

Original research article

Livelihood vulnerability to the changing climate: the experiences of smallholder farming households in the Free State Province, South Africa

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ABSTRACT

As a result of climatically regulated water sources, smallholder farming households in South Africa are severely impacted by climate change. Using the Livelihood Vulnerability Index, we assessed the vulnerability of smallholder farming households to climate change in Thaba Nchu, Mangaung District of the Free State Province of South Africa. Primary data from 301 smallholder farming households were collected and augmented with secondary data on temperature and rainfall from 2010 to 2020. The study found that farming households in Central Thaba Nchu are more vulnerable than those in North and South Thaba Nchu in terms of adaptive capacity: social network, livelihoods strategies, and socio-demographic structure. The Central Thaba Nchu were likewise more vulnerable to water resources than the Northern and Southern Thaba Nchu. However, Northern Thaba Nchu is more exposed and sensitive to health-related difficulties than Central and Southern Thaba Nchu. The study recommends that non-government and government institutions in the province should employ a pragmatic method to evaluate vulnerability using climate service information while prioritizing vulnerable households for adaptation support to improve adaptive capacity and resilience. The findings also imply that weather forecasters, in partnership with agricultural extension agents, must provide farmers with timely and adequate climate information reports to prepare them for climatic shocks. Moreover, it is important to deliver climate service information that is genuine, significant, and reliable.

Practical Implications

Agriculture is the leading contributor to Gross Domestic Product and a key employer of labour in the African continent. Nevertheless it is extremely vulnerable to changing climate (Naab et al., 2019), which manifests itself in increased droughts, floods, decreased yields, crop failure, and increased livestock mortality. Climate change is envisaged to increase the recurrence of natural hazards and have an impact on livelihood vulnerability, food security, and crop yields (Ali et al., 2017; IPCC, 2014). Dube et al. (2016) noted that smallholder farmers are vulnerable to the impacts of climate change because they are limited in their capacity to deal with these impacts and attain a viable living. The integration of climate change policy and implementation tactics is crucial for long-term adaptation in order to solve these pressing concerns (Naab et al., 2019). As the changing climate results in altered rainfall patterns, smallholder farmers will continue to face

threats to their livelihoods.

Climate change is a universal mega challenge that threatens our ecosystem, the society, and a number of nations (Vogel et al., 2019). The increasing human anthropogenic acts, deforestation and industrialization have resulted to climate change, with unavoidable and broad consequences (Naab et al., 2019). The African continent is widely recognized as being extremely vulnerable to changing climate, which will have uneven negative influence on their development (IPCC, 2014), posing a huge disadvantage to agricultural production (Naab et al., 2019). Smallholder farmers are unduly vulnerable, due to a number of issues that prevent them from adapting (Ncoyini et al., 2022). Despite unique indigenous and customary coping strategies to different climatic threats, several African nations are hindered by the lack of access to appropriate climate service information (Vogel et al., 2019). Climate service plays an important role in aiding the agricultural sector as regards to early warning signs, deducing of climate change trends and developing robust adaptation and mitigation methods (Conway, 2011).

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In view of the changing climate, it is essential to examine the livelihood vulnerability of smallholder farmers in order to develop appropriate policies to adapt to increasing vulnerability and to adopt a precautionary approach at different levels. This is because there are no one size fits all in terms of appropriate policies to adapt since vulnerability to changing climate are believed to be region specific. This was the case in the study area where different regions experienced different degree of vulnerability. The intrinsic vulnerability has fuelled a call to action in the need to provide climate services that aid in the development of adaption strategies to mitigate the effects of the changing climate. Climate Service information permits national, regional and local climate projections for impact adaptation and mitigation.

Among other things, the study's results show a number of practical implications. High degree of vulnerability in areas that do not receive early warning climate service information pertaining to climate variability and natural hazards. The study also demonstrated that a single intervention fit all approach is not appropriate, therefore farm level or area specific tailored intervention is more appropriate. This is based on the fact that different areas experienced different degree of vulnerability. Climate service information entails the creation, distribution, and contextualization of climate research-derived knowledge and information use in making of decision at all stages of the community (Vaughan and Dessai, 2014; Naab et al., 2019). Access to climate information helps farmers to handle the present changing climate and prepare for forthcoming climate challenges. Farmers are unable to establish appropriate and long-term adaptation and coping methods due to inadequate access of such information. Farmers may use climate information to improve their resilience and take advantage of favourable weather circumstances. However, in the face of the changing climate, the lack of such information makes smallholder farmers more vulnerable to anticipated climate extremes. Smallholder farmers will also find it difficult to adjust to climate change if current climate information is unavailable. Therefore, access to reliable climate information by smallholder farmers will assist their preparedness and also assist in the design of appropriate adaptation strategies.

