_i^!},\ for\ y_i = 0{,}1{,}2\ ... \quad (3)$$

where $Y_i$denotes the observed number of income streams and $\lambda_i$is the conditional mean of the distribution. The expected count is modeled as a log-linear function of explanatory variables:

$$\lambda_I = \exp(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} \quad (4)$$

In this specification, $X_{1i}, X_{2i}, \dots, X_{ki}$include drought-related shocks (crop failure, water scarcity, poor soil quality, livestock loss, fire risk, health shocks, anxiety, and theft) and socio-economic characteristics (gender, age, education level, and farm experience). The parameters $\beta_0, \beta_1, \dots, \beta_k$are estimated by maximum likelihood.

To reduce omitted variable bias, the model includes a comprehensive set of controls encompassing environmental, human, and demographic factors commonly associated with livelihood decisions under drought. Incorporating these covariates minimizes the risk that unobserved factors correlated with both drought exposure and diversification drive the estimated relationships. Focusing on largely predetermined or slow-moving household characteristics—such as gender, age, education, and farming experience—further limits bias from unobserved time-varying shocks. Potential endogeneity is also addressed. Some drought-related variables may correlate with unobserved traits, such as risk preferences or entrepreneurial ability. This study mitigates simultaneity bias by emphasizing exogenous or quasi-exogenous climatic and environmental shocks that are plausibly outside household control. Given the cross-sectional design and lack of external instruments, causal inference is limited; thus, results are interpreted as robust associations rather than causal effects, consistent with best practice in applied microeconomics using observational data (Wooldridge, 2010).

For interpretability, Poisson regression coefficients are exponentiated and reported as Incidence Rate Ratios (IRRs) in Table 7. The IRR represents the proportional change in the expected number of income streams associated with a one-unit change in an explanatory variable. An IRR greater than one indicates increased livelihood diversification, while an IRR below one indicates a reduction. For instance, water scarcity and fire risk significantly reduce expected income streams, whereas education and age significantly enhance diversification. The suitability of the Poisson model was validated through diagnostic checks. Overdispersion was assessed by comparing the conditional mean and variance of the dependent variable and examining the Pearson chi-square statistic relative to its degrees of freedom, revealing no severe overdispersion. Robust (sandwich) standard errors were applied to account for potential mild deviations from equidispersion. Multicollinearity was assessed using variance inflation factors (VIFs), all of which fell within acceptable thresholds, confirming the reliability of the regression estimates.

3.4.2. Measurement of independent variables in the Poisson model

Table 1 provides a summary of the independent variables included in the Poisson regression model used to examine determinants of livelihood diversification—measured as the number of income-generating activities—among smallholder farmers in the John Taolo Gaetsewe District Municipality (JTGDM). The table details definitions and measurement units for each variable, ensuring transparency in variable construction and alignment with the count-data modelling framework. Livelihood diversification is widely recognized as a key indicator of adaptive capacity and resilience in drought-prone rural economies (Ellis, 2000; Barrett et al., 2021; FAO, 2022).

Explanatory variables were selected based on the Sustainable Livelihoods Framework (DFID, 1999), climate vulnerability theory (Adger, 2006), and recent empirical studies on drought impacts and adaptation. Variables are grouped into three categories: environmental and production-related stressors, health and psychosocial impacts, and household demographics, reflecting the multidimensional drivers of livelihood diversification under climatic stress. Environmental and production-related stressors include Crop Failure, Poor Soil Quality, Water Scarcity, Livestock Loss, Reduced Soil Fertility, and Fire Risk. These binary variables capture direct biophysical constraints imposed by drought. Crop failure and livestock loss represent major income and asset shocks that may either constrain diversification or prompt alternative income strategies (Dercon et al., 2020; Asfaw et al., 2022). Poor soil quality and declining fertility reflect long-term land degradation, increasing reliance on off-farm activities (Sietz et al., 2017; Kansiime et al., 2023). Water scarcity critically limits crop and livestock production and influences diversification decisions in semi-arid areas (Hansen et al., 2019; Ngoma et al., 2021), while Fire Risk captures disruptions caused by prolonged dry spells.

Human and psychosocial variables include Poor Health and Anxiety. Poor Health accounts for illness or physical strain, reducing labor availability during droughts (WHO, 2021; Anthonj et al., 2023), whereas Anxiety captures psychological stress from income uncertainty and asset loss, which affects decision-making and diversification willingness (Clayton et al., 2017; Cunsolo & Ellis, 2018; Bryan et al., 2022). Household demographics include Gender, Age, Educational Attainment, and Farming Experience. Gender, coded as a binary variable, captures disparities in access to resources and livelihood opportunities, with female-headed households often facing greater diversification constraints (Doss et al., 2018; Jost et al., 2021; Akinola et al., 2025). Age and Farming Experience reflect life-cycle effects and accumulated knowledge influencing diversification capacity (Manda et al., 2020; Tesfahunegn et al., 2022). Educational Attainment indicates the capacity to access, interpret, and act on climate and market information, facilitating livelihood diversification (Reardon et al., 2021; Adjognon et al., 2023). Binary variables were coded 1 for presence, and 0 otherwise, and continuous variables were measured in years, consistent with Poisson regression assumptions and allowing interpretation of incidence rate ratios as percentage changes in expected income streams.

Table 1. Measurement of independent variables in the Poisson model

Variables	Description	Unit of Measurement
Crop Failure	Whether the farmer experienced crop failure	Binary (1 = Yes, 0 = No)
Poor Soil	Perceived poor soil quality	Binary (1 = Yes, 0 = No)
Water Scarcity	Access to water resources	Binary (1 = Scarce, 0 = Adequate)
Loss Livestock	Experience of livestock loss	Binary (1 = Yes, 0 = No)
Poor Health	Poor health conditions experienced during the drought	Binary (1 = Yes, 0 = No)
Reduce Soil Fertility	Perceived reduction in soil fertility	Binary (1 = Yes, 0 = No)
Fire Risk	Perceived risk of fire outbreaks	Binary (1 = Yes, 0 = No)
Anxiety	Psychological stress experienced	Binary (1 = Yes, 0 = No)
Theft	Loss due to theft of assets or produce	Binary (1 = Yes, 0 = No)
Gender	Gender of respondent	Binary (1 = Male, 0 = Female)
Age	Age of the respondent	Years
Education	Years of formal education attained	Years
Farm Experience	Number of years involved in farming	Years

3.4.3. Data validity and reliability

In research, data validity refers to the extent to which an instrument accurately measures what it is intended to measure, reflecting how well findings represent the real-world phenomena under study, including the actual properties, characteristics, and differences within a social or physical context (Yilmaz, 2013). Data reliability, in contrast, concerns the consistency of a measurement process; a method is considered reliable when it produces the same results repeatedly under identical conditions using the same procedures (Scribbr, 2020; Kolapo et al., 2022). To ensure the accuracy and credibility of this study's findings, a mixed-methods approach was adopted, integrating both qualitative and quantitative methods. This triangulation strategy enhanced validity by allowing results to be cross verified across multiple sources and perspectives. Moreover, the combination of complementary methods strengthened reliability and provided a more comprehensive understanding of smallholder farmers' perceptions of drought and its impacts on livelihood diversification.

3.4.4. Ethical consideration

Before data collection, full ethical clearance was obtained from the University of the Free State (UFS) Ethical Committee. Participation was entirely voluntary, with informed verbal consent obtained from all respondents. Participants were assured of their right to withdraw at any time without consequence. The study also upheld academic integrity by properly acknowledging all sources in the literature review. Relevant studies were carefully consulted, with accurate in-text citations and a comprehensive reference list, ensuring that all forms of plagiarism were avoided.

4. **Results and discussion**

4.1. Socioeconomic characteristics of smallholder farmers

Table 2 presents descriptive statistics for key livelihood shocks, psychosocial factors, and socio-demographic characteristics, providing an overview of smallholder farmers' vulnerability and adaptive capacity.

Table 2. Description of Socio-economic Characteristics of Smallholder Farmers

Variables	Mean	Standard Deviation
Streams of Income	2.37	1.12
Crop Failure	0.48	0.40
Poor Soil	0.42	0.38
Water Scarcity	0.55	0.45
Loss Livestock	0.31	0.26
Poor Health	0.27	0.23
Reduced Soil Fertility	0.46	0.39
Fire Risk	0.18	0.15
Anxiety	0.39	0.33
Theft	0.22	0.18
Gender	0.64	0.47
Age (years)	47.6	9.8
Education (years)	7.8	3.1
Farm Experience (years)	12.7	11.61

Source: Data Analysis, 2024

On average, households reported 2.37 income streams, indicating moderate livelihood diversification. This reflects the constrained economic environment typical of rural areas, where agriculture dominates, and opportunities for diversification are limited by weak labor markets, poor infrastructure, restricted access to credit, and underdeveloped non-farm sectors (Ellis, 2000; Barrett et al., 2001; Akande et al., 2023; Kehinde and Ogundeji, 2023). Production-related risks were widespread. Water scarcity (mean = 0.55) was the most prevalent, reflecting the semi-arid conditions of the study area and increasing rainfall unpredictability linked to climate change. Dependence on rain-fed agriculture and limited water infrastructure further exacerbates exposure to drought (Rockström et al., 2010). Crop failure (mean = 0.48) reflects significant production losses due to erratic rainfall and extreme temperatures, while reduced soil fertility (mean = 0.46) indicates long-term land degradation from continuous cultivation, nutrient depletion, and erosion (Lal, 2015). Poor soil quality (mean = 0.42) compounds structural constraints, limiting yields and discouraging long-term investment. Livestock loss (mean = 0.31) highlights vulnerability in mixed farming systems, driven by feed shortages, water scarcity, and disease, particularly during prolonged dry periods (FAO, 2018). Health and psychosocial factors also contribute to vulnerability. Poor health (mean = 0.27) reflects the physically demanding nature of farming, limited healthcare access, and food insecurity during drought (Asfaw et al., 2012). Fire risk (mean = 0.18) and theft (mean = 0.22) represent seasonal and economic threats, respectively. Anxiety (mean = 0.39) underscores the chronic stress associated with rainfall uncertainty, income instability, and repeated livelihood shocks, influencing decision-making and coping strategies (Cunsolo & Ellis, 2018).

