Article

Commercial Livestock Farmers’ Economic Vulnerability to Agricultural Drought in South Africa: Implications to SDG2 and African Union CAADP Strategy and Action Plan

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ABSTRACT

Identifying and measuring economic drought vulnerability indicators is an essential step in planning drought mitigation. This study evaluates the economic vulnerability of commercial livestock farmers to agricultural drought in the Northern Cape Province, South Africa, using an integrated Intergovernmental Panel on Climate Change (IPCC) vulnerability framework and a fractional logit model to explain vulnerability determinants. The results show that 85% of farmers are moderately vulnerable, while only 9.8% are highly vulnerable. Exposure to vulnerability is largely driven by price volatility and drought-induced income losses, while adaptive capacity is largely explained by on-farm diversification and drought adaptation practices. The level of economic vulnerability is significantly influenced by farmer age, farming experience, social networks, government assistance, and immovable asset structures, while farm size and herd size were not significant predictors. These findings suggest that economic resilience is shaped more by financial flexibility, adaptive management capacity, and institutional dynamics than by production scale alone. The study emphasises the need for policy interventions that move beyond disaster relief toward proactive resilience-building strategies, including diversification support, climate risk financing, and adaptive capacity strengthening. These insights are critical for designing policies to improve the long-term sustainability of commercial livestock systems amid increasing climate risk. As a result, farmers need a support mechanism to enhance their resilience to economic vulnerability from agricultural droughts and towards achieving SDG2 and the African Union CAADP Strategy and Action Plan: 2026–2035, which aims to end hunger and poverty by intensifying sustainable food production, agro-industrialisation, and trade.

KEYWORDS: financial safety nets; resilience; moderate vulnerability; drought relief; commercial livestock farmers; SDG

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INTRODUCTION

Research and Markets [1] highlighted that as of 2025, the international livestock and meat market is estimated to be worth USD 573 billion. Analysts predict the market will increase significantly, reaching USD 637 billion by 2029. Due to changing diets, population growth, and rising wages, the livestock industry is the fastest expanding agricultural subsector in middle- and low-income nations. The entire livestock value chain offers significant potential for farmers, agribusiness, and employment providers [2]. The livestock sector's significance should be emphasised as a consumer or user of natural resources and a source of livelihood support, which is essential in providing people and communities with sustainable options that, in turn, stimulate economic growth [3]. As the single biggest user of land systems on earth, the livestock industry occupies extensive areas of rangelands and utilises significant resources. It consumes a third of the world's freshwater sources and a similar proportion of cropland for feed production. Despite these demands, Herrero et al. (2013) [3] view the livestock industry as a cornerstone of the global economy, accounting for 40% of agricultural Gross National Product (GNP) and covering 30% of the planet's ice-free surface.

Drought significantly impacts commercial livestock farmers, affecting all regions of the world, including sub-Saharan Africa [4]. The reduced availability of water and quality pastures leads to nutritional deficiencies and decreased livestock productivity, increasing feed and water costs and placing financial strain on farmers [5]. Globally, these factors contribute to market fluctuations as supply decreases, impacting prices and overall stability in the livestock sector [6]. Furthermore, the increasing frequency of droughts linked to climate variability indicates long-term threats to food security and agriculture worldwide. Thus, influencing SDG2 and the African Union CAADP Strategy and Action Plan: 2026–2035, which aims to end hunger and poverty by intensifying sustainable food production, agro-industrialisation, and trade.

Farmers in South Africa face challenges that hinder their ability to achieve sufficient production and profitability. Key issues include increased demand for agricultural land and the rising costs of farming inputs, while output prices do not necessarily increase at the same rate [7]. These factors, among others, have created a financial squeeze for farmers. Additionally, farmers have to contend with erratic rainfall and other weather-related issues due to climate variability. The effects of climate change impact developing nations across all areas of development, particularly in agriculture [8]. As a result, the National Disaster Management Centre declared the persistent drought conditions throughout the Northern Cape Province of South Africa a disaster area [9]. This declaration highlighted the ongoing and varying intensity of drought in the province, which persisted over time. The Northern Cape Province has the lowest rainfall and is the most arid of all provinces in South Africa;

due to the climate conditions, livestock production is the only viable agricultural activity.

Given the anticipated increase in drought frequency and intensity due to climate change, the adverse effects on people and the economy will likely worsen. Economic vulnerability is a significant adverse outcome of drought in agriculture. Effective policies and resilience measures are imperative to minimise drought risk and support affected communities, especially livestock producers who are disproportionately impacted. Enhancing resilience involves adapting to gradual and rapid changes and creating robust systems, which can withstand and recover from these challenges [10–12].

Lottering et al. (2020) [13] used a systematic approach to examine the impact of droughts on smallholder agriculture in sub-Saharan Africa and found that droughts had varying effects on the environment, social structure, and economic development. The authors suggest that critical follow up actions should be taken to enhance preparedness and mitigation measures to minimise the impact of drought on smallholder farmers and rural populations. Holman et al. (2021) [14] used a Driver-Pressure-State-Impact-Response (DPSIR) approach, an analysis of weekly agricultural trade publications and conducted semi-structured interviews to explore drought impacts and responses in the United Kingdom. The authors found that on farm, a diverse range of measures were implemented across institutional scales and the supply chain, reflecting complex interactions within the food system. Drought responses were dominated by reactive and crisis-driven actions to cope with or enhance recovery from, drought, which contributed little to increased resilience towards future droughts. Mdungela et al. (2017) [15] conducted an exploratory study to identify and quantify the indicators of economic drought vulnerability among community farmers in South Africa. The authors found that farm debt and financial safety nets were highest in the vulnerability index, indicating a strong influence on financial vulnerability. Mare et al. (2018) [7] assessed the impact of drought on commercial cattle farmers in South Africa during the 2015–2016 drought. The descriptive study was based on primary data collected from 350 commercial livestock producers in seven provinces. The findings revealed that the effect of drought had a significant impact on average herd/flock size, and livestock feed.

Bahta and Myeki (2022) [16] conducted a study in the Northern Cape Province of South Africa to assess the impacts of agricultural drought on smallholder farming households. Results revealed that nearly 80% of smallholder livestock producers were not resilient to agricultural drought, which underscored the need for more robust resilience strategies. Statistics South Africa [17] investigated the impact of agricultural drought resilience on the welfare of smallholder livestock farming households in the Northern Cape Province. The findings revealed that smallholder farmers achieved improved outcomes when supported during periods of drought. The study also found that economic, social, human, and natural capital influenced the welfare of smallholder farmers.

Many studies focused on smallholder livestock farmers, with Mare et al. (2018) [7] concentrating on commercial farmers. However, their study did not address economic vulnerability, but examined the adaptive measures implemented by farmers and the impacts on drought on herd/flock size and livestock feed. As a result, there is a gap in the current understanding of economic vulnerability indicators for agricultural drought, particularly in the context of commercial farmers, their revenue, and adaptive drought strategies. Therefore, this study identified and evaluated indicators of economic vulnerability to agricultural drought among commercial farmers in the Northern Cape Province of South Africa. The aim is to contribute to the dialogue around drought risk and mitigation policies. The findings will be in accord with Sustainable Development Goal 2 and the African Union's Comprehensive Africa Agriculture Development Programme (CAADP) Strategy and Action Plan: 2026–2035, which focuses on eradicating hunger and poverty while enhancing sustainable food production, agro-industrialization, and trade. Although this research is conducted in South Africa, the conceptual framework could be applied to other regions.

MATERIALS AND METHODS

Study Area

The Northern Cape Province is situated in the northwest of South Africa, with Kimberley as its capital. With an estimated population of 1.2 million, the Northern Cape has the smallest population among South Africa's nine provinces. However, it has a surface area of 372,889 km^2, or 30.5% of the country's total land area, making it the largest province [18]. Five district municipalities are present in the province: Namakwa (126,900 km^2), Pixley Ka Seme (103,500 km^2), ZF Mgcawu (102,500 km^2), John Taolo Gaetsewe (27,300 km^2), and Frances Baard (12,800 km^2) (Northern Cape Municipalities, 2012).

According to Richaud (2019) [19], the Vegetation Condition Index (VCI) for 2019, compiled using 23 years of data, indicated that the drought was the most severe in the central, southern, and western parts of the Northern Cape Province. This area is west of the N10 road, north of the Western Cape border, east of the Atlantic Ocean, and south of the Namibian border. Regarding vegetation, three broad areas fall within this region: Namakwa, the Great Karoo, and the Green Kalahari. The Namakwa region comprises the Namakwa District Municipality, the Green Kalahari Region comprises part of the ZF Mgcawu District Municipality, and the Great Karoo Region comprises part of the Pixley ka Seme District Municipality. This area, as identified by Richaud (2019) [19], was designated as the study area and is shown in Figure 1. The local municipalities are listed in Table 1.