Introduction

Agriculture and other climate-sensitive sectors, such as forestry, are directly responsible for the livelihoods of farmers, particularly in developing nations. Agriculture is being hit by a slow-motion disaster caused by climate change (Naab et al., 2019), which manifests itself in increased agricultural pests and disease outbreaks, increased frequency and severity of landslides, droughts, and floods, decreased yields, crop failure, and increased livestock mortality. Climate change is envisaged to increase the recurrence of natural hazards and have an impact on livelihood vulnerability, food security, and crop yields (Ali et al., 2017; IPCC, 2014). Dube et al. (2016) noted that smallholder farmers are vulnerable to the impacts of climate change because they are limited in their capacity to deal with these impacts and attain a viable living. As the changing climate results in altered rainfall patterns, smallholder farmers will continue to face threats to their livelihoods and food security. Over the last two decades, climate change has intensified the recurrence of meteorological droughts in developing and developed nations (Ebhuoma et al., 2020).

Climate change is a universal mega challenge that threatens our ecosystem, the society and a number of nations (Vogel et al., 2019). The increasing human anthropogenic acts, deforestation and industrialization have resulted to climate change, with unavoidable and broad consequences (Naab et al., 2019). African countries are expected to be more vulnerable to the changing climate, which will have a disproportionate negative influence on the development of the continent (IPCC, 2014). Despite unique indigenous and customary coping strategies to different climatic threats, several African nations are hindered by the lack of

access to appropriate climate service information (Vogel et al., 2019). Climate service entails the creation, distribution, and contextualization of climate research-derived knowledge and information use in making of decision at all stages of the community (Vaughan and Dessai, 2014; Naab et al., 2019). It aims to help nations and different stakeholders and users to manage the risks of changing climate at all stages through formal and informal organizations and networks (Steynor and Pasquini, 2019; Vogel et al., 2019). For example, access to reliable climate service information by smallholder farmers on drought will help in mitigation and adaptation to drought.

Drought is the most widespread natural disaster that has affected the world, and agriculture is the most vulnerable sector (Wu et al., 2017; Moeletsi and Walker, 2012). According to Udmale et al. (2014), "drought is a creeping phenomenon, difficult to understand and is defined due to differences in hydro meteorological variables and socioeconomic factors, as well as the stochastic nature of water demand in various regions of the world". Droughts are broadly categorised into four, namely, socioeconomic, agricultural, hydrological, and meteorological (Udmale et al., 2014). Droughts account for about 5% of all natural disasters worldwide; however, drought losses accounted for up to 30% of all disasters, placing droughts first among all natural disasters (Wu et al., 2011). During South Africa's 1992 drought, it was evaluated that the agricultural sector lost 50 000 jobs, with another 20 000 lost in allied industries, affecting roughly 250 000 individuals (FAO, 2004; Mniki, 2009), and corn have to be imported into the country, because crop failure was about 70 % (Mniki, 2009). The 2015/2016 drought that occurred in South Africa was another significant event that caused lots of damages to the South African agricultural economy. For example, in the third quarter of 2015, the agriculture industry in South Africa dropped by 12.6 % and significant cattle losses were reported in the provinces of Free State, KwaZulu-Natal, Limpopo, and North-West (Ncube, 2017). This 2015/2016 drought caused South Africa farmers up to R10 million damages (Bahta et al., 2016; Maltou and Bahta (2019)). The livestock business (cattle and sheep) was one of those most badly hit by the drought, with a 15% drop in the national herd stock, according to study by Maltou and Bahta (2019). The region involved in cattle, goat and sheep husbandry (roughly 590 000 km²) was adversely impacted by the country's drought. As Mahlalela et al. (2020) indicated, drought has at times had a greater impact on agrarian communities as well as non-agrarian communities. Most emerging economies rely significantly on agriculture, which is largely dependent on rainfall. Droughts severely hinder agriculture, which is the principal source of income in non-metropolitan communities (Makoti and Waswa, 2015). The perception of farming households about the impact of drought on agriculture varies from place to place due to the interaction of natural drought and diverse human factors (Udmale et al., 2014).