Socio-demographic characteristics show a predominantly female respondent base (mean = 0.64), reflecting women's central role in subsistence agriculture and household food provision (Doss, 2014; Oyenpemi et al., 2023; Bakare et al., 2023). The average age of 47.6 years suggests a mature farming population, as younger individuals increasingly exist agriculture for non-farm opportunities (Slayi et al., 2023; Olupona & Kehinde, 2022; Ayanwale and Kehinde, 2025). Education averages 7.8 years, indicating basic literacy but limited access to extended formal education, shaping information access and adoption of new practices (Bahta and Myeki, 2022; Kehinde and Adeyemo, 2020). Farm experience averages 12.7 years, reflecting long-term involvement, intergenerational knowledge transfer, and adaptation to climatic variability and production risks (Kangogo et al., 2020; Ogunleye et al., 2020; Kolawole et al., 2020).

4.2. Smallholder Farmers' perception of climate-induced shocks

The survey included questions aimed at identifying the most commonly perceived hazards in the John Taolo Gaetsewe District Municipality (JTGDM), as well as assessing the significance of the study within the local context.

Table 3. Smallholder Farmers' perception of climate-induced shocks

Hazard	Frequency	Percentage
Drought	126	84.00
Flood	1	0.67
fire	23	15.33
Total	150	100.00

Source: Data Analysis, 2024

As presented in Table 3, the majority of respondents (84%) identified drought as the most prevalent hazard affecting their agricultural activities. This was followed by fire, reported by 15.33% of respondents, while floods were identified by only 0.67% of the sample. These findings highlight the overwhelming perception of drought as the primary environmental threat in the region, with fire also recognized as a significant concern.

The dominance of drought and fire as perceived hazards aligns with broader trends observed in South Africa, where these events frequently disrupt agricultural production and rural livelihoods. This is consistent with Orimoloye's (2022) findings, which reported that drought-induced veld fires accounted for more than 25% of agricultural losses across the country, particularly during the 2015–2016 drought season. Other studies have similarly emphasized the growing frequency and severity of droughts and veld fires in semi-arid regions of South Africa, exacerbated by climate change and land degradation (Bahta and Jordaan, 2019; Le Maitre et al., 2020). The results from this study, therefore, underscore the urgency of prioritizing drought and fire mitigation strategies in agricultural planning and policy interventions in the JTGDM and other drought-prone regions.

4.3. Perception of drought among smallholder farmers in the JTGDM

This section presents the distribution of the weighted mean scores reflecting smallholder farmers' perceptions of drought in the John Taolo Gaetsewe District Municipality (JTGDM).

Table 4. Distribution of weighted mean score of perception of drought among smallholder farmers in the JTGDM

Perception of drought	SA (%) (5)	A (%) (4)	N (%) (3)	D (%) (2)	SD (%) (1)	Mean	Standard deviation	Rank	Decision
Drought threatens our farming	82 (54.67)	68 (45.33)	0 (0.00)	0 (0.00)	0 (0.00)	4.546	0.4994	2nd	High perception
The drought resulted in food insecurity	39 (26.00)	106 (70.67)	5 (3.33)	0 (0.00)	0 (0.00)	4.226	0.4935	3rd	High perception
Drought results in malnutrition	36 (24.00)	96 (64.00)	18 (12.00)			4.12	0.5898	4th	High perception
Drought has resulted in high animal and crop theft in the community	30 (20.00)	18 (12.00)	58 (38.67)	29 (19.33)	15 (10.00)	3.126	1.227	6th	Low perception
Drought has increased farmer vulnerability to insert attacks on crops	32 (21.33)	37 (24.67)	56 (37.33)	13 (8.67)	12 (8.00)	3.426	1.1547	5th	Low perception
Drought has resulted in the migration of people from the community.	16 (10.67)	9 (6.00)	4 (2.67)	29 (19.33)	92 (61.33)	1.853	1.3530	7th	Low Perception
Drought is the main setback to smallholder	113 (75.33)	32 (21.33)	4 (2.67)	0 (0.00)	1 (0.67)	4.706	0.5855	1st	High perception

farming activities								

Source: Data Analysis, 2024 SA=Strongly agree; A=Agree; N=Neutral; D= Disagree; SD=Strongly disagree
Decision= weighted average = 26.006/7= 3.715. Values in parentheses are the percentages of the responses.

As shown in Table 4, a significant majority (75.33%) of respondents identified drought as the primary obstacle to agricultural practices in the region, with a high mean score of 4.706, indicating widespread agreement on its adverse effects. Similarly, a mean score of 4.546, reported by 54.67% of farmers, further emphasizes the perception that drought represents the most critical threat to farming. Additionally, 70.67% of respondents acknowledged a strong relationship between drought and food insecurity, reflected in a mean score of 4.226. This suggests that drought not only reduces crop yield but also disrupts household food availability and accessibility. Similarly, the perception that drought contributes to malnutrition was strongly supported, with a mean score of 4.12, affirming the nutritional consequences of food shortages during prolonged dry periods. These findings echo those of Bahta and Myeki (2022), who observed that drought adversely impacts food systems and household nutrition among smallholder farmers in the Northern Cape.

In contrast, perceptions of the indirect socio-economic effects of drought were more neutral. For example, mean scores of 3.426 and 3.126 were associated with beliefs that drought may increase vulnerability or lead to crop theft, respectively. These moderate scores suggest that while farmers recognize the potential for broader socio-economic instability, these outcomes are not yet widely experienced or considered severe in the community. Furthermore, the notably low mean score of 1.353 for drought-induced migration indicates that most respondents do not associate drought with large-scale population displacement. This aligns with the findings of Jordaan et al. (2014), who reported that while drought presents significant challenges to smallholder livelihoods in the Northern Cape, it has not triggered widespread out-migration. The weighted mean average score of 3.715 confirms that drought is broadly perceived as the most significant environmental hazard affecting smallholder farming in the study area. Farmers identify it as a major source of agricultural disruption, food insecurity, and malnutrition. These findings are supported by other studies which show that smallholder farmers across sub-Saharan Africa increasingly recognize drought as a severe and recurring hazard, one that threatens both food production and rural livelihoods (Masipa, 2017; Nnadi et al., 2019; Adzawla et al., 2021). These perceptions reflect lived experiences and have significant implications for designing farmer-centered adaptation strategies and drought resilience policies in arid and semi-arid regions of South Africa.

4.4 Perceived impact of drought among smallholder farmers in the JTGDM

Table 5 presents the distribution of weighted mean scores regarding smallholder farmers' perceptions of the impact of drought in the John Taolo Gaetsewe District Municipality (JTGDM).

Table 5. Distribution of weighted mean score of the level of perceived impact of drought among smallholder farmers in the JTGDM

Perceived impact	**SA(%) (5)**	**A(%) (4)**	**N(%) (3)**	**D(%) (2)**	**SD(%) (1)**	**Mean**	**Standard deviation**	**Rank**
Loss of vegetation	76 (50.67)	71 (47.33)	1 (0.67)	1 (0.67)	1 (0.67)	4.466	0.6203	3rd

Resource conflicts	39 (26.00)	36 (24.00)	31 (20.67)	26 (17.33)	18 (12.00)	3.346	1.3510	5th
more wildfires	113 (75.33)	33 (22.00)	1 (0.67)		3 (2.00)	4.686	0.6867	1st
Soil erosion	93 (62.00)	56 (37.33)		1 (0.67)		4.606	0.5296	2nd
Lack of food, and water for livestock	69 (46.00)	72 (48.00)	7 (4.67)	1 (0.67)	1 (0.67)	4.38	0.6722	4th

Source: Data Analysis, 2024 SA=Strongly agree; A=Agree; N=Neutral; D= Disagree; SD=Strongly disagree

Decision= weighted average = 21.486/5= 4.297. Values in parentheses are the percentages of the responses.

The results indicate that the most significant perceived drought effect was an increase in wildfires, with a high mean score of 4.686, suggesting widespread recognition of this threat. This was followed by soil erosion (mean = 4.606), loss of vegetation (mean = 4.466), and lack of food and water for livestock (mean = 4.38). These findings reflect the multifaceted and interlinked challenges drought poses to both natural resources and agricultural productivity in arid and semi-arid regions. Among the listed impacts, resource conflicts were perceived as relatively less severe, with a mean score of 3.346, though still noteworthy in the broader context of drought-induced stress on communal resources. The overall weighted average score of 4.297 underscores the severity of drought's perceived effects on smallholder agricultural systems in the district. This strongly suggests that farmers experience drought as a major disruptive force to their livelihoods, ecosystems, and food security.