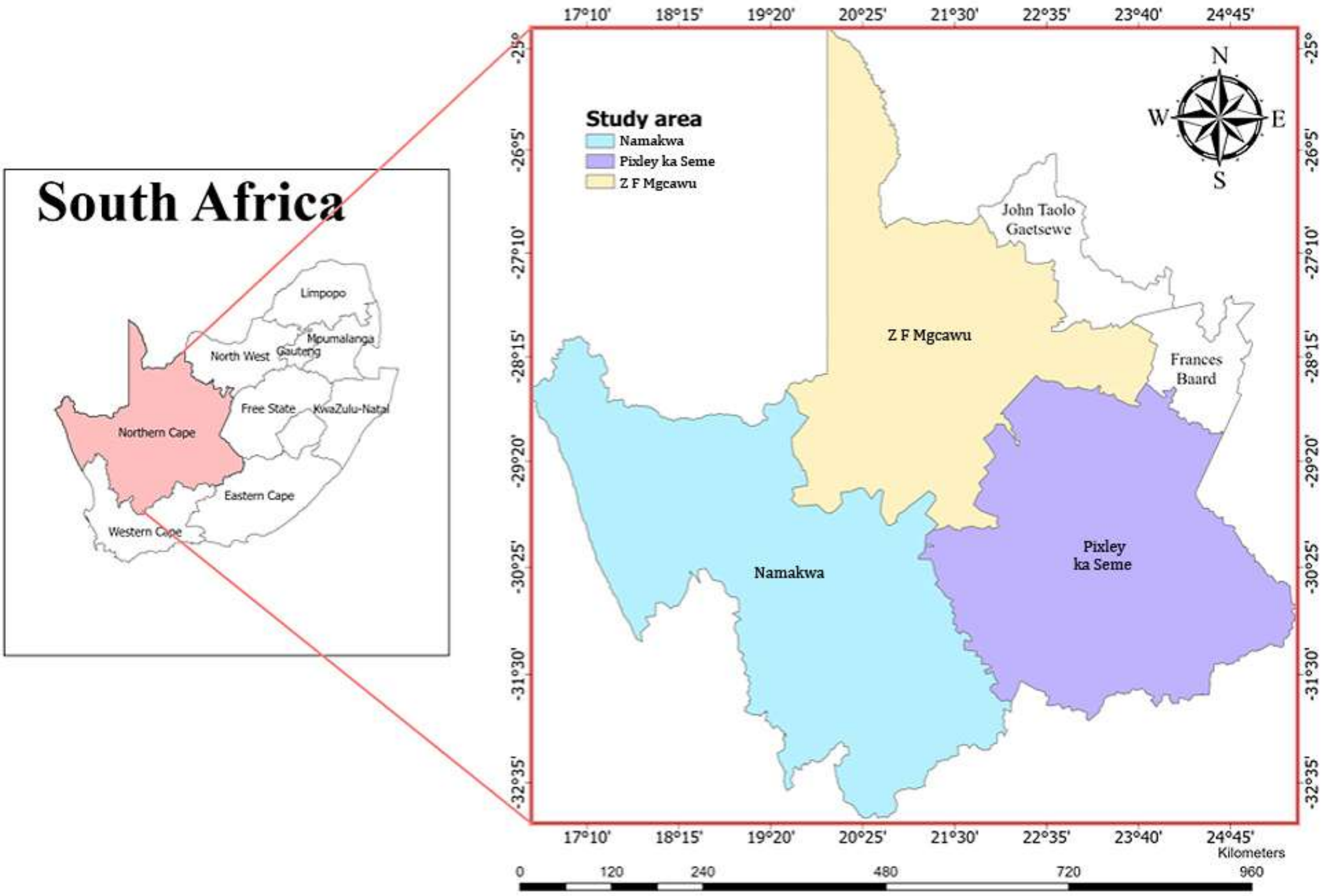

Figure 1. Study area. Source: Authors.

The livestock industry is a crucial part of the province's economy, making it the ideal setting for assessing the economic vulnerability of commercial livestock farmers. However, there are other drivers, such as irrigation schemes to produce crops that require large amounts of water. Table 1, based on Stats SA [20], provides the number of commercial (Value Added Tax (VAT) registered) farmers in the different areas.

Table 1. Total number of Value Added Tax (VAT) registered commercial farmers and those engaged in livestock farming in the study area.

Vegetation	District Municipalities	Local Municipalities	Total Farmers	Livestock (Large and Small) Farmers
Namakwa	Namakwa	Richtersveld, Nama Khoi, Khâi-Ma, Kamiesberg, Hantam, Karoo Hoogland	838	72
Green Kalahari	ZF Mgcawu	Kai !Garib !Kheis	484	57
Great Karoo	Pixley ka Seme	Siyathemba, Kareeberg, Emthanjeni, Ubuntu	886	173
	Total		2208	302

Source: Authors.

Sample Design and Data Collection

A multi-stage sampling procedure was used. In the first stage, the Northern Cape Province was deliberately selected because it is South Africa's primary livestock-producing province, and the National Drought Mitigation Center has declared the Northern Cape a disaster area 6 times since 2002, the latest in the 2020/2021 production season. The second stage involved random sampling of the study area by ballot from the VAT list of registered commercial livestock farmers. The ballot system involves randomly selecting a subset of cast ballots to ensure a representative, impartial sample. Three district municipalities were included because they were most affected during previous droughts. In the third stage, commercial livestock farmers were selected using simple random sampling and interviewed. Meanwhile, the sampling process had several stages; only people who met certain requirements were included in the sample. To be eligible for inclusion, participants had to be commercial livestock farmers, willing to take part, and members of the district municipalities.

As indicated in Table 1, 302 VAT-registered commercial livestock farmers were identified in the study area [20]. The Cochran (1997) [21] and Bartlett et al. (2001) [22] methods for simple random sampling were used to determine the sample size, with Bahta (2022) [23] also using this method to study smallholder farmers' social vulnerability. The correct sample size was determined using Cochran's (1977) [21] sample size formula (Equation (1)):

$$\text{Sample size} = \frac{(\mathrm{q})^2 * (\mathrm{z})(\mathrm{r})}{(\mathrm{w})^2} \tag{1}$$

where "q" is the level of confidence/alpha level (value for the selected alpha level indicates the level of risk the researcher is willing to take so that the actual margin of error may exceed the acceptable margin of error); z and r are the estimates of the variance of the population; estimate of variance calculated as = 0.25 (maximum possible proportion (0.5) × 1 − maximum possible proportion (0.5) produces maximum possible sample size); and "w" is an acceptable margin of error for proportion being estimated = 0.05 (5%) (error researcher is willing to take). If this formula were applied to the study with an alpha level of 1.28 (0.20), estimated variance of 0.5 and an error level of 0.05, the formula would be as follows (Equation (2)):

$$\text{Sample size} = \frac{(1.28)^2 * (0.5)(0.5)}{(0.05)^2} \tag{2}$$

Thus, resulting in a sample size of 164 participants. With 302 registered commercial livestock farmers and applying the formulas in Equations (3) and (4), a sample size of 164 would represent 54% of the total population, requiring the application of Cochran's (1977) [21] formula.

$$N_1 = \frac{\text{Sample size}}{1 + (N_0/\text{population})} \quad (3)$$

$$N_1 = \frac{164}{1 + \left(\frac{164}{302}\right)} \quad (4)$$

$$N_1 = 106$$

Therefore, 106 commercial livestock farmers had to be interviewed. However, the study obtained complete questionnaires from 123 participants. For sample adequacy, a post hoc power analysis using G × Power indicates that with 123 observations, 10 predictors, and an alpha of 0.05, the study attains 80 per cent power to detect medium effect sizes (Cohen's $f^2 = 0.15$).

Primary data were collected from the questionnaires, visits to farmers' associations, and face-to-face interviews. The data collection period was from August 2023 to October 2024. Both qualitative and quantitative data were gathered via the questionnaires. The questionnaire covered a wide range of topics, including the effects of drought, socio-economic characteristics of farmers, perceptions of drought, changes in the availability of natural resources, livestock production, and other farming activities. It also addressed resource availability, household vulnerability, food security, and social safety nets. The questionnaire covered a broad range of topics in a larger study, with this article focusing on economic vulnerability. The study received the necessary ethical clearance to gather the data (Ethical clearance number: UFS-HSD2023/0373/3).

Data Analysis

Economic Vulnerability Index

The survey data from the participants were processed and utilised to calculate the economic vulnerability index. Composite indices are widely used in economic vulnerability and resilience research because vulnerability is inherently multidimensional and cannot be captured using a single indicator. These indices are also widely employed by international organisations, including the United Nations, World Bank, and OECD, to support policy prioritisation, vulnerability screening, and resource allocation decisions. Meanwhile, these composite indicators inevitably involve methodological choices; their value rests on their ability to synthesise complex information into interpretable metrics that support comparative analysis and evidence-based decision making.

From both conceptual and empirical perspectives, economic vulnerability is well documented [24]. Briguglio et al. (2009) [24] define economic vulnerability as an economy's exposure to exogenous shocks arising from economic openness. The initial step in identifying the economic vulnerability indicators for drought in the Northern Cape used the BBC (Bogardi, Birkman, Cardona) framework, presented in Figure 2.