Farmers' perceptions of the impact of drought refer to a set of behaviours, beliefs and judgments about droughts that are formed as a result of expectations, definitions, memories, experience of and exposure to drought (Sam et al., 2020). Drought perception can help to ensure that drought adaptation strategies are implemented successfully. Comprehending the people's sensitivity to droughts and their impacts, and their perceptions of how droughts affect them, has the ability to help define that which can be done, and by who, who benefits from it, and how will it be assessed (Aldunce et al., 2017). A reduction in the prices of livestock, production losses in livestock with mortality, poor health, rising food prices, crop failure and drying of water resources are the most instantaneous effects of drought perceived by farmers (Menghistu et al., 2018; Udmale et al., 2014). The extent of farmers' perceptions and consciousness of drought, the intensity of diverse drought impacts, and the different adaptation techniques in place at the household level are very important (Udmale et al., 2014). The perception of drought ultimately guides an individual's adaptation behaviour (Debela et al., 2015).

Rural residents who have experienced drought and have knowledge of drought and climate change would probably believe in the possibility

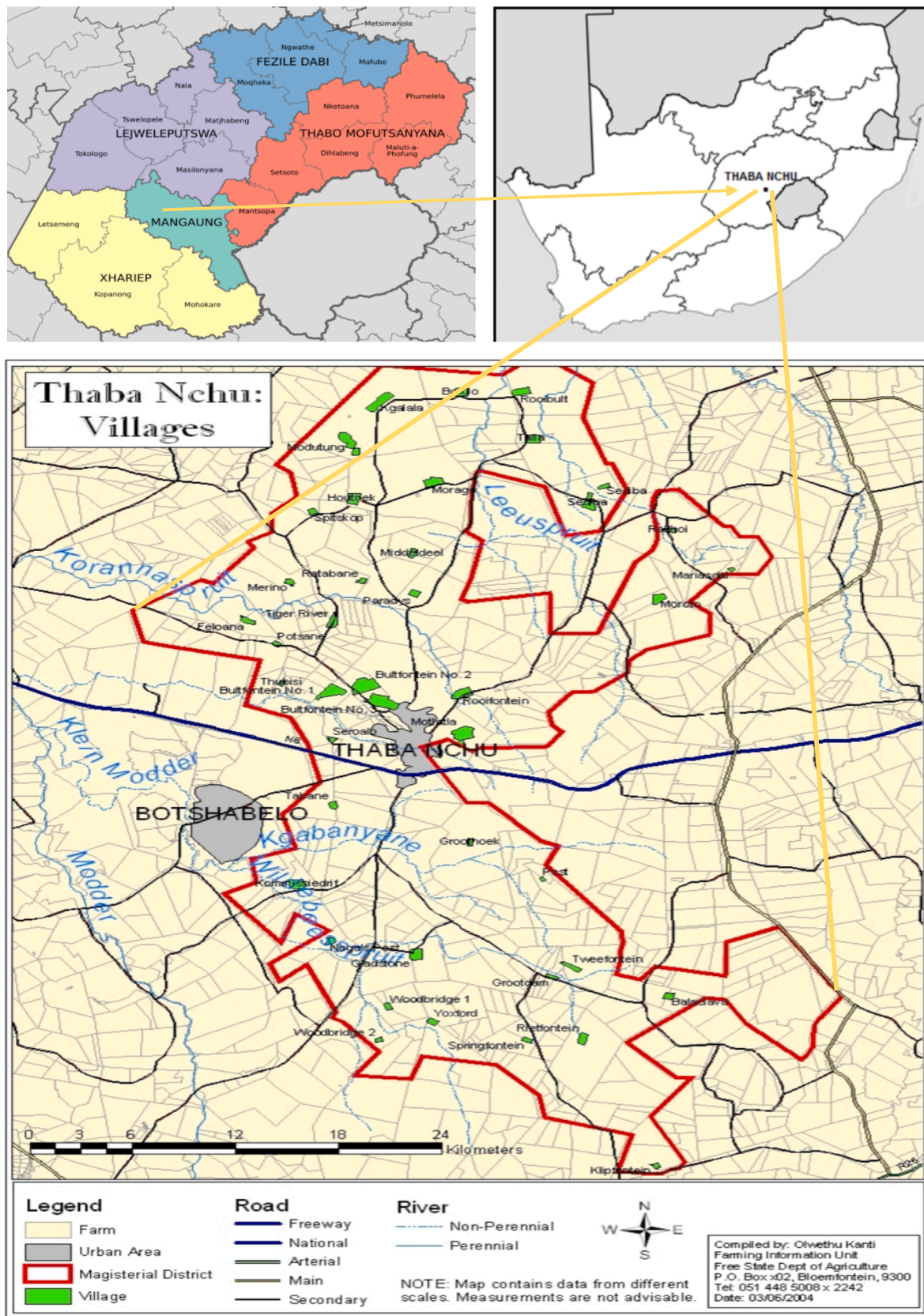


Fig. 1. Map of the Free state showing Thaba Nchu with its villages. P1, 2, 3: Sources: Department of Rural Development and Land Reform (Free State office, 2019), Municipalities.co.za (2018). Map of Thaba Nchu showing its' villages (Goitsemodimo, 2015) respectively.

of upcoming hazard and, as a result, would be more likely to take action to mitigate the negative effects (Sam et al., 2020). Rakgwale and Oguttu (2020), noted that some of the coping methods used by farmers during drought included receiving help from the government, digging boreholes, purchasing supplemental feed for their animals, and lowering their livestock numbers. Masupha and Moeletsi (2018) noted that changing planting dates and mulching can be used in areas where drought stress is more common. Furthermore, there are several strategies that could be put into place on a national scale to lessen and adapt to the effects of climate change, these include: expanding research on drought management, implementing appropriate financial plans, encouraging sustainable crop management and stocking densities to relieve pressure on vulnerable ecosystems, and using efficient monitoring, early warning systems, and decision