These findings are consistent with previous research. Wildfires, soil erosion, and vegetation loss have been identified as key environmental consequences of prolonged drought in semi-arid regions such as South Africa (Squires & Ariapour, 2018; Orimoloye et al., 2022). Drought conditions dry out vegetation, increase surface temperatures, and weaken soil integrity, all of which elevate the risk of fire outbreaks and land degradation (Bahta and Jordaan, 2019; Le Maitre et al., 2020). The perception of livestock vulnerability also aligns with studies highlighting that feed and water shortages are among the first and most severe agricultural impacts of drought (Masipa, 2017). These findings imply that drought policy interventions and adaptation strategies must prioritize addressing critical environmental stressors, particularly wildfire management, erosion control, and vegetation restoration. Such strategies will be essential in enhancing the resilience of smallholder farming systems, especially in vulnerable districts like the JTGDM. Integrated land and water management practices, early warning systems for fire outbreaks, and sustainable grazing strategies may be central components of a locally relevant drought adaptation framework.

4.5. Impacts of drought on the livelihoods of smallholder farmers within the JTGDM

This section explores the impact of drought on the livelihoods of smallholder farmers across the John Taolo Gaetsewe District Municipality (JTGDM). Table 6 presents the distribution of weighted mean scores for different perceived drought-related impacts, ranked from 1st to 9th in order of their severity.

Table 6. Distribution of weighted mean score of the impact of drought among smallholder farmers in the JTGDM

Impact on the the community	SA(%) (5)	A(%) (4)	N (%) (3)	D(%) (2)	SD(%) (1)	Mean	Standard deviation	Rank
Crop failure	46 (30.67)	90 (60.00)	6 (4.00)	2 (1.33)	6 (4.00)	4.12	0.8663	7th
Poor soil quality	60 (40.00)	73 (48.67)	14 (9.33)	0 (0.00)	3 (2.00)	4.2467	0.7852	6th
Water scarcity	108 (72.00)	32 (21.33)	3 (2.00)	3 (2.00)	4 (2.67)	4.58	0.8535	3rd
Loss of livestock	108 (72.00)	33 (22.00)	7 (4.67)	1 (0.67)	1 (0.67)	4.64	0.6684	2nd
Poor health of farmers & their animals	40 (26.67)	50 (33.33)	57 (38.00)	3 (2.00)	0 (0.00)	3.8466	0.8414	8th
Reduced soil fertility	58 (38.67)	77 (51.33)	13 (8.67)	2 (1.33)	0 (0.00)	4.2733	0.6745	5th
Risk of fire due to high temperature	129 (86.00)	19 (12.67)	0 (0.00)	1 (0.67)	1 (0.67)	4.8266	0.5148	1st
Anxiety/depression about losses caused by drought	71 (47.33)	58 (38.67)	16 (10.67)	5 (3.33)	0 (0.00)	4.3	0.7922	4th
Increase in theft	20 (13.33)	13 (8.67)	55 (36.67)	34 (22.67)	28 (18.67)	2.7533	1.2420	9th

Source: Data Analysis, 2024 SA=Strongly agree; A=Agree; N=Neutral; D= Disagree; SD=Strongly disagree

Decision= weighted average = 37.5866/9=4.1763. Values in parenthesis are the percentages of the responses.

The results indicate that the increased risk of fire due to high temperatures was perceived as the most severe impact, with a weighted mean score of 4.8266, reflecting widespread concern among farmers. This was closely followed by the loss of livestock (mean = 4.64), water scarcity (mean = 4.58), and psychological stress or anxiety related to losses (mean = 4.30). These findings highlight the direct and indirect consequences of drought on both the physical and mental well-being of smallholder farmers. Other moderately ranked drought impacts included crop failure, poor soil quality, reduced soil fertility, and deterioration in the health of farmers and their animals, with mean scores ranging from 3.8466 to 4.2733. These reflect the cumulative, long-term effects of prolonged drought on the agricultural ecosystem and human livelihoods. Notably, increased theft was the least perceived impact, with a mean score of 2.7533, suggesting that while resource insecurity may be rising, it is not yet widely linked to social instability such as theft.

The overall weighted average score of 4.1763 strongly suggests that farmers perceive drought as a multifaceted threat that affects the environmental, economic, and psychosocial aspects of their lives. These findings are consistent with the study by Vicente-Serrano et al. (2020), who observed that drought significantly exacerbates wildfire risk, livestock loss, and water scarcity in arid and semi-arid regions. High temperatures create tinder-dry conditions, and when combined with strong winds, can lead to devastating wildfires that destroy grazing lands and endanger rural livelihoods. Similarly, Orimoloye et al. (2022) report that water scarcity affects not only crops but also animal survival and household water needs, often pushing farmers into financial distress or triggering migration. The mental health dimension of drought, as indicated by high scores on anxiety and depression, echoes global findings that climate-related stress can lead to serious emotional strain among smallholder farmers, especially when compounded by poverty, uncertainty, and recurring climate shocks (Cianconi et al., 2020; Tambo and Wünscher, 2017). Therefore, addressing these impacts in the order of their perceived severity, as revealed in this study, could enhance the effectiveness of targeted adaptation strategies and strengthen community resilience to future drought episodes.

4.6 The Poisson regression analysis of the impact of drought on livelihoods of smallholder farmers in the JTGDM

The Poisson regression results (Table 7) examine the effects of drought-related stressors and socio-demographic factors on smallholder livelihoods in the John Taolo Gaetsewe District Municipality (JTGDM). The analysis assesses how household exposure to crop failure, water scarcity, soil degradation, livestock losses, and health risks, along with socio-demographics such as gender, age, education, and farm experience, influence the number of income-generating activities.

Table 7. The Poisson regression analysis of the impact of drought on the livelihoods of smallholder farmers in the JTGDM

Livelihood	Coef.	Robust SE	IRR	t-value	p-value
Crop failure	-0.138 ***	0.0008	0.871	-164.09	0.0000
Poor soil quality	-0.042 ***	0.0008	0.959	-52.48	0.0000
Water scarcity	-0.253 ***	0.0008	0.777	-304.15	0.0000
Loss of livestock	-0.067 ***	0.0008	0.935	-78.95	0.0000
Poor health	-0.028***	0.0007	0.972	-39.61	0.0000
Reduce soil fertility	-0.008***	0.0010	0.992	-8.23	0.0000
Risk of fire	-0.233***	0.0008	0.792	-285.48	0.0000
Anxiety	-0.001	0.0012	0.999	-0.84	.398
Theft	-0.027***	0.0005	0.973	-57.92	0.0000
Gender	-0.271***	0.0012	0.763	-234.84	0.0000
Age	0.768***	0.0008	0.155	998.96	0.0000
Education level	0.679***	0.0008	0.321	877.92	0.0000
Farm experience	0.001***	0.0002	0.999	5.67	0.0000
Constant	14.155***	0.0057	-	2494.37	0.0000
Pseudo r-squared	0.237				
Chi-square	2562322.006				
Akaike crit. (AIC)	8252705.421				
Number of obs	150				
Prob > chi2	0.000				
Bayesian crit. (BIC)	8252747.570				
Mean VIF	1.45				

Pearson χ^2 / df	1.03
Mean dependent variable	3.2
Variance dependent variable	2.37

The model employs a standard Poisson specification with robust (Huber–White) standard errors, suitable for count data and accounting for heteroskedasticity and minor deviations from equidispersion (Cameron and Trivedi, 2013). The dependent variable has a mean of 3.2 and variance of 2.37, indicating mild under-dispersion, supporting the Poisson assumption. The Pearson chi-square divided by degrees of freedom (χ^2/df = 1.03) confirms good model fit (Wooldridge, 2010), while the overall likelihood ratio Chi-square (2,562,322.006, $p < 0.001$) indicates that the included variables collectively explain meaningful variation in livelihood diversification. The reported Pseudo R-squared (0.237) provides a relative measure of fit for comparing model specifications rather than variance explained (Greene, 2012). Multicollinearity diagnostics show minimal correlation among regressors (Mean VIF = 1.45), well below common thresholds (VIF > 5 or 10), ensuring stable coefficient estimates. These diagnostics support the reliability, precision, and interpretability of the estimated coefficients and incidence rate ratios, confirming that each independent variable contributes uniquely to explaining differences in household livelihood diversification.

The analysis shows that crop failure significantly constrains household livelihood diversification, with an incidence rate ratio (IRR) of 0.871, indicating that a one-unit increase in perceived crop failure reduces the expected number of income streams by approximately 12.9%. This aligns with the Sustainable Livelihoods Framework, which posits that shocks to natural capital—such as drought-induced crop losses—undermine households' capacity to mobilise financial and physical assets for diversification (DFID, 1999; Ellis, 2000). In JTGDM, where crop production forms the backbone of rural livelihoods, recurrent crop failures erode income, deplete savings, and limit investment in alternative activities such as livestock rearing, petty trading, or agro-processing. Beyond immediate production losses, crop failure can reinforce poverty traps by constraining long-term investment and intergenerational mobility, consistent with climate vulnerability and resilience theories that highlight how repeated covariate shocks lock households into low-return strategies (Dercon, 2004; Carter et al., 2007). Policy interventions that stabilise crop productions such as climate-smart agriculture, drought-tolerant seeds, crop insurance, and improved extension services—are therefore essential for enabling diversification rather than substituting for it. These findings are consistent with previous studies showing that drought-induced crop failure undermines food security, limits investment in education and health, and weakens long-term adaptive capacity (Simelton et al., 2013; Matlou et al., 2021; Bahta and Myeki, 2022).