According to Cardona (1999 &2001) [25,26], the BBC conceptual framework underscores the intricate nature of vulnerability and resilience in the face of external shocks, whether human- or environment-related. This framework was chosen for its comprehensive approach in addressing social, environmental, and economic vulnerabilities, which are fundamental to sustainable development. It emphasises that vulnerability assessment goes beyond merely evaluating the impact of disasters; it focuses on coping capabilities and intervention methods to mitigate vulnerabilities. Moreover, the BBC model is favoured for its emphasis on proactive risk reduction, which highlights the importance of identifying economic vulnerabilities before a disaster strikes to understand the degree of vulnerability [27].

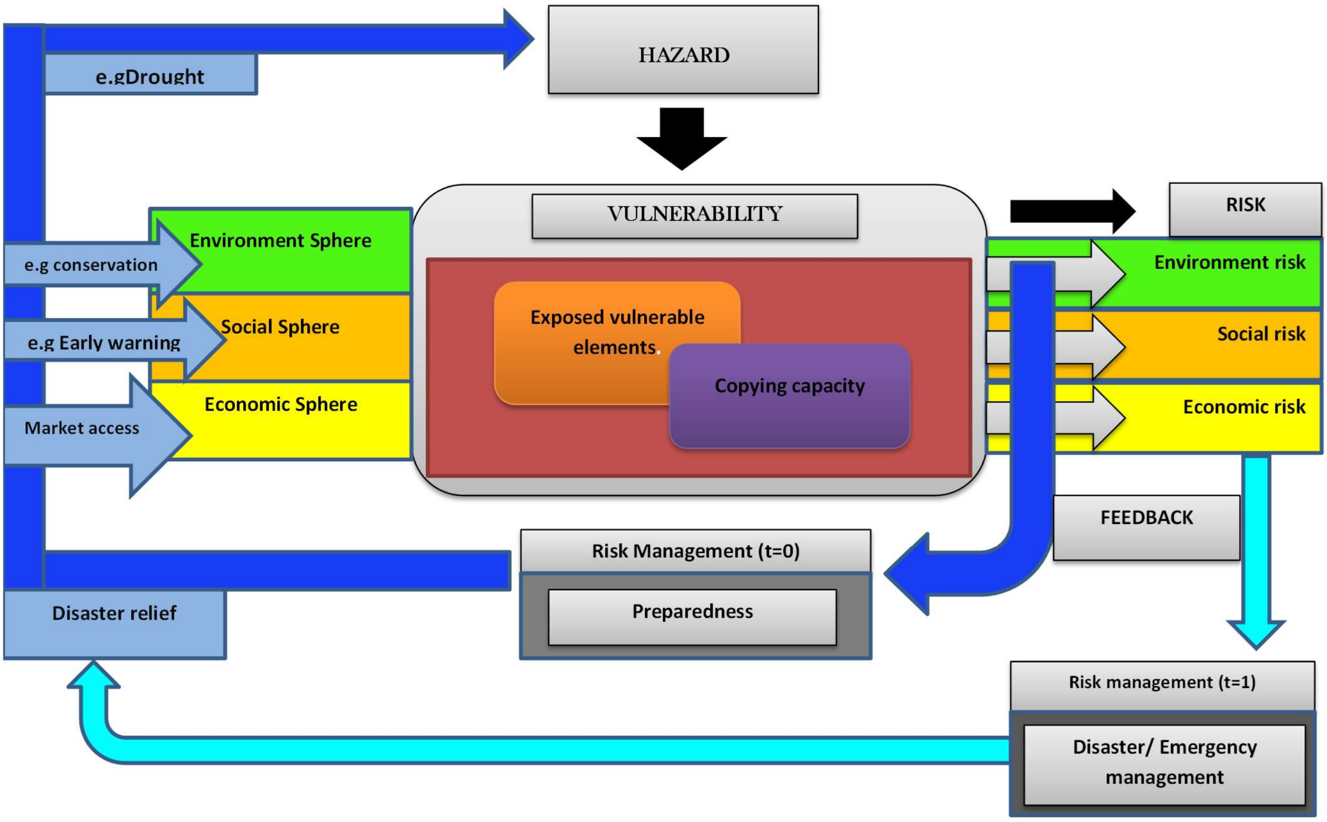

Figure 2. Conceptual Framework for Vulnerability. Source: Bogardi and Birkmann (2004) [27]; Cardona (1999 &2001) [25,26].

The selected economic indicators are presented in Table A1. Indicators were selected from literature, expert opinions (extension officers), observations, ease of measurement, feedback from farmers, relevance, availability, and the importance of the indicator to the Northern Cape Province of South Africa. A lack of access to essential resources such as water and quality feed can heighten vulnerability. Additionally, the sensitivity of livestock product prices to market changes significantly affects farmers' income stability. On-farm diversification allows farmers to mitigate risks by producing a variety of livestock or crops, providing a buffer against adverse conditions. The level of debt is also crucial; those with higher debt may struggle to recover from losses. Market access is vital in ensuring that farmers can sell their products effectively. Financial safety nets and alternative income sources offer essential support during adverse times, while off-farm diversification can secure additional revenue when farm income declines.

A decrease in farm income (revenue) was added, calculated by subtracting the farm income of drought years from farm income during normal years (income earned without drought) and dividing it by the normal year's income (income earned without drought) to use as a base. A decline in farm income and subsequent additional costs during a drought can worsen vulnerability. Farming practices instituted to minimise potential drought effects were added to the indicators; these practices, such as conservation agriculture, can make farmers less vulnerable to drought. Examining the interconnected elements enabled a comprehensive understanding of how agricultural drought influenced commercial livestock farming. A Likert scale was used to categorise the indicators by assigning the following scores: extremely high (5), high (4), moderate (3), low (2), and extremely low vulnerability (1). Empirically, the economic vulnerability index is calculated as (Equations (5) and (6)):

$$V^{eco} = \sum_{i=1}^{20} w_i^{eco} v_i^{eco} \quad (5)$$

$$V^{eco} f(w_1^{eco} v_1^{eco}, w_2^{eco} v_2^{eco}, \dots \dots, w_9^{eco} v_9^{eco}) \quad (6)$$

where: v_1^{eco} = Lack of access to resources; v_2^{eco} = Price sensitivity of products; v_3^{eco} = On-farm diversification; v_4^{eco} = Level of debt; v_5^{eco} = Market access; v_6^{eco} = Financial safety nets/alternative sources of income; v_7^{eco} = Off-farm diversification; v_8^{eco} = Decrease in farm income (farm income in normal years (without drought) (Definitions for "normal years" and "drought years" are generally determined by comparing precipitation or water supply levels against long-term averages (climatology) for a specific region, often using standardised indices. Drought year is a prolonged period of below-normal precipitation resulting in water shortages, environmental damage, or, in socioeconomic terms, demand exceeding supply. Normal year comprises years with precipitation, streamflow, or soil moisture levels close to the long-term average.)—farm income during drought years)/farm income during normal years (without drought) × 100); v_9^{eco} = Farming practices applied; and w_1^{eco} – w_9^{eco} are weights created using principal components analysis.

Principal Component Analysis (PCA) was used to construct the Economic Vulnerability Index from the nine economic indicators. Before analysis, all variables were standardised using z-score normalisation to eliminate scale differences. The suitability of PCA was confirmed using the Kaiser-Meyer-Olkin (KMO) test and Bartlett's Test of Sphericity in Table 2. The first principal component was retained as the Economic Vulnerability Index based on eigenvalues greater than one and the proportion of variance explained. Factor scores generated using the regression method were used as the composite vulnerability index.

The KMO measure of sampling adequacy was 0.581, which reflects an acceptable suitability of the data for Principal Component Analysis. The Bartlett's Test of Sphericity was also significant at one percent which confirms that the correlations among variables were sufficiently large for PCA.

Table 2. KMO and Bartlett's Test of Sphericity.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**0.581**
Bartlett's Test of Sphericity	Approx. Chi-Square	95.011
	df	36
	Sig.	0.000

Sources: Authors.

The results of in Table 3 below show the total variance explained where PCA extracted four components with eigenvalues greater than one, which explaining 61.7% of the total variance. The first component explained 21.98% of the variance, which suggests that economic vulnerability is multidimensional rather than driven by a single dominant factor, and the cumulative variance exceeds the recommended 50%.

Table 3. Total Variance Explained.

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	1.978	21.976	21.976	1.978	21.976	21.976
2	1.264	14.047	36.023	1.264	14.047	36.023
3	1.187	13.188	49.211	1.187	13.188	49.211
4	1.124	12.493	61.704	1.124	12.493	61.704
5	0.903	10.036	71.740	-	-	-
6	0.751	8.344	80.084	-	-	-
7	0.731	8.119	88.203	-	-	-
8	0.637	7.076	95.279	-	-	-
9	0.425	4.721	100	-	-	-

Sources: Authors.

Economic Vulnerability Index in the IPCC Framework

Due to the multidimensional nature of vulnerability as discussed by Ayanlade (2023) [28], this study adopts the Intergovernmental Panel on Climate Change (IPCC) vulnerability framework, which defines vulnerability as a multidimensional, complex phenomenon, a propensity or predisposition to be adversely affected by climate change. In its Sixth Assessment Report (AR6), the IPCC highlights that economic vulnerability is not just a measure of GDP, but a compound risk influenced by social, political, and environmental factors. The IPCC conceptualises vulnerability as a function of exposure, sensitivity, and adaptive capacity. Within this framework, economic vulnerability to agricultural drought is understood as the extent to which farming households are economically susceptible to drought shocks, their structural sensitivity to these shocks, and their ability to cope and adapt through available resources and strategies.