support tools (Masupha and Moeletsi, 2018). Masupha and Moeletsi (2018) further added that farmers should think about growing crop varieties that are resistant to drought and have a short maturation period. Among the most effective land and water management techniques in Africa, including South Africa are conservation agriculture, agroforestry (integrated soil fertility control, rainwater collecting), intercropping, rotations of crops, and cover crops (Henry et al., 2018; Diop et al., 2022), which are used to lessen the potential effects of drought caused by climate change. Maltou and Bahta (2019), suggested that government should assist smallholder farmers who are impacted by drought in providing fodder, enhancing access to farm input and agricultural credit, increasing smallholder farmers' participation in agricultural drought resilience activities by providing training, and disseminating information to help build their resilience. The nature and intensity of drought impacts varies depending on the relative impacts of numerous socioeconomic, geophysical, and agro-climatic factors. Vulnerability assessment provides a foundation for assessing the environmental, economic, and socio-demographic implications of climate activities on household livelihoods, which is expected to inform adaptation strategies, increase mitigation, and resilience to climate shocks (Zarafshani et al., 2020).

Intergovernmental Panel on Climate Change (IPCC), (2001) defined "climate change vulnerability as the magnitude of exposure or risks to the adverse effect of climate change, including the inability to cope with those risks". Vulnerability is defined as the extent that a structure is vulnerable to or incapable of dealing with the negative impacts of climate change, in addition to climatic extremes and variability (Alhassan et al., 2019). Vulnerability has three components: adaptive capacity, sensitivity, and exposure (Eze and Onokala, 2021; Kumar et al., 2020a). The capacity of a structure to successfully adjust to climate extremes and variability is referred to as adaptive capacity. Sensitivity refers to the system's responsiveness to climate influences and the extent to which climate change may affect it in its present form. The nature, duration, and the extent that a system is exposed to considerable changes in the climate are referred to as exposure (Kumar et al., 2020a). The degree of vulnerability varies by location (Spielman et al., 2020), yet high or low vulnerability could increase or decrease the drought disaster situation (Wu et al., 2017).