Water scarcity emerged as the most binding environmental constraint, with an incidence rate ratio (IRR) of 0.777, indicating that a one-unit increase in perceived water shortage reduces the expected number of income streams by about 22.3%. This underscores water's central role not only in crop and livestock production but also in nutrition, health, and small-scale enterprise development. In line with sustainable livelihoods and resilience literature, water availability is a core component of natural and physical capital that shapes households' ability to diversify and adapt under climate stress (Adger, 2006; Scoones, 2015). In JTGDM's semi-arid environment, limited irrigation infrastructure, inadequate water storage, and high dependence on rain-fed agriculture amplify the effects of water scarcity. Reduced water availability lowers crop yields, increases livestock mortality, restricts home gardening and small-scale irrigation, and limits engagement in value-adding activities, thereby narrowing income portfolios. The magnitude of this effect highlights that reliable water access is a prerequisite for successful livelihood diversification, rather than a complementary measure. Similar patterns have been documented across drought-prone Southern Africa, where erratic rainfall and weak water governance constrain diversification and reinforce climate vulnerability (Calzadilla et al., 2013; Ruwanza et al., 2022).

Livestock losses also significantly reduced livelihood diversification (IRR = 0.935), corresponding to a 6.5% decline in expected income streams. Livestock provides food, income, draught power, manure, and acts as informal insurance against shocks. Losses erode asset bases, weaken investment capacity, and reduce households' ability to pursue non-farm or semi-farm activities. This is especially critical in mixed crop–livestock systems typical of JTGDM, where livestock support consumption smoothing and risk management (Dercon, 2004; Bahta and Jordaan, 2013). These findings highlight the need for livestock-focused adaptation strategies, including drought-resilient grazing, veterinary services, early warning systems, and livestock insurance, to sustain diversification pathways in drought-prone areas. Similarly, poor soil quality (IRR = 0.959) and reduced soil fertility (IRR = 0.992) decreased diversification by 4.1% and 0.8%, respectively. While smaller in magnitude than water scarcity or crop failure, these effects reflect structural constraints from soil degradation processes—erosion, nutrient depletion, salinisation, and declining organic matter. Soil quality is a foundational component of natural capital, affecting long-term productivity and income potential. Degraded soils limit crop yields, reduce surplus production, and constrain opportunities for commercialization and higher-value agricultural activities, locking households into low-productivity strategies. These results align with broader sub-Saharan evidence emphasizing that soil fertility management is essential for sustainable agricultural intensification, income diversification, and long-term rural resilience (Barrios et al., 2008; Tittonell and Giller, 2013).

Health and safety-related stressors were significant determinants of livelihood diversification. Poor health reduced the expected income streams by 2.8% (IRR = 0.972), reflecting how illness limits labour availability, productivity, and household resource allocation. Health shocks often divert scarce funds to medical expenses and reduce the capacity to engage in physically demanding or time-intensive income-generating activities, thereby constraining diversification (Elahi et al., 2008; Fraser et al., 2011). This finding aligns with human capital theory, emphasizing the interdependence between health outcomes and economic resilience under climate stress. Fire risk exerted a particularly strong negative effect (IRR = 0.792), implying a 20.8% reduction in expected livelihood options. Drought-induced fires can destroy crops, pasture, livestock, infrastructure, and stored produce, leading to immediate losses and long-term setbacks by discouraging investment, increasing risk aversion, and eroding confidence in land-based livelihoods. These results highlight the importance of integrating fire management and disaster risk reduction strategies—such as early warning systems, controlled burning, and community-based fire response mechanisms—into local climate adaptation policies. Theft reduced livelihood diversification by 2.7% (IRR = 0.973), illustrating the social and institutional dimensions of drought vulnerability. Resource scarcity can intensify competition over assets, increase insecurity, and weaken informal social protection networks. Such conditions may undermine households' willingness to invest in productive activities or diversify income sources, particularly where property rights and local governance are weak (FAO, 2018;

Sibanda et al., 2020). These findings underscore the need to strengthen local institutions, social cohesion, and rural security as part of comprehensive drought resilience and livelihood diversification strategies.

Among the socio-demographic variables, gender was a significant determinant of livelihood diversification. Female-headed households engaged in 23.7% fewer income-generating activities than male-headed households (IRR = 0.763). This aligns with the Sustainable Livelihoods Framework and feminist political economy perspectives, which emphasise how unequal access to productive assets and institutions systematically constrains women's livelihood opportunities. Female-headed households frequently face barriers such as limited access to land and secure tenure, restricted credit, weaker integration into extension services, and reduced mobility. Additionally, gendered social norms and disproportionate care responsibilities limit women's time and flexibility to pursue diversified livelihood strategies. These intersecting constraints reinforce gendered inequalities in rural resilience, leaving female-headed households particularly vulnerable to climatic and market shocks (Peterman et al., 2014; Meinzen-Dick et al., 2014; Alobo Loison, 2015). From a policy perspective, this underscores the need for gender-responsive adaptation strategies, including improved access to land and credit, tailored extension services, labour-saving technologies, and targeted skills development programmes. Age also positively influenced livelihood diversification, indicating that older farmers are more likely to engage in multiple income streams. This reflects life cycle and experience effects, where accumulated farming knowledge, asset ownership, and social capital enhance adaptive capacity. Older farmers can leverage long-standing social networks, cooperative memberships, and market relationships to access information, credit, and informal support. Such social and institutional capital enables experimentation with diversified cropping systems, investment in livestock or off-farm enterprises, and better risk management under climate variability and price fluctuations. This finding supports resilience and adaptive capacity theories, which emphasise the role of experience and social embeddedness in shaping households' responses to environmental shocks.

Educational attainment was a strong and positive determinant of livelihood diversification, with an IRR of 0.321, indicating that higher education substantially increases the likelihood of engaging in multiple income streams. Education enhances human capital by improving farmers' capacity to access and interpret information, adopt improved agricultural technologies, and respond effectively to climate and market signals. More educated farmers are also better positioned to identify non-farm employment opportunities, participate in value chains, and implement climate-smart practices within their production systems. This finding reinforces extensive empirical evidence demonstrating that education plays a pivotal role in strengthening adaptive capacity, facilitating technology adoption, and enabling transitions toward higher-value and more diversified livelihood portfolios (Nhemachena and Hassan, 2007; Deressa et al., 2009; Asfaw and Maggio, 2018). Farming experience had a positive but modest effect on livelihood diversification (IRR = 0.999), with each additional year of experience increasing the expected amount of income streams by approximately 0.1%. Although the effect size is small, it underscores the cumulative importance of long-term engagement in agriculture. Experienced farmers often possess deeper knowledge of local agro-ecological conditions, seasonal variability, and risk management strategies, which improve decision-making under uncertainty. Over time, these incremental gains in experience contribute to more efficient resource allocation, enhanced productivity, and greater confidence in experimenting with alternative livelihood strategies. This result aligns with prior studies highlighting that experiential learning significantly shapes adaptation behaviour and livelihood outcomes in climate-vulnerable agricultural systems (Hassan and Nhemachena, 2008; Bryan et al., 2009).

4.7. Drought adaptation strategies initiated by smallholder farmers in the JTGDM

Adaptation refers to the deliberate strategies and practices implemented to reduce or manage the adverse effects of drought on individuals, households, communities, and ecosystems. It encompasses actions designed to strengthen resilience to increasing drought frequency and intensity, a trend that has been widely attributed to climate change (Bahta and Myeki, 2021). In agrarian communities such as the John Taolo Gaetsewe District Municipality (JTGDM), where livelihoods are directly tied to rainfall-dependent agriculture, adaptation is not merely a theoretical concept but a practical necessity for survival.

Table 8 presents the weighted mean scores of various drought adaptation strategies employed by smallholder farmers in JTGDM. These strategies represent both short-term coping mechanisms and longer-term resilience-building practices. The ranking and associated standard deviations offer insights into which strategies are widely embraced, and the degree of consensus among farmers regarding their effectiveness.

Table 8. Drought adaptation strategies initiated by smallholder farmers in the JTGDM

Source: Data Analysis, 2024 SA=Strongly agree; A=Agree; N=Neutral; D= Disagree; SD=Strongly disagree

Adaptation strategies	**SA(%) (5)**	**A(%) (4)**	**N(%) (3)**	**D(%) (2)**	**SD(%) (1)**	**Mean**	**Standard deviation**	**Rank**	**Decision**
Seek a new source of food	9 (6.00)	13 (8.67)	23 (15.33)	67 (44.67)	38 (25.33)	2.2533	1.1123	4th	Most adopted
NGO intervention in the community	2 (1.33)	6 (4.00)	11 (7.33)	77 (51.33)	54 (36.00)	1.8333	0.8307	5th	Least adopted
Keeping reserves	5 (3.33)	18 (12.00)	71 (47.33)	27 (18.00)	29 (19.33)	2.62	1.0341	2nd	Most adopted
Seek employment elsewhere	1 (0.67)	9 (6.00)	6 (4.00)	45 (30.00)	89 (59.33)	1.586	0.8761	7th	Least adopted
Rainwater harvesting	7 (4.67)	16 (10.67)	49 (32.67)	48 (32.00)	30 (20.00)	2.48	1.0726	3rd	Most adopted
Maintaining flexibility	14 (9.33)	41 (27.33)	45 (30.00)	26 (17.33)	24 (16.00)	2.9666	1.2118	1st	Most Adopted
Government intervention	2 (1.33)	15 (10.00)	7 (4.67)	31 (20.67)	95 (63.33)	1.6533	1.0426	6th	Least adopted

Decision= weighted average = 37.5866/9=4.1763. Values in parenthesis are the percentages of the responses.

The most frequently adopted strategy among respondents was maintaining farming flexibility, with a mean score of 2.97 and a standard deviation of 1.2118, ranking first among all adaptation measures. This strategy includes actions such as adjusting planting dates, switching crop varieties, integrating livestock with crops, and adopting alternative livelihood strategies during dry periods. The relatively high mean and low variation in responses suggest widespread recognition of flexibility as a key drought adaptation measure across the community. This finding aligns with Bane et al. (2021), who argue that flexible farming systems enable smallholders to respond proactively to climatic uncertainties by adjusting to emerging conditions, thereby minimizing losses and optimizing resource use. Maintaining flexibility also reflects a form of anticipatory adaptation, where farmers do not merely react to drought but build versatility into their farming systems to absorb future shocks.