The Economic Vulnerability Index was constructed using a PCA-based weighting approach based on the IPCC vulnerability framework. In this process, indicators were first grouped into the exposure, sensitivity, and adaptive capacity dimensions according to economic vulnerability theory, as shown in Table 4. Principal Component Analysis was thereafter employed separately within each dimension to derive data-driven weights and construct sub-indices. The resulting factor scores were normalised using a min-max transformation, and the Economic Vulnerability Index was obtained as the sum of the weighted (using the PCA variance explained) exposure and sensitivity indices, plus the inverse of the adaptive capacity index, to ensure that higher values reflect greater economic vulnerability.

$$EVI_i = [w * Exposure) + (w * Sensitivity) + w(1 - Adaptive)] \quad (7)$$

Table 4. Indicators used in constructing the Economic Vulnerability Index-IPCC.

Vulnerability Dimension	Indicator	Expected Relationship with Vulnerability
Exposure	Price sensitivity of livestock products	Positive
	Percentage decrease in farm revenue	Positive
Sensitivity	Lack of access to resources	Positive
	Level of debt	Positive
	Market access constraints	Positive
Adaptive capacity	On-farm diversification	Positive
	Off-farm diversification	Positive
	Financial safety nets	Positive
	Drought adaptive practices	Positive

Sources: Authors.

Principal Component Analysis Diagnostics for EVI-IPCC

The principal component analysis (PCA) diagnostics in Table 5 confirm that the selected indicators are statistically appropriate for constructing the economic vulnerability index. The Kaiser-Meyer-Olkin (KMO) values for the exposure (0.50), sensitivity (0.55), and adaptive capacity (0.64) sub-indices all meet the minimum acceptable threshold of 0.50, indicating adequate sampling adequacy and sufficient intercorrelations among the variables. Moreover, the Bartlett's Test of Sphericity was statistically significant across all three sub-indices, confirming that the correlation matrices are not identity matrices and that meaningful latent structures exist within the data. This provides strong statistical justification for applying PCA as a data reduction and weighting technique in the construction of the vulnerability index. The PCA results further show that one principal component was retained for each vulnerability dimension following the eigenvalue greater than one criterion.

The PCA factor loadings in Table 6 provide valuable insights into the relative significance of indicators contributing to economic vulnerability among commercial livestock farmers. In the exposure dimension, price sensitivity (0.759) and a decrease in farm income (0.759) show identical and strong factor loadings, indicating that market price fluctuations and drought-induced income shocks together constitute the primary sources of economic exposure. This finding underscores the vulnerability of commercial livestock farmers not only to climatic stress but also to market instability, reinforcing the notion that drought vulnerability encompasses both production and market risk phenomena.

Table 5. KMO and Bartlett's Test of Sphericity for EVI-IPCC.

Sub-Index	KMO	Bartlett Test (Sig)	Components Retained	Variance Explained (%)
Exposure	0.50	<0.001	1	57
Sensitivity	0.55	<0.001	1	42
Adaptive capacity	0.64	<0.001	1	46

Sources: Authors.

Table 6. Factor loadings for vulnerability indicators.

Indicator	Exposure	Sensitivity	Adaptive Capacity
Price sensitivity	0.759	-	-
Income decrease	0.759	-	-
Lack of resources	-	0.745	-
Debt level	-	0.490	-
Market access	-	0.750	-
On-farm diversification	-	-	0.774
Off-farm diversification	-	-	0.562
Financial safety nets	-	-	0.554
Adaptive practices	-	-	0.778

Sources: Authors.

In the sensitivity dimension, market access constraints (0.750) and lack of access to resources (0.745) emerge as the strongest contributors, highlighting the major role structural constraints play in shaping farmers' economic vulnerability. These results suggest that farmers with limited access to production resources and markets are less equipped to absorb economic shocks. The relatively lower loading for debt levels (0.490), though still significant, may imply that debt alone does not necessarily heighten vulnerability unless it is coupled with other structural disadvantages such as poor market integration or limited productive assets.

Regarding adaptive capacity, the strongest contributors are adaptive farming practices (0.778) and on-farm diversification (0.774), followed by off-farm diversification (0.562) and financial safety nets (0.554). These findings emphasise the crucial role of diversification and proactive drought management strategies in mitigating economic vulnerability. Farmers who adopt multiple production activities and drought adaptation practices seem better positioned to withstand financial shocks. The results also suggest that while financial safety nets contribute to resilience, practical on-farm adaptation strategies may play an even more significant role in bolstering economic resilience.

Determinants of Economic Vulnerability

To analyse the determinants of economic vulnerability among commercial livestock farmers, this study employs a fractional logit regression model by Papke and Wooldridge [29]. This model is adopted because the economic vulnerability index is bounded between zero and one (see Figure A1). The fractional logit model produces consistent and efficient estimates compared to ordinary least squares regression (OLS), which may generate biased predictions outside the feasible range. A Tobit model was later estimated as a robustness check, given the nature/distribution of indices, with 0 to 1 bound.

The fractional logit model is a quasi-likelihood method that does not assume a distribution but only requires the conditional mean to be correctly specified, yielding consistent parameter estimates with an identical likelihood function that has a structure similar to that of a Bernoulli distribution [30]. The quasi-log likelihood for observation i is similar to the logit binary response model and presented as:

$$l_i(\alpha) = y_i \log[h(X_i\alpha)] + (1 - y_i)\log[1 - h((X_i\alpha)]; \text{with } 0 \le y_i \le 1 \quad (8)$$

where $h(X_i\alpha)$ the logistic Cumulative Distribution Function and $y_i \in [0,1]$ (that differs from binary logit, which limits y to values of 0 and 1). The expectation form of the model is specified as:

$$E(y_i|X_i) = \frac{\exp(X_i\alpha)}{[1 + \exp\,((X_i\alpha)]} = h((X_i\alpha) \quad (9)$$

With the boundary probabilities for the dependent and independent variables specified as:

$$\Pr((y_i = 0|X_i) > 0 \text{ and } \Pr((y_i = 1|X_i) > 0 \quad (10)$$

To confirm the suitability of the fractional logit model, a double limit Tobit regression for a robust check with a latent variable setup with the possibility of two corner solutions, as 0 for no vulnerability and 1 for complete vulnerability, was estimated. The Tobit model assumes that there is a latent variable Y* such that

$$y_i^* = X_i\alpha + f(y_{i-1})\rho + k_i + \varepsilon_i \quad (11)$$

$$\varepsilon_i|(X_i, y_{i-1}, \ldots\ldots, y_{i0}, k_i) \sim N(0, \sigma_\varepsilon^2) \quad (12)$$

$$y_i = \begin{cases} 0 \; if \; y_i^* \le 0 \\ y_i^* \; if \; 0 < y_i^* < 1 \\ 1 \; if \; y_i^* \ge 1 \end{cases} \quad (13)$$

where X_i represent independent variables, k_i represent the unobserved effects and ε_i is the normally distributed error term. Before estimation, multicollinearity was tested using the Variance Inflation Factor (VIF), with an average VIF of 1.5, which is below 10, confirming no serious multicollinearity is observed (see Table A2). Variables with VIF values above 10 were examined for potential removal. Heteroskedasticity was addressed using robust standard errors.

RESULTS AND DISCUSSIONS

Socio-Economic Characteristics of the Participants

Table 7 displays the socio-economic features of the participants. In South Africa, the norm is that males dominate commercial farming. This is supported by the results, which show that 98.4% of the farmers are male and 1.6% are female. The dominance of male farmers can be attributed to the physical work involved as well as social and institutional factors, such as land tenure structure. Similarly, Ngaka (2012) [31] found that farmers are predominantly male.

Most participants were married (89.4%), followed by single (9%), with widows/widowers and divorced at 0.8% each. Being married can add value in times of drought, as partners can help deal with stress, or, if needed, can seek other work to provide additional income. Bahta (2021) [32] reported somewhat different results among smallholder farmers, where only 67% were married, and 11% were widowed.

Education can be critical in deciding what steps should be taken to cope with drought. Few (6.5%) participants left school before Grade 12, with 26.8% finishing Grade 12.8%. Most participants, however, had a degree or diploma (48.8%) or a postgraduate qualification (17.9%). Education can assist with making better decisions on the farm. In contrast, Mdungela and Bahta (2017) [15] found that most smallholder farmers were only educated to a primary school level, and only 3.68% obtained tertiary-level qualifications.

Farmers' primary occupation is not necessarily full-time farming, where some might have another primary job and farm on weekends or when time allows. In the current study, farming was significantly the main occupation (93.5%) compared to other formal employment (4.9%) and businesses (1.6%). Thus, most participants depended primarily on farming as an income source, making them more vulnerable to the impact of drought. This concurs with DAFF's [33] findings where most households depended on livestock farming as the only income source.