The Livelihood Vulnerability Index (LVI), a framework created by Hahn et al. (2009) for assessing households' vulnerability to changing climate has since been utilized globally by scientists (Adu et al., 2018; Oo et al., 2018; Azumah et al., 2020). The Index is formulated to give an overview to policymakers concerning livelihood strategies, and more associated issues which gives rise to climate change vulnerability at a regional, provincial, or community level. An index of vulnerability serves three key functions: First, when looking at frameworks of development policy, they can be used as a starting point for comparison. Second, they can help in the development of mitigation and adaptation strategies (Gbetibouo et al., 2010). Third, it's possible to use them to standardize vulnerability measurements, allowing comparisons between different circumstances. As a result of this, resource allocation priorities can be established for adaptation and mitigation (Preston et al., 2011).

The changing climate is expected to have a greater impact on

agriculture, water supply, human and animal health, among other areas (Nicklin et al., 2012). Although the effects of changing climate manifesting themselves in several areas, agriculture industry is highly impacted in the Global South, owing to the fact that it is rain-fed (Naab et al., 2019). Previous studies on vulnerability in South Africa have primarily focused on gender, poverty, or food insecurity (Vincent et al., 2010; Baiyegunhi and Fraser, 2011; Schotte et al., 2017; Mthethwa and Wale, 2021). These past studies usually used national aggregates data ignoring household level data. Only a few studies have focused on the vulnerability of households to changing climate (Ncube et al., 2016; Ofoegbu et al., 2017). In order to compare and evaluate various units of study (e.g. households, geographic regions), indexes must be able to incorporate local, context-specific characteristics (Eakin and Bojórquez-Tapia, 2008). Analysis may suffer from a lack of particular, local indicators that can be utilized to distinguish between vulnerability assessments based on information of the best quality and the limited resources or skills available (Shah and Rivera, 2007). This study hopes to fill a research gap by using household-level data to examine farmers' vulnerability to changing climate through the perspectives of livelihood vulnerability frameworks. In view of the changing climate, it is essential to examine the livelihood vulnerability of smallholder farmers in order to develop appropriate policies to adapt to increasing vulnerability and to adopt a precautionary approach at different levels. This is because there are no one size fits all in terms of appropriate policies to adapt since vulnerability to changing climate are believed to be region specific. For instance, coastal communities may be more vulnerable to cyclones and sea level rise while communities in semi-arid areas may be more vulnerable to drought. Thus, the study hopes to recommend adequate policies for different regions in Thaba Nchu, since their level of vulnerability is believed to differ from each other. This study will equally contribute to the growing body of knowledge about drought vulnerability using the LVI approach, in Free State province, particularly in Thaba Nchu. More also, this research equally provides an important information to researchers who desire an empirical scientific article regarding drought vulnerability in its current study, which is necessary to build the drought body of knowledge.

Using the Livelihood Vulnerability Index (LVI), this study examines the vulnerability of smallholder farming households to changing climate in the Free State Province of South Africa.

Methodology

Study area, sampling and method of data collection

Free State Province has a land area of 129 464 km² and a population of 2.8 million people, accounting for 4.9 percent of the national population. The study was carried out in Thaba Nchu, Mangaung District of Free State. Mangaung is regarded as having one of the most diversified economies and contributing the most to the GDP in the province (Profile Mangaung metro, 2020). Thaba Nchu is 67 km east of Bloemfontein which has a more dispersed development pattern, with 42 communities around the city centre. Agriculture and allied activities are the primary source of income. The majority of residents are smallholder farmers who grow sorghum, soybeans, potatoes, wheat, sunflower, and maize. Animal breeding, primarily of poultry and cattle, is another important agricultural sector in the Thaba Nchu region. Fig. 1(a, b, and c): A map of Free State depicting Thaba Nchu and its communities.

Multistage sampling procedure was used, and the Thaba Nchu in the Free State Province was predetermined because of the occurrence of drought over the last few years. In the first stage, Thaba Nchu was stratified into three strata: central, northern, and southern, where proportionate random sampling was applied to selected communities from each stratum. This is due to the fact that central, northern, and southern Thaba Nchu have 5, 21, and 16 villages, respectively. Subsequently, we chose four villages from Northern Thaba Nchu and three from Southern and one from Central Thaba Nchu. We used the proportionate sampling