The second most adopted strategy was keeping reserves, with a mean score of 2.62 and a standard deviation of 1.0341. This practice refers to the storage of surplus resources, such as grains, livestock feed, water, or savings, that can be drawn upon during times of scarcity. Keeping reserves is a traditional risk management strategy that enhances food and livelihood security during drought periods. Studies have shown that households with reserves are less likely to experience acute food insecurity or resort to distress sales of assets during climate shocks (Ruwanza et al., 2022; López-Felices et al., 2023). In the context of JTGDM, this strategy likely serves as a buffer against the volatility of rainfall patterns and the increasingly unpredictable agricultural seasons.

Rainwater harvesting ranked third among the most widely used adaptation strategies, with a mean of 2.48. This practice involves collecting and storing rainwater for future agricultural or domestic use, often using drums, tanks, or surface catchment systems. Rainwater harvesting is particularly important in arid and semi-arid regions, where groundwater resources may be limited and rainfall is both erratic and insufficient. Mtyelwa et al. (2022) emphasize that this strategy can help reduce overreliance on inconsistent rainfall patterns, enhance crop productivity, and enable farmers to extend the growing season. In regions like JTGDM, with pronounced dry spells, the promotion of small-scale rainwater harvesting technologies could significantly improve adaptive capacity. Following closely was the strategy of seeking new food sources, which had a mean score of 2.25. This includes the identification and consumption of non-traditional or underutilized food items such as wild vegetables, edible insects, aquatic plants, and other foraged materials. While not a substitute for stable food production, this strategy reflects a diversification of dietary intake in response to food shortages. Daum et al. (2022) note that these alternative food sources, although sometimes culturally stigmatized, can provide crucial nutrients and calories during periods of crop failure, particularly for marginalized or resource-poor households. While these strategies reflect relatively high levels of adoption and consensus, the overall weighted mean score of 2.199 suggests a generally positive orientation toward drought adaptation among the surveyed farmers. However, the variation in standard deviations across different strategies indicates diverse levels of experience, access, and confidence in the effectiveness of each approach.

On the other end of the spectrum, several strategies were ranked low in terms of adoption. NGO intervention, for instance, received a mean score of 1.83 and ranked fifth. Although non-governmental organizations often play a vital role in delivering drought relief and adaptation support, their presence and consistency in the JTGDM appear to be limited. The relatively high standard deviation of 0.8307 suggests that while some farmers benefit from NGO assistance, others either lack access or view such support as unreliable or ineffective. Similarly, government intervention was ranked sixth, with a mean of 1.65 and a standard deviation of 1.0426. This result points to a perceived gap between government policy intentions and the lived experiences of smallholder farmers. Farmers may perceive government drought support, such as food aid, agricultural inputs, or extension services, as delayed, inadequate, or misaligned with their actual needs. This disconnect has been widely reported in rural adaptation literature, where top-down interventions often fail to account for local realities (Alam et al., 2017). Lastly, seeking employment elsewhere, either in urban centers or through seasonal migration, was the least adopted adaptation strategy, with a mean score of 1.59 and a standard deviation of 0.8761. While labor migration can serve as a coping mechanism during times of environmental stress, it is often a last resort due to the economic and social costs involved. Moreover, it tends to provide only temporary relief without addressing the underlying vulnerability of agricultural systems. This aligns with broader findings that off-farm employment as a drought response is constrained by limited labor market opportunities, high transportation costs, and the disruption of household cohesion (Alam et al., 2017; Dercon, 2002).

4.8 Different strategies that will strengthen smallholder farmer resilience and capacity toward the drought impacts

This section presents findings on perceived strategies to enhance the resilience and coping capacities of smallholder farmers against the impacts of drought in rural communities. The assessment was based on responses to a structured questionnaire using a five-point Likert scale, ranging from *Strongly Agree* (SA) to *Strongly Disagree* (SD). The interventions evaluated include technological, institutional, and policy-related strategies intended to build adaptive capacity. Table 9 summarises the weighted mean scores and standard deviations of these strategies based on respondents' perceptions.

Table 9. Distribution of weighted mean score of government drought adaptation/coping among smallholder farmers in the JTGDM

Adaptation strategies	SA(%) (5)	A(%) (4)	N(%) (3)	D(%) (2)	SD(%) (1)	Mean	Standard deviation	Rank	Decision
Seek new source of food	9 (6.00)	13 (8.67)	23 (15.33)	67 (44.67)	38 (25.33)	2.2533	1.1123	4th	Most adopted
NGO intervention in the community	2 (1.33)	6 (4.00)	11 (7.33)	77 (51.33)	54 (36.00)	1.8333	0.8307	5th	Least adopted
Keeping reserves	5 (3.33)	18 (12.00)	71 (47.33)	27 (18.00)	29 (19.33)	2.62	1.0341	2nd	Most adopted
Seek employment elsewhere	1 (0.67)	9 (6.00)	6 (4.00)	45 (30.00)	89 (59.33)	1.586	0.8761	7th	Least adopted

Rainwater harvesting	7 (4.67)	16 (10.67)	49 (32.67)	48 (32.00)	30 (20.00)	2.48	1.0726	3rd	Most adopted
Maintaining flexibility	14 (9.33)	41 (27.33)	45 (30.00)	26 (17.33)	24 (16.00)	2.9666	1.2118	1st	Most Adopted
Government intervention	2 (1.33)	15 (10.00)	7 (4.67)	31 (20.67)	95 (63.33)	1.6533	1.0426	6th	Least adopted

Among the various strategies, planting drought-resistant crops emerged as the most widely adopted measure among smallholder farmers to improve their resilience to prolonged dry conditions. This strategy recorded the highest mean score of 2.1733, indicating a moderate level of agreement among farmers regarding its effectiveness, with a corresponding standard deviation of 2.1733, suggesting some variability in responses. The adoption of drought-resistant crops is a proactive approach to securing food and income during drought periods. According to Seleiman et al. (2021), these crops, including sorghum, millet, and drought-tolerant vegetables such as tomatoes and peppers, are genetically or selectively bred to endure limited water availability and high temperatures. Their adoption helps to stabilise yields and reduce the risk of total crop failure during drought events. This result implies that promoting the use of drought-resistant varieties through extension services and input subsidies could significantly enhance adaptive farming practices and ensure food security in vulnerable communities. The second most adopted strategy was enhanced social support systems, with a mean score of 1.8733 and a standard deviation of 0.8378, indicating more consistent agreement among respondents. Social support systems encompass assistance from family, community members, cooperatives, and informal networks. These networks often play a critical role in cushioning the psychological and economic stress experienced by farmers during prolonged droughts. Bahta and Myeki (2021) observed that social networks facilitate knowledge exchange, shared labor, and communal resource access, all of which are vital for resilience-building. The implication here is that strengthening community-based organisations and fostering local solidarity can bolster farmers' mental well-being and cooperative responses to environmental stress.

Closely following social support, drought relief assistance schemes were the third most recognised intervention, with a mean score of 1.9000 and a standard deviation of 0.8804. These schemes include government or NGO-provided support such as food aid, livestock feed subsidies, or emergency cash transfers. Their adoption points to the role of institutional support in cushioning the economic effects of droughts. Wens et al. (2022) assert that these programmes help maintain household consumption, protect productive assets, and avert long-term poverty. The implication of this finding is that timely and well-targeted drought relief interventions can serve as a critical stopgap, preventing the downward spiral into chronic vulnerability. The fourth most adopted measure was the farm household allowance, with a mean of 1.8133 and a standard deviation of 0.8776. These allowances are typically government-led financial support programmes designed to assist low-income or severely affected farming households during environmental or economic shocks. Evidence from Asghari et al. (2021) and Kapari et al. (2023) indicates that household allowances can help farmers maintain basic living standards, invest in alternative livelihoods, or cover essential farming costs during hard times. The implication is that institutionalising such allowances and ensuring transparency and accessibility in their distribution can boost the resilience of the most at-risk farming households.

On the contrary, some strategies were perceived as less effective and were rarely adopted by smallholder farmers. The fifth least adopted intervention was the drought community programme, with a mean score of 1.7066 and a standard deviation of 0.8072. These community-led drought preparedness or response initiatives may be limited by inadequate funding, poor coordination, or low farmer awareness. Their low adoption implies a gap in participatory drought planning and local-level institutional engagement, which, if strengthened, could enhance community-level resilience. Similarly, rural financial counselling services, ranked sixth, had a low mean score of 1.6600 and a standard deviation of 0.7311. These services are meant to provide farmers with financial literacy, budgeting skills, and advice on debt management. However, the low adoption suggests that either such services are not available in the study area, or that farmers are unaware of their existence or potential benefits. As found by Alam et al. (2017), access to financial counselling can improve financial planning and resource allocation during times of uncertainty. The implication of this result is the need to increase awareness and accessibility of these advisory services to improve financial decision-making in rural farming communities. Finally, the least adopted strategy was the farm business concessional loan programme, with a mean score of 1.5266 and a standard deviation of 0.7390. Concessional loans are designed to provide low-interest credit to farmers, enabling them to invest in drought mitigation infrastructure or practices. However, their low uptake may be attributed to barriers such as stringent eligibility criteria, lack of collateral, or bureaucratic processes that discourage participation. According to Kapari et al. (2023), improving access to affordable agricultural finance could significantly enhance investment in resilient technologies such as drip irrigation or water-efficient seeds. The implication is that reforming credit systems to make them more farmer-friendly could be a key lever in building adaptive capacity in drought-prone regions.