The youngest and oldest participants were 24 and 84 years old, respectively; the average age was 53 years. The highest age group, 50 years and older, accounted for 72.4% of the participants. Similar results were found by Mdungela et al. (2017) [15], who found that 42% of farmers were older than 55 years. The years of farming experience ranged from 3 to 58 years, with an average of 28 years. The groups of 20 to 29 years of farming experience and 30 to 39 years of experience comprised 24.4% and 25.2%, respectively. The age trade-off is that younger farmers are more likely to take risks and test new methods, while older farmers stick to what they know [34]. Conversely, more years of farming experience imply that farmers have more knowledge to apply to specific situations, which can be important during times such as drought.

Table 7. Socio-economic characteristics of livestock farmers.

Variable	**Characteristics**	**Frequency**	**Percentage**
Gender	Male	121	98.4
	Female	2	1.6
Total		123	100
Marital status	Single	11	9
	Married	110	89.4
	Widow/Widower	1	0.8
	Divorced	1	0.8
Total		123	100
Highest educational level	<Grade 12	8	6.5
	Grade 12	33	26.8
	Degree/Diploma	60	48.8
	Postgraduate qualification	22	17.9
Total		123	100
Main occupation	Farmer	115	93.5
	Formal employment	6	4.9
	Business	2	1.6
Total		123	100
Age (years)	Minimum	24	-
	Maximum	84	-
	Mean	53	-
	20–29	4	3.3
	30–39	9	7.3
	40–49	21	17
	50+	89	72.4
Total		123	100
Years farming	Minimum	3	-
	Maximum	58	-
	Mean	28	-
	0–9	12	9.7
	10–19	20	16.3
	20–29	30	24.4
	30–39	31	25.2
	40+	30	24.4
Total		123	100
Farm size (ha)	Minimum	1000	-
	Maximum	33,000	-
	Mean	9436	-
	0–1999	2	1.7
	2000–3999	11	8.9
	4000–5999	9	7.3
	6000+	101	82.1
Total		123	100

Source: Authors' compilation based on survey data.

Farm size included farms owned, rented, and the total area used for production. The smallest area was 1000 hectares, and the largest was 33,000 hectares, with an average of 9436 hectares. Farm sizes are considerably larger than in other provinces, as the carrying capacity is much lower. Thus, farmers need much larger farms to carry the same number of animals and make it financially feasible. Over two-thirds (82.1%) of the farms' sizes were larger than 6000 hectares. The vast area is supported by Meissner et al. [35], who state that more land is needed in semi-arid to arid areas than in any other area in South Africa to make farming profitable.

Economic Vulnerability Index

EVI distribution

The economic vulnerability index was first computed using the factor scores generated using the regression method. The distribution of EVI, as presented in Table 8, shows that 64.2% of commercial livestock farmers fall within the high vulnerability category, while only 7.3% exhibiting low vulnerability. This may be driven by a lack of adaptive strategies, diversification options, high sensitivity of product prices, and constrained access to markets. This shows that most farmers lack sufficient financial buffers, diversification strategies, and market resilience to withstand drought shocks. The findings indicate prevalent exposure to financial risk among commercial livestock farmers, largely driven by income losses, price volatility, and limited adaptive capacity [36]. This outcome further invites multidimensional assessment of vulnerability.

Table 8. Economic vulnerability index distribution.

EVI	Frequency	Percent
Low vulnerability	9	7.3
Moderate vulnerability	35	28.5
High vulnerability	79	64.2
Total	123	100.0

EVI in IPCC Framework

Economic vulnerability-IPCC distribution

The Economic Vulnerability Index distribution based on the IPCC framework in Table 9 indicates that most commercial livestock farmers (84.6%) are categorised as moderately vulnerable, with only 5.7% classified as having low vulnerability and 9.8% as highly vulnerable. This distribution indicates that while economic vulnerability is widespread among the sampled farmers, it is typically not severe. The high prevalence of moderate vulnerability suggests that while farmers experience significant financial stress during droughts, they possess a limited coping capacity that prevents them from falling into severe economic hardship. This may be attributed to the commercial nature of their farming systems, where farmers characteristically have some productive assets and management skills but remain susceptible to drought-induced financial pressures such as increased feed costs, reduced productivity, and unstable market prices [37,38].

The relatively small percentage of highly vulnerable farmers indicates that extreme economic fragility is not widespread but remains a concern for a specific group facing compounded challenges like high debt exposure, limited diversification, and weak financial buffers. These farmers likely represent priority targets for policy interventions aimed at enhancing financial resilience and risk management capabilities. The small proportion of low vulnerability farmers further suggests that achieving robust economic resilience is challenging even for commercial producers [39]. This finding may reflect that increasing climate variability and rising production costs are narrowing the margin of economic safety, even for relatively well-resourced farmers. These insights suggest that policy interventions should focus not only on highly vulnerable farmers but also on the large proportion of moderately vulnerable farmers who could potentially become highly vulnerable under severe or prolonged drought conditions if adequate support mechanisms are not reinforced.

Table 9. Economic vulnerability based on IPCC.

Category	**Frequency**	**Percent**
Low vulnerability	7	5.7
Moderate vulnerability	104	84.6
High vulnerability	12	9.8
Total	123	100

Sources: Authors.

Vulnerability Statistics

The descriptive statistics of the vulnerability indices in Table 10 and Figure 3 provide further understanding of the economic vulnerability structure among commercial livestock farmers. The exposure index, with the highest mean of 0.705, indicates that most farmers are significantly exposed to economic shocks associated with agricultural drought. This underpins the previous inference, also supported by Bell et al. (2021) [39], that price volatility and income fluctuations are major risk factors impacting financial stability in livestock production systems.

The adaptive capacity index also shows a relatively high mean value of 0.656, which appears counterintuitive given the moderate vulnerability observed. However, this may likely reflect the existence of coping mechanisms among farmers, such as diversification and adaptive management practices, despite the fact that these strategies may not fully counterbalance exposure and sensitivity pressures [36].

The sensitivity index, with a lower mean value of 0.482, suggests moderate structural constraints among farmers, which may suggest that while some farmers encounter resource and market access challenges, these constraints are not uniformly severe across all farmers. The moderate variability observed across all sub-indices reflects heterogeneity in farmers' economic conditions, which suggests that vulnerability is not uniform but varies according to farm characteristics, financial structure, and management capacity [40].

The general Economic Vulnerability Index has a mean value of 0.510, which indicates a moderate level of vulnerability across the surveyed commercial livestock farmers. The relatively small standard deviation of 0.109 suggests limited dispersion, with most farmers clustering around moderate vulnerability levels. The observed range of 0.235–0.818 confirms the presence of both relatively resilient and highly vulnerable farmers, which underscores the need for differentiated policy strategies rather than uniform interventions. These results confirm that economic vulnerability among commercial livestock farmers is predominantly driven by exposure to drought-related financial shocks, moderated by varying levels of adaptive capacity and structural sensitivity.

Table 10. Statistics for EVI-IPCC.

	Mean	Std. Dev	Minimum	Maximum
Exposure index	0.705	0.197	0.000	1
Sensitivity index	0.482	0.162	0.000	1
Adaptive index	0.656	0.207	0.000	1
Economic vulnerability index	0.510	0.109	0.235	0.818

Sources: Authors.

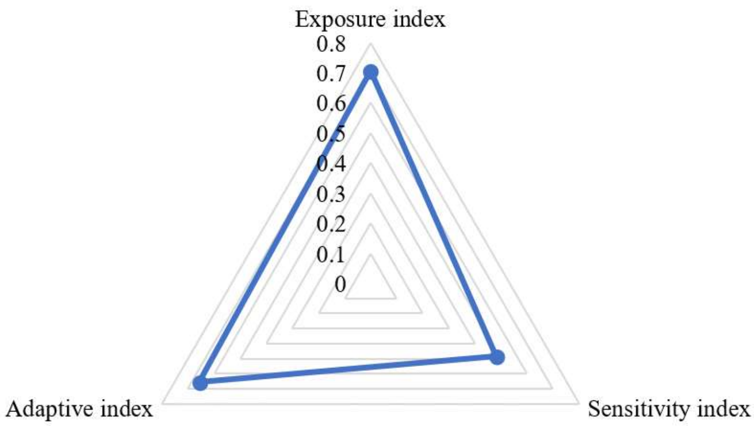

Figure 3. Vulnerability triangle diagram of the contributing factors of the Economic Vulnerability Index-IPCC (EVI–IPCC) for commercial livestock farmers in Northern Cape, South Africa. Sources: Authors.

Determinants of Economic Vulnerability to Agricultural Drought

To examine the factors influencing the economic vulnerability of commercial livestock farmers to agricultural drought, fractional logit and Tobit regression models were estimated. The Tobit regression is estimated as an alternative technique for robustness to the results. The consistency in coefficient signs and significance levels across both models suggests that the findings are stable and reliable. This is supported by the overall significance of both the chi-square (chi²) and F statistics, which indicate that the selected explanatory variables jointly explain variation in farmers' economic vulnerability. Furthermore, the similarity in the direction and statistical significance of coefficients between the fractional logit and Tobit models strengthens confidence in the empirical results.

The results presented in Table 11 show that farmer age has a negative and significant effect on economic vulnerability at the one percent level, which shows that older farmers are less economically vulnerable to agricultural drought compared to younger farmers. This reflects the role of accumulated farming knowledge, financial stability, and stronger coping experience. As also discussed by Yeleliere et al. (2023) [41], older farmers may also have well-established networks and assets that help to buffer economic shocks related to drought.