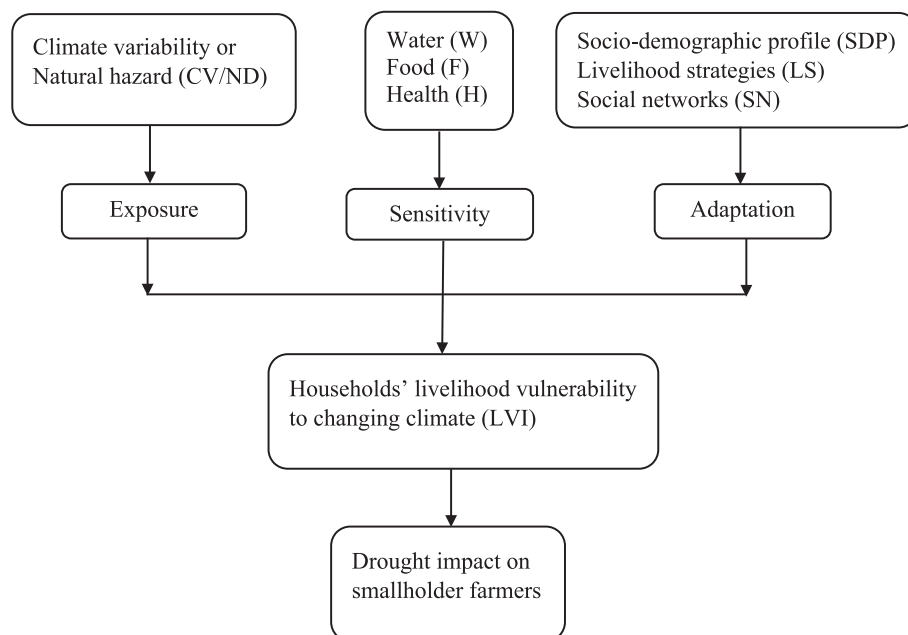


Fig. 2. Conceptual framework. (Authors concept).

method while applying Yamane's formula: $n = N/(1 + N(e)^2)$ to each of the communities to select various agricultural households because the communities do not all have an equal number of households. A total of 324 targeted participants were chosen, including 165 households from four communities in the North, 110 households from three communities in the South, and 49 households from one community in Central Thaba Nchu (See Appendix 1).

After data cleaning and validation, a success rate of 93% was obtained, leading to overall sample size of 301 households. A detailed and well-structured questionnaire was used to collect the data. In addition, secondary data on rainfall and temperature were obtained from the South African Weather Services. The meteorological data were collected between 2010 and 2020. This range was chosen as human-induced global warming is presently increasing at a rate of 0.2°C per decade and changing climate is believed to occur for a long period. Research articles, project works, and textbooks were used to gather information about changing climate and variability in the globe, Africa, and South Africa.

Conceptual framework

The changing climate, among other things, is thought to have a significant impact on the living conditions of smallholder farmers, particularly in developing nations (Azadi et al., 2018). Farmers who are mindful of the potential repercussions of adverse weather conditions, like drought, are more inclined to take preventive steps and support programmes aimed at mitigating its effects (Niles et al., 2013). Drought effects on smallholder farmers are the result of a combination of farmers' demand for water and natural events. Climate variability or natural hazard, water, food, health, socio-demographic profile, livelihood strategies, social networks are the seven key element considered in this article (Fig. 2).

The kind of human interplay with the environment has a large influence on the frequency and severity of climatic droughts (Almasi and Tavakkoli, 2019). There is a need for some changes in dealing with drought, like avoiding impermanent and sporadic measures, shifting from passivity to readiness, and implementing active drought risk management system in a continuous process (Speed et al., 2016). Given the number of droughts that have occurred in the last decade (Ebhuoma et al., 2020) and the inefficiency of crisis management methods, there is

a need to access drought vulnerability among smallholder farmers.

Among the most important facets of any drought planning and management measure is the vulnerability evaluation, which entails determining what and who are most vulnerable and why (Swain and Swain, 2011). Assessing the farmers' vulnerability to the impact of a changing climate may be required to boost resilience (Jamshidi et al., 2019). The livelihood vulnerability assessment developed by Hahn et al. (2009) describes a set of methods for systematically integrating and investigating connections between humans and their social and physical environments. Their study attempted to fill the gap between the physical, natural and social sciences, and has made a significant contribution to new methodologies to address changing environmental condition (Hahn et al., 2009). Most of these methodologies are heavily reliant on the IPCC description of vulnerability as a function of adaptive capacity, sensitivity and exposure (IPCC, 2001). Hahn et al. (2009) considered three key factors when assessing the vulnerability of people (Fig. 2), and they include: adaptive capacity, sensitivity and exposure.