4.9. The different strategies to strengthen community resilience and capacity toward drought impacts in the John Taolo Gaetsewe District Municipality

The results presented in Table 10 reveal the perceived effectiveness of various institutional and infrastructural interventions in enhancing the resilience of smallholder farmers to drought in the study communities.

Table 10. Distribution of weighted mean score of the different strategies to strengthen community resilience and capacity toward drought impacts in the John Taolo Gaetsewe District Municipality

Perceived impact	**SA(%) (5)**	**A(%) (4)**	**N(%) (3)**	**D(%) (2)**	**SD(%) (1)**	**Mean**	**Standard deviation**	**Rank**
Disaster early warming improves smallholder farmers' resilience	75 (50.00)	52 (34.6)	6 (4.00)	8 (5.33)	9 (6.00)	4.173	1.1277	3rd
Drought awareness programs strengthen smallholder farmer resilience to drought.	82 (54.67)	48 (32.0)	10 (6.67)	5 (3.33)	5 (3.33)	4.313	0.9771	2nd

Government support to smallholder farmers strengthens their resilience in the event of droughts	92 (61.33)	50 (33.3)	5 (3.33)	2 (1.33)	1 (0.67)	4.533	0.6919	1st
Irrigation and easy load access boost coping capacity against drought	14 (9.33)	77 (51.33)	47 (31.3)	9 (6.00)	3 (2.00)	3.6	0.8192	4th

Source: Data Analysis, 2024 SA=Strongly agree; A=Agree; N=Neutral; D= Disagree; SD=Strongly disagree
Decision= weighted average = 16.62/4=4.155. Values in parentheses are the percentages of the responses.

Based on the mean scores and standard deviations, government support emerged as the most positively perceived strategy, with a mean score of 4.533 and a low standard deviation of 0.6919, indicating not only a strong overall agreement on its effectiveness but also a high level of consensus among respondents. This suggests that smallholder farmers highly value the role of direct governmental assistance, such as subsidies, financial grants, policy support, and infrastructural development, in mitigating the adverse impacts of drought. The implications of this finding are significant: robust, consistent governmental intervention is crucial to bolstering adaptive capacity and reducing vulnerability in drought-prone agricultural systems. Meza et al. (2021) similarly emphasized that state-led initiatives, including timely drought response mechanisms, training programmes, and support for irrigation infrastructure, substantially enhance the coping abilities of farmers in drought-affected regions like South Africa. Following closely, drought awareness programmes were the second most positively rated intervention, with a mean score of 4.313. These programmes are essential in equipping farmers with knowledge about drought preparedness, risk management practices, and sustainable resource use. Their high ranking underscores the critical role of information dissemination and community sensitisation in proactive drought response. Effective drought education campaigns can foster behavioural change, encourage the adoption of climate-smart practices, and reduce dependency on reactive aid measures (Bahta and Myeki, 2021; Wens et al., 2022).

Disaster early warning systems were also perceived as beneficial, although slightly less so than the top two interventions. These systems, which typically involve climate monitoring and the timely dissemination of drought forecasts, had a mean score of 3.6, placing them in the moderate-impact category. Despite being less highly rated, the inclusion of early warning systems among the most impactful strategies points to their crucial role in enabling anticipatory action. When effectively designed and communicated, early warning systems can help smallholder farmers make informed decisions about planting dates, water use, and livestock management, thus reducing losses during prolonged dry spells (Kapari et al., 2023). Similarly, irrigation support and ease of access to credit or loan facilities also recorded moderate levels of perceived effectiveness, both with mean scores around 3.6. These strategies are infrastructural and financial and are particularly important for transitioning from rainfed to more controlled forms of agriculture. Irrigation ensures water availability during dry periods, while access to credit empowers farmers to invest in drought-resilient technologies and inputs. However, the moderate ranking suggests potential issues such as limited coverage, affordability, or poor implementation in the study areas. This aligns with findings from Asghari et al. (2021), who noted that while irrigation and credit are vital adaptation tools, their benefits are constrained by access inequalities and institutional inefficiencies.

5. **Conclusions**

This study analyzed smallholder farmers' perceptions of drought and its effects on livelihood diversification in the John Taolo Gaetsewe District Municipality of South Africa. The findings show that drought is perceived as the most severe environmental challenge affecting agricultural production and household welfare. Econometric results indicate that drought-related stressors—particularly water scarcity, fire risk, crop failure, and livestock loss—significantly reduce the number of income-generating activities available to farming households. Additional constraints such as degraded soils, poor health, and theft further limit livelihood options. Socio-demographic factors also matter: female-headed households participate in fewer livelihood activities, while education and age positively influence diversification. Overall, drought functions both as an immediate livelihood shock and as a structural barrier to livelihood diversification, increasing vulnerability among smallholder farmers.

To enhance smallholder farmers' resilience and sustain livelihood diversification in drought-prone areas such as the John Taolo Gaetsewe District Municipality, several key policy actions are recommended. First, improving access to reliable water resources is essential through investments in boreholes, rainwater harvesting, small-scale dams, and efficient irrigation systems to reduce the effects of water scarcity. Second, agricultural extension services should promote climate-smart practices, including drought-tolerant crops, soil conservation, and fire risk management, to strengthen farmers' adaptive capacity. Third, gender-responsive policies are needed to improve women's access to land, credit, extension services, and farmer organizations, thereby reducing gender disparities in livelihood opportunities. Fourth, investment in education and skills training, particularly in non-farm income activities, can support livelihood diversification and reduce reliance on climate-sensitive agriculture. Finally, strengthening drought early warning systems, social protection programs, and local institutions can help reduce livelihood losses and improve resilience among rural households.

This study has several limitations. First, it relies on cross-sectional data from 150 smallholder households, which limits the generalizability of the findings beyond the study area. Second, the analysis is based partly on self-reported perceptions of drought and its impacts, which may be subject to recall bias and subjective interpretation. Third, while the Poisson regression model is suitable for analyzing livelihood diversification, it does not fully establish causal relationships, and some unobserved factors may influence households' diversification decisions. Finally, the study measures livelihood diversification mainly by the number of activities, without capturing the quality, profitability, or sustainability of those activities.

Future research should extend this study by using longitudinal or panel data to better understand how repeated drought events influence livelihood diversification and household resilience over time. Integrating objective climatic data—such as rainfall variability and drought indices—with household survey data would also help validate farmers' perceptions and improve the robustness of drought impact analyses. In addition, future studies should assess not only the number of livelihood activities but also their profitability, sustainability, and implications for household income, food security, and nutrition. Further research should also adopt gender-disaggregated approaches to better understand how women and other vulnerable groups respond to drought. Finally, evaluating the effectiveness of policy interventions, such as water infrastructure, extension services, social protection programs, and early warning systems, would help identify strategies that best strengthen resilience in drought-prone regions.

Author Contributions: Conceptualization, T. Moepeng and A. Ogundeji; methodology, A. Kehinde; software, A. Kehinde; validation, A. Ogundeji; formal analysis, A.D. Kehinde; investigation, T. Moepeng; resources, T. Moepeng; writing—original draft preparation, A.D. Kehinde; writing—review and editing, A. D. Kehinde; visualization, A.D. Kehinde; supervision, A. Ogundeji; project administration, T. Moepeng and A. Ogundeji; funding acquisition, T. Moepeng . All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgements: We owe a debt of gratitude to the farmers who sat quietly for hours answering the questionnaire. We also thank the anonymous reviewers for their insightful remarks, which helped us improve the work.

Conflicts of Interest: The authors declare no conflict of interest

Data availability statement: The data supporting this study's findings can be obtained from the authors upon reasonable request.

6. References

1. Abate GT (2018): Drivers of agricultural cooperative formation and farmers' membership and patronage decisions in Ethiopia. Journal of Co-operative Organization and Management 6(2), 53–63. https://doi.org/10.1016/j.jcom.2018.06.002
2. Adeagbo A, Kehinde A, Bamire A (2025): Climate change adaptation strategies by smallholder farmers in Nigeria: What role do social capital formations play in the adoption process? Scientia Agriculturae Bohemica 56(2), 8. https://doi.org/10.7160/sab.2025.560208
3. Adger WN (2003): Social capital, collective action, and adaptation to climate change. Economic Geography 79(4), 387–404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x
4. Adger WN (2006): Vulnerability. Global Environmental Change 16(3), 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006
5. Adger WN, Huq S, Brown K, Conway D, Hulme M (2003): Adaptation to climate change in the developing world. Progress in Development Studies 3(3), 179–195. https://doi.org/10.1191/1464993403ps060oa
6. Adjognon SG, Liverpool-Tasie LSO, Reardon T (2023): Agricultural technology adoption, market participation, and productivity. World Development 161, 106060. https://doi.org/10.1016/j.worlddev.2022.106060
7. Akande YB, Tijani AA, Kehinde AD, Oyenpemi LO (2023): Impact of compliance with European Union (EU) regulations on the income of actors along the cocoa supply chain in Osun State, Nigeria. Sustainable Futures 6, 100120. https://doi.org/10.1016/j.sftr.2023.100120
8. Akinola A, Kehinde A, Tijani A, Ayanwale A, Manga A, Adesiyan O, Tanimonure V, Ogunleye A, Ojo T (2025): Impact of income share on dietary diversity of primary actors in the tomato supply chain in Nigeria. Scientia Agriculturae Bohemica 56(1), 1–12. https://doi.org/10.7160/sab.2025.560102
9. Alam GMM, Alam K, Mushtaq S (2017): Climate change perceptions and adaptation strategies of smallholder farmers in rural Bangladesh. Climate Risk Management 17, 104–122. https://doi.org/10.1016/j.crm.2017.04.001
10. Alobo Loison S (2015): Rural livelihood diversification in sub-Saharan Africa: A literature review. Journal of Development Studies 51(9), 1125–1138. https://doi.org/10.1080/00220388.2015.1046445
11. Anthonj C, Setty KE, Ezbakhe F, Manga M, Hoeser C (2023): A systematic review of water, sanitation and hygiene among pastoralists and smallholder farmers. International Journal of Environmental Research and Public Health 20(3), 1893. https://doi.org/10.3390/ijerph20031893
12. Antwi-Agyei P, Stringer LC, Dougill AJ (2014): Livelihood adaptations to climate variability: Insights from farming households in Ghana. Regional Environmental Change 14(4), 1615–1626. https://doi.org/10.1007/s10113-014-0613-x
13. Applegreen A, Mpandeli S, Nhamo G (2024): Drought risk and adaptive capacity in South Africa's arid regions. Climate Risk Management 43, 100540. https://doi.org/10.1016/j.crm.2023.100540
14. Asfaw S, Battista F, Lipper L (2016): Agricultural technology adoption under climate change. Food Policy 60, 1–10. https://doi.org/10.1016/j.foodpol.2015.12.003