Table 11. Fractional logit and Tobit model regression results of determinants of economic vulnerability.

EVIIPCC	Fractional logit					Tobit		
	Coefficient	Rob std. err.	z	dy/ex	z	Coefficient	std. err.	t
Age	−0.015***	0.005	−3.060	−0.195	−3.08	−0.004***	0.001	−3.080
Gender	0.382	0.256	1.490	0.093	1.49	0.094	0.062	1.510
Household size	0.025	0.029	0.840	0.018	0.84	0.006	0.007	0.840
Farm experience	0.013***	0.005	2.570	0.084	2.59	0.003**	0.001	2.590
log_farmsize	−0.122	0.083	−1.460	−0.275	−1.46	−0.030	0.021	−1.460
log_herdsize	0.053	0.061	0.860	0.095	0.86	0.013	0.015	0.860
Cooperative	−0.108	0.093	−1.160	−0.023	−1.16	−0.027	0.023	−1.170
Social network	0.156**	0.075	2.090	0.020	2.1	0.039**	0.018	2.100
Government assistance	0.247**	0.124	1.980	0.001	2.01	0.060**	0.030	1.990
Credit access	−0.123	0.099	−1.240	−0.010	−1.24	−0.031	0.025	−1.240
Number of droughts	0.035	0.025	1.400	0.025	1.4	0.009	0.006	1.400
Auction distance	−0.001	0.000	−1.220	−0.024	−1.22	0.000	0.000	−1.230
Abattoir distance	−0.001	0.000	−1.470	−0.021	−1.48	0.000	0.000	−1.490
Feedlot distance	0.000	0.000	0.750	0.010	0.75	0.000	0.000	0.750
Immovable asset index	0.050**	0.023	2.140	0.000	−1.87	0.012**	0.006	2.090
Vehicle asset index	0.073	0.053	1.390	0.000	−0.88	0.018	0.013	1.390
Constant	0.853	0.651	1.310	-	-	0.711	0.160	4.440
Wald chi2(16)	114.300	-	-	--	-	-	-	-
Prob>chi2/>F	0.000	-	-	-	-	0.000	-	-
Log pseudolikelihood	84.678	-	-	-	-	111.984	-	-
Pseudo R2	0.007	-	-	-	-	−0.1317	-	-
var(e.EVIIPCC)	-	-	-	-	-	0.009	0.001	-
F(16, 107)	-	-	-	-	-	7.570	-	-

Note: *** and ** represent statistical significance at 1%, and 5% level. Sources: Authors.

Commercial livestock farmers with more farming experience, on the other hand, were observed to have a positive and significant relationship with economic vulnerability. While this appears to be contrary to expectations, it may suggest that more experienced farmers tend to remain heavily invested in livestock production and may therefore face greater financial exposure during drought events [40]. This is also connected to the fact that experienced farmers may operate larger and more commercially oriented enterprises, which increases their exposure to production and market risks [40,42].

Gender and household size were not found to significantly influence economic vulnerability, suggesting that economic exposure to drought among commercial livestock farmers may be driven more by structural and institutional factors rather than household demographic characteristics.

Farm-related attributes, such as farm size and herd size, showed a weaker statistical association with economic vulnerability, suggesting that simply owning larger farms or more livestock does not necessarily reduce economic vulnerability. This indicates that vulnerability depends more on management strategies and financial resilience rather than scale alone [43]. Similar results were observed for cooperative membership, although the negative coefficient suggests a potential shielding role. This outcome may reflect that existing cooperatives are not influential enough to effectively provide drought risk management support or financial protection services to their members.

Farmers with stronger social networks were found to be positively and significantly associated with economic vulnerability. This result may suggest that farmers experiencing higher economic vulnerability are more likely to rely heavily on their close relatives, family, or close-knit groups as coping mechanisms rather than social networks, which necessarily reduces vulnerability. Also supported by Zhang and Zhao (2024) [44], this means these social networks act more as ex-post reactive coping strategies of dealing with the economic fallout rather than preventive resilience mechanisms.

Government assistance to livestock farmers affected by agricultural drought showed a positive and statistically significant relationship with economic vulnerability across all models. This shows the targeting effects of the program, where more vulnerable farmers are more likely to receive government support, which underscores the case that government-supported programs may be reaching intended beneficiaries rather than implying that government support increases vulnerability. This is consistent with the vulnerability studies by Bahta and Myeki (2022) [16], and Sarmah et al. (2025) [45], in which support programs often respond to existing vulnerability conditions by targeting specific socioeconomic, structural, and environmental factors that limit farmers' adaptive capacity.

Factors connected to climate exposure, market access, and credit do not significantly influence economic vulnerability. Although the number of droughts experienced had a positive coefficient, which may suggest that repeated drought exposure may increase economic vulnerability, the lack of statistical impact may reflect adaptation learning effects after repeated drought exposure. Similarly, distance to auction, abattoir, and feedlot were insignificant, which may show that commercial livestock farmers have developed logistical arrangements that lower the importance of distance.

Concerning the effect of farm wealth and asset effects, remarkably, the immovable asset index showed a positive and statistically significant relationship with vulnerability. This suggests that farmers with greater investment in fixed assets may face higher vulnerability due to the illiquid nature of these investments, which cannot easily be converted into cash in cases of financial stress, which heightens financial rigidity during drought shocks [46,47]. The insignificance of movable/vehicle assets, although positive, may suggest that transport assets alone are insufficient to reduce vulnerability unless combined with other financial or adaptive resources. Similarly, for access to credit, the lack of significance may imply limited access to effective agricultural credit or insufficient credit amounts to meaningfully reduce drought-related financial risks [48].

CONCLUSION AND POLICY IMPLICATIONS

Drought has a significant impact and continues to have long-lasting consequences on South Africa’s agricultural sector. Many factors contribute to the impact of drought, one of which is economic vulnerability. This study examined the economic vulnerability of commercial livestock farmers to agricultural drought in the Northern Cape province of South Africa using the IPCC vulnerability framework combined with Principal Component Analysis and fractional logit and Tobit regression models to determine the associated factors for farmers’ level of vulnerability. By integrating IPCC exposure, sensitivity, and adaptive capacity dimensions, the study provides a comprehensive understanding of how drought affects the economic stability of commercial farming systems. The findings reveal that economic vulnerability among commercial livestock farmers is largely moderate, with most farmers experiencing some degree of financial exposure to drought shocks but maintaining limited coping capacity that prevents extreme vulnerability. Results of PCA showed that economic exposure is largely driven by price volatility and income losses due to drought, while sensitivity is shaped primarily by structural constraints such as limited resource access and market participation. Adaptive capacity is strongly influenced by on-farm diversification and the adoption of drought-adaptive practices, highlighting the importance of management strategies in reducing vulnerability. Results from the fractional logit and Tobit regression models showed that age reduces vulnerability, whereas farming experience increases vulnerability. Moreover, government assistance and social networks are positively associated with vulnerability. Traditional structural variables such as farm and herd size were not found to significantly reduce vulnerability, whereas a positive relationship between immovable assets and vulnerability was observed, suggesting that capital locked in fixed investments may reduce financial flexibility during drought periods. This concludes that economic vulnerability among commercial livestock farmers is shaped more by financial structure, adaptive management capacity, and institutional dynamics than by production scale. These findings highlight the importance of strengthening adaptive capacity and financial resilience mechanisms rather than focusing solely on increasing production capacity.

Therefore, with most farmers being moderately vulnerable, policy should focus on strengthening preventative resilience measures rather than only responding to crises. Programs promoting drought preparedness, enterprise diversification, and climate risk management could significantly reduce the likelihood of farmers transitioning into high vulnerability categories.

The critical role of diversification to adaptive capacity suggests that policies should actively promote both on-farm and off-farm diversification strategies. Support for mixed farming systems, alternative livestock enterprises, and complementary income sources could help reduce financial exposure to drought-related shocks.

While financial structure is observed to play a major role in vulnerability, improving access to financial risk management tools such as agricultural insurance, flexible credit schemes, and drought contingency financing is called for. This may include improving liquidity support mechanisms, mainly for farmers with high fixed asset investments who may face cash flow constraints during drought periods.

The positive impact of government assistance on vulnerability suggests that government support programs are largely reactive. This shows that there is a need to shift from reactive assistance toward proactive resilience-building interventions such as drought preparedness grants, adaptation investment support, and early warning response financing.

The importance of adaptive farming practices suggests that a larger emphasis on promoting drought adaptation strategies, such as conservation practices, improved breeding strategies, and feed management systems, should be encouraged via extension services. In addition to the African Union CAADP Strategy and Action Plan: 2026–2035, which aims to end hunger and improve sustainable food production, agro-industrialisation, and trade, this study contributes to accomplishing SDG 2, which calls for the eradication/reduction of hunger and poverty by 2030.