"The resilience of a system considers the future measures that can enhance its ability to tackle with external events. Adaptation actions are implementations or operations that assist in promoting resilience of farmers to extreme events and can encompass government policies, NGO programs and independent decisions made by people. Sensitivity of the current condition of a system to the hazards. Both the environmental and human factors determine the sensitivity of a system. Exposure to hazards focuses on the magnitude, duration and frequency of the exposure" (Nazari et al., 2015: 5).

Knowledge of the vulnerability of smallholder farmers is vital for formulating subsequent drought solutions. Policymakers can propose to minimise the most serious impacts of drought by their level of vulnerability. At different levels, an understanding of the drought impact on smallholder farmers is required to enact a robust policy for the well-being of the farming society (Fig. 2).

Empirical method

The LVI was designed to evaluate households' vulnerability to climatic fluctuation, and is based on the IPCC's concept of vulnerability. The LVI method includes various factors that represent the level of exposure of smallholder farming households to climate variability or

Table 1

Indexed subcomponents, main component for climate change and natural disasters and overall LVI for North, Central and Southern Thaba Nchu.

| Sub-elements | North | Central | South | Key-elements | North | Central | South |
|---|-------|---------|-------|--------------------------------------|--------------|--------------|--------------|
| Percentage of household whose food consumption pattern decreased due to drought | 0.36 | 0.34 | 0.43 | Food | 0.467 | 0.420 | 0.513 |
| Percentage of household whose choice of food preferences were affected because of drought | 0.74 | 0.75 | 0.77 | | | | |
| Percentage of household that do not save crops | 0.30 | 0.17 | 0.34 | | | | |
| Percentage of household with poor health condition because of drought | 0.42 | 0.48 | 0.50 | Health | 0.330 | 0.285 | 0.305 |
| Percentage of household where a family member had to miss school or work due to drought | 0.58 | 0.37 | 0.36 | | | | |
| Percentage of household that experienced anxiety and depression due to drought | 0.29 | 0.28 | 0.33 | | | | |
| Average time on foot to reach a health facility | 0.03 | 0.01 | 0.03 | Water | 0.510 | 0.517 | 0.503 |
| Percentage of household who experienced inconsistency water supply for last 5 years | 0.72 | 0.76 | 0.75 | | | | |
| Percentage of household that quit farming due to water scarcity | 0.64 | 0.69 | 0.61 | | | | |
| Percentage of household who experienced water conflict | 0.48 | 0.44 | 0.51 | Natural Hazard & Climate Variability | 0.505 | 0.472 | 0.483 |
| Percentage of household that are making use of rainwater harvesting | 0.20 | 0.18 | 0.14 | | | | |
| Percentage of household that did not receive early warning climate service information | 0.61 | 0.67 | 0.55 | | | | |
| Average drought events in the last 5 years | 0.96 | 0.68 | 0.93 | Socio-Demographic Profile | 0.348 | 0.363 | 0.338 |
| Percentage household who lost a family member due to natural hazard | 0.06 | 0.08 | 0.02 | | | | |
| Monthly average minimum daily temperature (2010–2020) | 0.52 | 0.52 | 0.52 | | | | |
| Monthly average maximum daily temperature (2010–2020) | 0.41 | 0.41 | 0.41 | Livelihood Strategies | 0.245 | 0.248 | 0.245 |
| Monthly average precipitation (2010 = 2020) | 0.47 | 0.47 | 0.47 | | | | |
| Dependency ratio | 0.19 | 0.14 | 0.18 | | | | |
| Percentage of headed household that was not headed by female | 0.50 | 0.62 | 0.48 | Social Network | 0.630 | 0.653 | 0.633 |
| Average age of female head household | 0.47 | 0.48 | 0.44 | | | | |
| Percentage of household where the household head has not attended formal education | 0.23 | 0.21 | 0.25 | | | | |
| Percentage of household that depends only on agriculture | 0.62 | 0.67 | 0.60 | Livelihood Strategies | 0.245 | 0.248 | 0.245 |
| Average agricultural livelihood diversification | 0.27 | 0.25 | 0.36 | | | | |
| Percentage of households practicing freelancing | 0.07 | 0.04 | 0.01 | | | | |
| Percentage of household that participates in farm-based insurance | 0.02 | 0.03 | 0.01 | Social Network | 0.630 | 0.653 | 0.633 |
| Percentage of household that does not receives drought relief benefits from government | 0.83 | 0.83 | 0.74 | | | | |
| Percentage of household that has no access to extension services | 0.55 | 0.58 | 0.60 | | | | |
| Percentage of household that does not belongs to farm association | 0.51 | 0.55 | 0.56 | | | | |
| Overall LVI | | | | | 0.430 | 0.418 | 0.425 |

natural hazards, as well as their sensitivity and adaptation capacity to climate change effects.