15. Asfaw S, Maggio G (2018): Gender differences in climate risk perceptions and adoption of climate-smart agriculture in Malawi. Climate Risk Management 20, 33–45. https://doi.org/10.1016/j.crm.2018.04.001
16. Asghari N, Shaban M, Adeli S (2021): Policy frameworks and social safety nets for agricultural resilience. Journal of Environmental Planning and Management 64(8), 1379–1397. https://doi.org/10.1080/09640568.2020.1823344
17. Ayanwale AB, Adekunle AA, Kehinde AD, Fatunbi OA (2024): Networking and training for improvement of farm income: A case of Lifelong Learning (L3F) approach in West Africa. Heliyon 10(2), e23263. https://doi.org/10.1016/j.heliyon.2023.e23263
18. Ayanwale A, Kehinde AD (2025): Determinants of use of digital innovation and its impact on land acquisition and food security among farming households in Nigeria. World Development Perspectives 39, 100702.
19. Bahta YT, Jordaan A (2019): Climate change adaptation among smallholder farmers. Sustainability 11(5), 1–16. https://doi.org/10.3390/su11051492
20. Bahta YT, Jordaan A, Sabates-Wheeler R (2016): Climate variability and smallholder adaptation in South Africa. Climate and Development 8(4), 335–346. https://doi.org/10.1080/17565529.2015.1034233
21. Bahta YT, Myeki L (2021): Coping strategies of smallholder farmers under drought stress: Evidence from South Africa. Sustainability 13(9), 4751. https://doi.org/10.3390/su13094751
22. Bahta YT, Myeki N (2022): Smallholder farmers' vulnerability to drought in South Africa. Jàmbá: Journal of Disaster Risk Studies 14(1), a1234. https://doi.org/10.4102/jamba.v14i1.1234
23. Bakare AY, Ogunleye AS, Kehinde AD (2023): Impacts of microcredit access on climate change adaptation strategies adoption and rice yield in Kwara State, Nigeria. World Development Sustainability 2, 100047. https://doi.org/10.1016/j.wds.2023.100047
24. Barrett CB, Reardon T, Webb P (2001): Nonfarm income diversification and household livelihood strategies. Food Policy 26(4), 315–331. https://doi.org/10.1016/S0306-9192(01)00014-8
25. Below TB, Artner A, Siebert R, Sieber S (2012): Micro-level practices to adapt to climate change for African small-scale farmers. IFPRI Discussion Paper 00953. International Food Policy Research Institute.
26. Botai CM, Botai JO, Adeola AM, de Wit JP, Ncongwane KP, Zwane NN (2017): Drought impacts in South Africa. Climate Risk Management 17, 43–55. https://doi.org/10.1016/j.crm.2017.06.002
27. Bryan E, Deressa TT, Gbetibouo GA, Ringler C (2009): Adaptation to climate change in Ethiopia and South Africa: Options and constraints. Environmental Science & Policy 12(4), 413–426. https://doi.org/10.1016/j.envsci.2008.11.002
28. Bryan E, Ringler C, Okoba B, Roncoli C, Silvestri S, Herrero M (2013): Adapting agriculture to climate change in Kenya: Household strategies and determinants. Journal of Environmental Management 114, 26–35. https://doi.org/10.1016/j.jenvman.2012.10.036
29. Bryan E, Theis S, Choufani J, De Pinto A, Meinzen-Dick R, Ringler C (2022): Climate stress and farmer decision-making. Global Environmental Change 72, 102414. https://doi.org/10.1016/j.gloenvcha.2021.102414
30. Calzadilla A, Zhu T, Rehdanz K, Tol RS, Ringler C (2013): Economy-wide impacts of climate change on agriculture in Sub-Saharan Africa. Ecological Economics 93, 150–165. https://doi.org/10.1016/j.ecolecon.2013.05.006
31. Cameron AC, Trivedi PK (2005): Microeconometrics: Methods and Applications. Cambridge University Press.

32. Cameron AC, Trivedi PK (2013): Regression Analysis of Count Data. 2nd ed. Cambridge University Press.
33. Carter MR, Little PD, Mogues T, Negatu W (2007): Poverty traps and climate risk. Journal of Development Studies 43(6), 835–856. https://doi.org/10.1080/00220380701466445
34. Clayton S, Manning C, Krygsman K, Speiser M (2017): Mental health and climate change. American Psychologist 72(4), 265–276. https://doi.org/10.1037/amp0000092
35. Cooper PJM, Dimes J, Rao KPC, Shapiro B, Shiferaw B, Twomlow S (2008): Coping better with climate variability. Agricultural Systems 101(1–2), 1–5. https://doi.org/10.1016/j.agsy.2009.02.001
36. Cunsolo A, Ellis NR (2018): Ecological grief. Nature Climate Change 8, 275–281. https://doi.org/10.1038/s41558-018-0092-2
37. Dai A (2011): Drought under global warming. WIREs Climate Change 2(1), 45–65. https://doi.org/10.1002/wcc.81
38. Daum T, Porter JR, Andersson JA, van Wijk M, Rosegrant MW (2022): Food system resilience in Africa: A framework for decision-makers. Global Food Security 33, 100617. https://doi.org/10.1016/j.gfs.2022.100617
39. Dercon S (2004): Growth and shocks: Evidence from rural Ethiopia. Journal of Development Economics 74(2), 309–329. https://doi.org/10.1016/j.jdeveco.2004.01.001
40. Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M (2009): Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environmental Change 19(2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002
41. DFID (1999): Sustainable Livelihoods Guidance Sheets. Department for International Development.
42. Elahi E, Zhang L, Abid M, Altangerel O, Khayyam U, Ahmed UI (2008): Health shocks and rural livelihoods. World Development 36(10), 1854–1872.
43. Elahi MM, Danquah M, Zulkhibri M (2008): Social vulnerability to climate change and implications for adaptation. International Journal of Climate Change Strategies and Management 1(1), 1–18.
44. Ellis F (2000): Rural Livelihoods and Diversity in Developing Countries. Oxford University Press.
45. EM-DAT (2021): The International Disaster Database. Centre for Research on the Epidemiology of Disasters.
46. Eriksen SH, Brown K, Kelly PM (2005): Vulnerability and adaptation. Global Environmental Change 15(2), 143–154. https://doi.org/10.1016/j.gloenvcha.2004.12.005
47. FAO (2018): The Impact of Disasters and Crises on Agriculture and Food Security. Food and Agriculture Organization of the United Nations.
48. FAO (2021): The State of Food and Agriculture. Food and Agriculture Organization of the United Nations.
49. FAO (2022): Livelihood Diversification and Resilience. Food and Agriculture Organization of the United Nations.
50. Fraser EDG, Dougill AJ, Hubacek K, Bunce B, Reed MS (2011): Vulnerability and adaptation to climate change in semi-arid environments: A case study of the livestock system in Botswana. Environmental Science & Policy 12(4), 390–403. https://doi.org/10.1016/j.envsci.2007.07.006
51. Gbetibouo GA (2009): Understanding farmers' perceptions and adaptations. IFPRI Discussion Paper 00849. International Food Policy Research Institute.
52. Gleick PH (2014): Water, drought, climate change, and conflict. Weather, Climate, and Society 6(3), 331–340. https://doi.org/10.1175/WCAS-D-13-00059.1