This study is limited in scope and generalisability as it was undertaken in one province, based on cross-sectional data, which falls short of capturing the economic dynamics, while falling short of discriminating the outcome based on farmer herd composition. Further research is therefore called to scale up the coverage to other provinces in South Africa, incorporating social and environmental vulnerability aspects which may alter the level of vulnerability, and the influence of herd heterogeneity. Additional research could determine whether specific adaptations (such as irrigation investment, solar-powered irrigation as an adaptation and recovery pathway, conservation practices, and financial instruments) reduce vulnerability and improve income resilience.

APPENDIX A. FIGURES AND TABLES DISPLAYING ECONOMIC VULNERABILITY INDEX DESCRIPTIONS, DISTRIBUTION, AND MULTICOLLINEARITY TEST

Table A1. The Economic Vulnerability Index.

Economic indicators	Index (Likert scale)	Description of indicator classification	Statement of measure	Relationship with vulnerability	Data source
Lack of access to resources	1	Land, water, inputs, additional feed, and finance	The proportion of farmers who do not have access to resources	The fewer resources they have, the more the vulnerability	Survey
	2	Land, water, and one other	-	-	-
	3	Land, water, and two others	-	-	-
	4	Land, water	-	-	-
	5	Land	-	-	-
Price sensitivity of products	1	Increase in product prices as a result of drought	The likelihood of getting higher price	An increase in the price of products increases the vulnerability	Survey
	2	Drought has no influence	-	-	-
	3	Product prices might decrease due to over-supply resulting from drought	-	-	-
	4	Product prices might decrease due to the poor condition of animals as a result of drought	-	-	-
	5	Product prices will definitely be lower during drought due to over-supply and poor condition of animals	-	-	-
On-farm diversification	1	Practice (fodder banks, different species of livestock, different breeds, mixed farming, irrigation)	An indication that on-farm diversification is practised	The less/no on-farm practices, the greater the vulnerability	Survey
	2	Apply three of the above	-	-	-
	3	Apply two of the above	-	-	-
	4	Apply one of the above	-	-	-
	5	Not practised–only one activity	-	-	-
Level of debt	1	No debt	% of farmers struggling to pay debt	The more farmers struggle to pay debt, the greater the vulnerability	Survey
	2	Can safely service debt	-	-	-
	3	Debt servicing brings cash flow problems	-	-	-
	4	Needed extended payments of debt	-	-	-
	5	Sell assets to service debt	-	-	-
Market access	1	Good market and open access through different channels	Indication of market availability	No market accessibility, the greater the vulnerability	Survey
	2	Open market with more than one regular buyer	-	-	-
	3	Only one regular buyer and far from main central	-	-	-
	4	Only one irregular buyer	-	-	-
	5	No market	-	-	-
Financial safety nets/	1	Plenty of sources. Financial reserves, other sources of income, none-drought sensitive agriculture, physical reserves	Indication of market availability	The more economic activities, the greater the coping capacity	Survey

alternative source of income	2	Apply three from above	-	-	-
	3	Apply two from above	-	-	-
	4	Apply one from above	-	-	-
	5	None	-	-	-
Off-farm diversification	1	Many alternative economic activities. Tourism, mining, forestry, services, etc.	Indication of other economic activities	The more economic activities, the greater the coping capacity	Survey
	2	At least three different economic activities	-	-	-
	3	At least two different economic activities	-	-	-
	4	Livestock farming plus one other economic activity	-	-	-
	5	Livestock farming is the only economic activity	-	-	-
Percentage decrease in farm revenue	1	No decrease in income	% of income loss due to drought	More income loss, more vulnerable to cope with extra costs	Survey
	2	10% decrease in income	-	-	-
	3	20% decrease in income	-	-	-
	4	30% decrease in income	-	-	-
	5	30%+ decrease in income	-	-	-
Drought adaptive farming practices applied	1	Many strategies (drought-coping breeds, diversifying enterprises, enough savings for the drought years, conservation agriculture, national migration, international migration	Different drought adaptive measures applied	The more measures in place, the easier it will be to cope with drought	Survey
	2	Apply three of the above	-	-	-
	3	Apply two of the above	-	-	-
	4	Apply one of the above	-	-	-
	5	Not practiced	-	-	-

Source: Authors compilation.

Table A2. VIF for multicollinearity.

Variable	VIF	1/VIF
Experience	2.77	0.36
Age	2.4	0.42
Number of droughts	1.72	0.58
log_herdsize	1.71	0.58
log_farmsize	1.71	0.58
Vehicle asset index	1.49	0.67
Credit access	1.35	0.74
Auction distance	1.29	0.77
Immovable asset index	1.29	0.77
Household size	1.23	0.81
Abattoir distance	1.22	0.82
Social network	1.2	0.84
Cooperative	1.19	0.84
Gender	1.17	0.86
Feedlot distance	1.13	0.88
Government assistance	1.1	0.91
Mean VIF	1.5	-

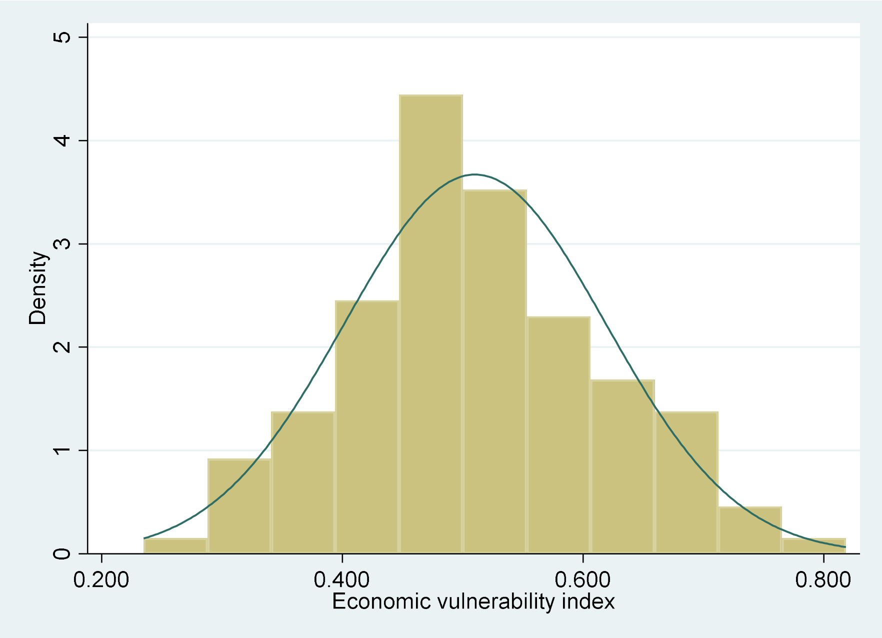

Figure A1. Economic vulnerability index distribution.

Ethics Approval

The Research Ethics Committee approved ethical clearance for the protocol in accordance with the General/Human Research Ethics (GHREC) guidelines and regulations. Reference number UFS-HSD2023/0373/3.

Participants volunteered after the ethical principles were publicly announced. All participants were informed, and they completed and signed a consent form before actively participating in the study.

DATA AVAILABILITY

Data will be available from the corresponding author (YTB) upon request.

AUTHOR CONTRIBUTIONS

All authors significantly contributed to the present manuscript's preparation. AJV Collected the data and wrote the first draft of the article. YTB, FM, HNvN and SAN were the supervisors of AJV and aided in the review and writing of the final draft. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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REFERENCES

1. Research and Markets. Livestock & Meat Market—Global Forecast 2026-2032. Available from: https://www.researchandmarkets.com/reports/5666306/livestock-and-meat-market-global-forecast-2026?#product--toc. Accessed on 2026 April 10.
2. World Bank. Moving Towards Sustainability: The Livestock Sector and the World Bank. Available from: https://www.worldbank.org/en/topic/agriculture/brief/moving-towards-sustainability-the-livestock-sector-and-the-world-bank. Accessed on 2025 Dec 10.
3. Herrero M, Havlík P, Valin H, Notebaert A, Rufino MC, Thornton PK, et al. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. Proc Natl Acad Sci USA. 2013;110:20888-93. doi: 10.1073/pnas.1308149110
4. Thornton PK, Herrero M. Climate change adaptation in mixed crop-livestock systems in developing countries. Glob Food Secur. 2014;3:99-107. doi: 10.1016/j.gfs.2014.02.002
5. Lamega A, Komainda M, Hoffmann P, Ayisi K, Odhiambo O, Isselstein J. It depends on the rain: Smallholder farmers' perceptions on the seasonality of feed gaps and how it affects livestock in semi-arid and arid regions in Southern Africa. Clim Risk Mang. 2021;34:100362. doi: 10.1016/j.crm.2021.100362
6. Wheeler T, von Braun J. Climate Change Impacts on Global Food Security. Science. 2013;341:508-13. doi: 10.1126/science.1239402
7. Mare F, Bahta YT, Van Niekerk W. The impact of drought on commercial livestock farmers in South Africa. Dev Pract. 2018;28:884-98. doi: 10.1080/09614524.2018.1493091

8. Nangoma E. National Adaptation Strategy to Climate Change Impact: A Case Study of Malawi. New York (NY, US): Human Development Report Office; 2007.
9. Agriculture South Africa (AGRI SA). National drought disaster declaration: A step in the right direction. Pretoria (South Africa): AGRI; 2021.
10. Manzini D, Oosthuizen R, Chikwanda H. Enhancing organisational resilience through systems thinking. Soc Sci Humanit Open. 2025;12:101783. doi: 10.1016/j.ssaho.2025.101783
11. Muhame C, Ncube A, Bahta YT. Toward SDG-11: How Social resilience affect urban settlement in South Africa? J Sustain Res. 2023;4(5):e230014. doi: 10.20900/jsr20230014
12. Bahta YT. Nexus between Coping Strategies and Households' Agricultural Drought Resilience to Food Insecurity in South Africa. Land. 2022;11:893. doi: 10.3390/land11060893
13. Lottering S, Mafongoya P, Lottering R. Drought and its impacts on small-scale farmers in sub-Saharan Africa: a review. S Afr Geogr J. 2020;103(3):319-41. doi: 10.1080/03736245.2020.1795914
14. Holman IP, Hess TM, Rey D, Knox JW. A Multi-Level Framework for Adaptation to Drought Within Temperate Agriculture. Front Environ Sci. 2021;8:589871. doi: 10.3389/fenvs.2020.589871
15. Mdungela NM, Bahta YT, Jordaan AJ. Indicators for economic vulnerability to drought in South Africa. Dev Pract. 2017;27:1050-63.
16. Bahta YT, Myeki VA. The Impact of Agricultural Drought on Smallholder Livestock Farmers: Empirical Evidence Insights from Northern Cape, South Africa. Agriculture. 2022;12:442. doi: 10.3390/agriculture12040442
17. Statistics South Africa. Census 2022 Results; Mbalo brief, the missing piece of the puzzle. 2023; Available from: https://www.statssa.gov.za/wp-content/uploads/2023/10/Mbalo-brief-October-2023-WEB-FINAL.pdf. Accessed on 2025 Nov 6.
18. Coleman A. Northern Cape farmers' drought misery continues. Farmer's Weekly. 2023. Available from: https://www.farmersweekly.co.za/agri-news/south-africa/northern-cape-farmers-drought-misery-continues/. Accessed on 2025 Nov 6.
19. Richaud B. Vegetation index NDVI and VCI indices. UNCCD-led Drought toolbox. Ankara (Turkey): UN Environment-DHI Centre on Water and Environment; 2019. Available from: https://www.unccd.int/sites/default/files/inline-files/04_Vegetation_index.pdf. Accessed on 2025 Oct 16.
20. Statistics South Africa (Stats SA). Stats SA releases Census of Commercial Agriculture 2017 Report. Pretoria (South Africa): Statistics South Africa; 2017.
21. Cochran WG. Sampling Techniques. 3rd ed. New York (NY, US): John Wiley & Sons; 1977.
22. Bartlett JE, Kotrlik J, Higgins C. Organizational Research: Determining Appropriate Sample Size in Survey Research. Inf Technol Learn Perform J. 2001;19(1):43-50.
23. Bahta YT. Social vulnerability to agricultural drought: Insights from northern cape, South Africa. Sci Afr. 2022;17:e01324. doi: 10.1016/j.sciaf.2022.e01324

24. Briguglio L, Cordina G, Farrugia N, Vella S. Economic Vulnerability and Resilience: Concepts and Measurements. Oxf Dev Stud. 2009;37(3):229-47. doi: 10.1080/13600810903089893
25. Cardona OD. Environmental Management and Disaster Prevention: Two Related Topics: A Holistic Risk Assessment and Management Approach. In: Ingleton J, editor. Natural Disaster Management. London (UK): Tudor Rose; 1999. p. 151-3.
26. Cardona OD. Estimación Holística del Riesgo Sísmico Utilizando Sistemas Dinámicos Complejos (Estimation of Risk Using Dynamic Complex Systems). Barcelona (Spain): Technical University of Catalonia; 2001.
27. Bogardi J, Birkmann J. Vulnerability assessment: the first step towards sustainable risk reduction. In: Malzahn D, Plapp T, editors. Disaster and Society—From Hazard Assessment to Risk Reduction. Berlin (Germany): Logos Verlag Berlin; 2004. p. 1-83.
28. Ayanlade A, Smucker TA, Nyasimi M, Sterly H, Weldemariam LF, Simpson NP. Complex climate change risk and emerging directions for vulnerability research in Africa. Clim Risk Manag. 2023;40:100497.
29. Papke LE, Wooldridge JM. Econometric methods for fractional response variables with an application to 401 (k) plan participation rates. J Appl Econ. 1996;11(6):619-32.
30. Fonchamnyo DC, Akame AR. Determinants of export diversification in Sub-Sahara African region: a fractionalized logit estimation model. J Econ Finance. 2017;41(2):330-42.
31. Ngaka MJ. Drought preparedness, impact and response: A case of the Eastern Cape and Free State provinces of South Africa. Jàmbá: J Disaster Risk Stud. 2012;4:10. doi: 10.4102/jamba.v4i1.47
32. Bahta YT. Perception of agricultural drought resilience in South Africa: A case of smallholder livestock farmers. Jàmbá: J Disaster Risk Stud. 2021;13(1):a984. doi: 10.4102/jamba.v13i1.984
33. Department of Agriculture, Forestry and Fisheries (DAFF). Policy Brief: Agriculture in the Northern Cape. In: Portfolio Committee on Water and Sanitation. Pretoria (South Africa): DAFF; 2015.
34. Brown P, Daigneault A, Dawson J. Age, values, farming objectives, past management decisions, and future intentions in New Zealand agriculture. J Environ Manag. 2019;231:110-20. doi: 10.1016/j.jenvman.2018.10.018
35. Meissner HH, Scholtz M, Engelbrecht F. Sustainability of the South African Livestock Sector towards 2050 Part 2: Challenges, changes and required implementations. S Afr J Anim Sci. 2014;43:289. doi: 10.4314/sajas.v43i3.6
36. Manfouo NF, Von Fintel D. Investigating the effects of drought and lockdowns on smallholder and commercial agricultural production in KwaZulu-Natal using remotely sensed data. Heliyon. 2022;8(11):e11637. doi: 10.1016/j.heliyon.2022.e11637
37. Rusere F, Houngue NR, Mkuhlani S, Soropa G, Hunter L, Twine W, et al. Rural households' vulnerability to drought and implications for resilience: Insights from Bushbuckridge, Mpumalanga, South Africa. Prog Disaster Sci. 2026;24:100520. doi: 10.1016/j.pdisas.2026.100520

38. Ayuni IK, Hizbaron DR, Sudrajat S. Assessing the Social and Economic Vulnerability of Farmers by Group Categories in Volcano-Prone Disaster Area in Sempu Village, Kediri Regency. Int J Disaster Manag. 2024;7(2):167-84. doi: 10.24815/ijdm.v7i2.40306
39. Bell LW, Moore AD, Thomas DT. Diversified crop-livestock farms are risk-efficient in the face of price and production variability. Agric Syst. 2021;189:103050. doi: 10.1016/j.agsy.2021.103050
40. Bahta YT, Nyaki SA, Maré F. What does the future hold? An assessment of commercial livestock farmers' perceptions towards agricultural drought in South Africa. J Appl Anim Res. 2025;53(1):2574029. doi: 10.1080/09712119.2025.2574029
41. Yeleliere E, Antwi-Agyei P, Guodaar L. Farmers response to climate variability and change in rainfed farming systems: Insight from lived experiences of farmers. Heliyon. 2023;9(9):e19656. doi: 10.1016/j.heliyon.2023.e19656
42. Salmon G, Teufel N, Baltenweck I, van Wijk M, Claessens L, Marshall K. Trade-offs in livestock development at farm level: Different actors with different objectives. Glob Food Sec. 2018;17:103-12. doi: 10.1016/j.gfs.2018.04.002
43. Nontu Y, Mbelebele Z, Mdoda L, Dumisa BM, Ndwandwe N, Gidi LS, et al. Determinants and risk mitigation in livestock management practices among smallholder farmers in the Eastern Cape Province of South Africa. Front Sustain Food Syst. 2025;9:1636417. doi: 10.3389/fsufs.2025.1636417
44. Zhang Y, Zhao W. Social capital's role in mitigating economic vulnerability: Understanding the impact of income disparities on farmers' livelihoods. World Dev. 2024;177:106515. doi: 10.1016/j.worlddev.2023.106515
45. Sarmah T, Balta-Ozkan N, Konak A, Shrimpton E, Sass KS, De Macedo MB, et al. Usability of agricultural drought vulnerability and resilience indicators in planning strategies for small farms: A principal component approach. Clim Serv. 2025;38:100569. doi: 10.1016/j.cliser.2025.100569
46. Newman C, Tarp F. Shocks and agricultural investment decisions. Food Policy. 2020;94:101810. doi: 10.1016/j.foodpol.2019.101810
47. Tingey-Holyoak J, Cooper B, Crase L, Pisaniello J. A framework for supporting climate-exposed asset decision-making in agriculture. Land Use Policy. 2024;137:106989. doi: 10.1016/j.landusepol.2023.106989
48. Shiferaw B, Tesfaye K, Kassie M, Abate T, Prasanna BM, Menkir A. Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. Weather Clim Extrem. 2014;3:67-79. doi: 10.1016/j.wace.2014.04.004

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