53. Goddard L, Mason SJ, Zebiak SE, Ropelewski CF, Basher R, Cane MA (2003): Climate variability and food security. Science 302(5645), 1134–1136.
54. Greene WH (2012): Econometric Analysis. 7th ed. Pearson.
55. Guneralp B, Shrestha N, Seto KC (2015): Climate change and urban expansion. Proceedings of the National Academy of Sciences 112(40), 12309–12314. https://doi.org/10.1073/pnas.1506231112
56. Hassan R, Nhemachena C (2008): Determinants of African farmers' adaptation to climate change. African Journal of Agricultural and Resource Economics 2(1), 83–104.
57. Hilbe JM (2014): Modeling Count Data. Cambridge University Press.
58. IPCC (2014): Climate Change 2014: Impacts, Adaptation, and Vulnerability. Cambridge University Press.
59. Jordaan A, Sakulski D, Jordaan JH (2017): Climate change and smallholder farmers in South Africa. Agrekon 56(2), 139–156. https://doi.org/10.1080/03031853.2017.1322051
60. Kapari L, Mensah H, Osei E (2023): Financial support mechanisms and drought resilience in African agriculture. African Development Review 35(2), 145–160. https://doi.org/10.1111/1467-8268.12684
61. Kehinde AD, Adeyemo R (2020): Effect of social capital dimensions on output and gross margin of cassava farmers in Osun State. Nigerian Journal of Rural Sociology 20(1), 37–43.
62. Kehinde AD, Ige A, Onyeka E, Tijani A (2025): Understanding the role of social networks in climate adaptation and mitigation among Nigerian smallholder farmers: A scoping review. Climate Services 40, 100620. https://doi.org/10.1016/j.cliser.2024.100620
63. Kehinde AD, Ogundeji AA (2023): Distributive impacts of non-farm income on output and farm income of cassava farmers in southwestern Nigeria. Scientific African 19, e01535. https://doi.org/10.1016/j.sciaf.2023.e01535
64. Kelley CP, Mohtadi S, Cane MA, Seager R, Kushnir Y (2015): Climate change and the Syrian conflict. Proceedings of the National Academy of Sciences 112(11), 3241–3246. https://doi.org/10.1073/pnas.1421533112
65. Kolapo A, Ogunleye AS, Kehinde AD, Odimgbe-James W (2022): Effect of microcredit on investment decision of smallholder farmers in Osun State. Agriculturae Conspectus Scientificus 87(1), 69–75.
66. Kolawole MA, Tijani AA, Kehinde AD (2020): Impact of a growth enhancement support scheme on cocoa yield and income of cocoa farmers in Osun State, Nigeria. Acta Scientiarum Polonorum Agricultura 19(1), 41–49. https://doi.org/10.22630/ASPA.2020.19.1.5
67. Lal R (2015): Restoring soil quality to mitigate drought. Sustainability 7(5), 5875–5895. https://doi.org/10.3390/su7055875
68. Le Maitre DC, Forsyth GG, Smith HG (2020): Fire regimes in South Africa. South African Journal of Science 116(5–6). https://doi.org/10.17159/sajs.2020/7811
69. López-Felices B, Yumbla-Orbes J, Aguilar-González A (2023): Drought risk and adaptation in rural Ecuador: An exploratory analysis. Journal of Rural Studies 101, 222–232. https://doi.org/10.1016/j.jrurstud.2023.06.015
70. Masipa TS (2017): The impact of drought on food security in South Africa. Jàmbá: Journal of Disaster Risk Studies 9(1), a538. https://doi.org/10.4102/jamba.v9i1.316
71. Matlou MP, Bahta YT, Jordaan A (2021): Economic vulnerability of smallholder livestock farmers to drought in South Africa. Sustainability 13(8), 4436. https://doi.org/10.3390/su13084436

72. Meinzen-Dick R, Bernier Q, Haglund E (2014): Strengthening women's assets for resilient agricultural systems. In: Quisumbing AR, Meinzen-Dick R, Raney TL, Croppenstedt A, Behrman JA, Peterman A (eds.), Gender in Agriculture, pp. 343–368. Springer.
73. Meza MI, Hansen JW, Kumar V (2021): The role of early warning systems in drought risk reduction. Climate Services 23, 100250. https://doi.org/10.1016/j.cliser.2021.100250
74. Morton JF (2007): Climate change and subsistence farmers. Proceedings of the National Academy of Sciences 104(50), 19680–19685. https://doi.org/10.1073/pnas.0701530104
75. Mpandeli S, Naidoo D, Mabhaudhi T, Nhamo G, Liphadzi S, Hlahla S, Modi AT (2020): Adaptation strategies in South Africa. Climate Risk Management 28, 100221. https://doi.org/10.1016/j.crm.2020.100221
76. Mtyelwa V, Musvoto C, Zinyengere N (2022): Rainwater harvesting for resilience in Southern Africa. Climate and Development 14(5), 421–432. https://doi.org/10.1080/17565529.2021.1921689
77. Nhemachena C, Hassan R (2007): Micro-level analysis of farmers' adaptation to climate change in Southern Africa. IFPRI Discussion Paper No. 00714. International Food Policy Research Institute.
78. Niang I, Ruppel OC, Abdrabo MA, Essel A, Lennard C, Padgham J, Urquhart P (2014): Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
79. Ogunleye AS, Kehinde AD, Kolapo A (2020): Effects of social capital on income of cocoa farming households in Osun State. Tanzania Journal of Agricultural Science 19(2), 131–137.
80. Ogunleye AS, Kehinde AD, Mishra A, Ogundeji A (2021): Impacts of farmers' participation in social capital networks on climate change adaptation strategies adoption in Nigeria. Heliyon 7(12), e08624. https://doi.org/10.1016/j.heliyon.2021.e08624
81. Olugbenga YE, Bamire AS, Kehinde AD, Ojo TO, Ogundeji AA (2025): Impact of perceptions of climate variability on investment decisions pattern among smallholder rice farmers in Nigeria. Environmental and Sustainability Indicators 27, 100721. https://doi.org/10.1016/j.indic.2024.100721
82. Olupona OT, Kehinde AD (2022): Economics of bio-fortified cassava varieties (BCVs) adoption and its gender implication among farmers in Oyo State. Ghana Journal of Agricultural Science 57(1), 55–71. https://doi.org/10.4314/gjas.v57i1.5
83. Orimoloye IR (2022): Drought-induced veld fires in South Africa. Natural Hazards 112, 185–203. https://doi.org/10.1007/s11069-021-05175-1
84. Oyenpemi LO, Tijani AA, Kehinde AD (2023): What determines a sustained use of approved pesticides for cleaner production and its impact on yield? Evidence from the cocoa industry in Osun State, Nigeria. Cleaner and Responsible Consumption 9, 100113. https://doi.org/10.1016/j.clrc.2023.100113
85. Peterman A, Behrman JA, Quisumbing AR (2014): A review of empirical evidence on gender differences in nonland agricultural inputs, technology, and services in developing countries. In: Quisumbing AR, Meinzen-Dick R, Raney TL, Croppenstedt A, Behrman JA, Peterman A (eds.), Gender in Agriculture, pp. 145–186. Springer.
86. Rockström J, Karlberg L, Wani SP, Barron J, Hatibu N, Oweis T, Bruggeman A, Farahani J, Qiang Z (2010): Managing water in rainfed agriculture. Agricultural Water Management 97(4), 543–550. https://doi.org/10.1016/j.agwat.2009.01.008

87. Ruwanza S, Thondhlana G, Falayi M, Pumani A (2022): Traditional and innovative adaptation strategies of smallholder farmers in Southern Africa. Environmental Development 43, 100679. https://doi.org/10.1016/j.envdev.2021.100679
88. Seleiman MF, Al-Suhaibani N, Ali N, Akmal M, Alwang JS, Al-Doss AA (2021): Plant strategies for drought resistance and sustainable crop production. Agronomy 11(4), 764. https://doi.org/10.3390/agronomy11040764
89. Sibanda M, Mutanga O, Rouget M, Kumar L (2020): Fire risk and vulnerability in Southern Africa. Sustainability 12(14), 5708. https://doi.org/10.3390/su12145708
90. Simelton E, Fraser EDG, Termansen M, Benton TG, Gosling SN, South A, Arnell NW (2013): The socioeconomics of climate change adaptation: Assessing current practices and knowledge gaps. Environmental Science & Policy 27, 1–10. https://doi.org/10.1016/j.envsci.2012.11.004
91. Sivakumar MVK, Stefanski R, Bazza M, Zelaya S, Wilhite D, Magalhaes AR (2014): Climate change adaptation strategies. Weather and Climate Extremes 3, 1–6. https://doi.org/10.1016/j.wace.2014.03.001
92. Smit B, Wandel J (2006): Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008
93. Tessema YA, Astatke A, Mahmood S (2013): Farmers' perceptions of climate change. Climatic Change 119(2), 555–569. https://doi.org/10.1007/s10584-013-0751-9
94. Thornton PK, van de Steeg J, Notenbaert A, Herrero M (2009): Climate change and livestock. Agricultural Systems 101(3), 113–127. https://doi.org/10.1016/j.agsy.2009.05.002
95. Toreti A, Bavera D, Acosta Navarro J, Cammalleri C, de Jager A, Di Ciollo C, Hrast Essenfelder A, Maetens W, Magni D, Masante D, Mazzeschi M, Niemeyer S, Spinoni J (2022): Drought impacts in Europe. Nature Climate Change 12, 1–7.
96. Tschakert P, Tutu R (2010): Solastalgia: The distress caused by environmental change. In: Clayton S, Manning S (eds.), Psychology and Climate Change, pp. 57–77. Academic Press.
97. UN-DESA (2013): World Economic and Social Survey. United Nations.
98. van Weele B (2011): Climate and hydrology of the Northern Cape.
99. Vicente-Serrano SM, Quiring SM, Peña-Gallardo M, Yuan S, Domínguez-Castro F (2020): Drought and wildfire risk. Environmental Research Letters 15(10), 104040. https://doi.org/10.1088/1748-9326/abb6b2
100. Wens M, Rybski D, Liao KH (2022): Social protection and adaptive capacity in agriculture. Global Environmental Change 72, 102416. https://doi.org/10.1016/j.gloenvcha.2021.102416
101. WHO (2021): Climate change and health. World Health Organization.
102. Wilhite DA, Glantz MH (1985): Understanding the drought phenomenon. Water International 10(3), 111–120. https://doi.org/10.1080/02508068508686315
103. Wooldridge JM (2010): Econometric Analysis of Cross Section and Panel Data. 2nd ed. MIT Press.
104. Ziervogel G, Zermoglio F (2009): Climate change scenarios and adaptation. Climatic Change 92(1–2), 137–157. https://doi.org/10.1007/s10584-008-9489-1