A balance weighted technique was used to estimate the vulnerability of smallholder farming households to changing climate by computing the LVI. A balance weighted average is the average of a data set with different associated values or weights (Hahn et al., 2009). It assists the user in obtaining a more accurate result than the standard average and is commonly used in statistical analysis. The Livelihood Vulnerability framework is particularly vital for understanding vulnerability to changing climate because it offers a base for examining both the essential elements that constitute livelihoods and the corresponding elements that impact them. The LVI was calculated for all the sample units using the IPCC definition of vulnerability to climate effects established by Hahn et al. (2009). It incorporates seven important element: natural hazards, climate change, access to water, and access to food, health, socio-demographic profile, livelihood strategies and social networks. Each element consists of numerous sub-elements, which is assessed on a distinct range; hence, each must be standardized as an index by equation (1 or 2). Equation (1) was used when a sub-element had a positive association with vulnerability, otherwise we use equation (2).

$$Index_{Schi} = \frac{SC_{hi} - SC_{min}}{SC_{max} - SC_{min}} \tag{1}$$

$$Index_{Schi} = \frac{SC_{max} - SC_{hi}}{SC_{max} - SC_{min}} \tag{2}$$

where *Schi* represents the average value of the sub-element. *SC_{hi}* is the observed sub-elements of the indicator for household and are the maximum and lowest values. The sub-element indicators are averaged

using equation (3) after they have been normalized to give the index of each main component:

$$MC_{Schi} = \frac{\sum_{i=1}^n index_{Schi}}{n} \tag{3}$$

where *MC_{Schi}* denotes one of the major components: Food (F), Health (H), Water (W), Climate Variability or Natural Hazard (CV/ND), Socio-demographic profile (SDP), Livelihood Strategies (LS), and Social Network (SN) for each household. *index_{Schi}* represents the sub-elements that make up each key element, indexed by *i* and *n* is the number of sub-elements in each key element.

The household-level LVI is calculated by averaging the scores for each of the seven key elements for a household in Thaba Nchu using equation (4).

$$LVI_h = \frac{\sum_{i=1}^7 w_{MC_{Schi}}}{\sum_{i=1}^7 w_{MC_{Schi}}} \tag{4}$$

which might be stated as

$$LVI_h = \frac{w_F F_h + w_H H_h + w_W W_h + w_{CV/ND} CV/ND_h + w_{SDP} SDP_h + w_{LS} LS_h + w_{SN} SN_h}{w_F + w_H + w_W + w_{CV/ND} + w_{SDP} + w_{LS} + w_{SN}} \tag{5}$$

where *LVI_h*, is the LVI for the household *h*, which is equals the weighted average of the seven key elements. The weights of every key element, *w_{MC_{Schi}}*, is identified by the number of sub-elements that comprises each key element and are included to guarantee that all sub-elements has equal contribution to the total LVI. Th *LVI* was graded from 0 to 0.7, low to severe vulnerability, respectively.

LVI calculation framework developed by the IPCC

The IPCC vulnerability definition was included in the alternative way of computing LVI by grouping the seven primary elements under sensitivity, adaptation capability, and exposure. As with the LVI, each main element was made up of multiple indicators or sub-elements. Interestingly, rather than using a single weighted average as in the LVI technique, the LVI-IPCC was derived using Eqs. (1)–(5). This procedure created three weighted averages of the major sub-components based on the three contributing elements indicated in Eq. (6)

$$CF_h = \frac{\sum_{i=1}^n w_{MC_{schi}} MC_{schi}}{\sum_{i=1}^n w_{MC_{schi}}} \quad (6)$$

where CF_h is the IPCC-defined contributing factor (adaptation capacity, sensitivity, and exposure) for the household, MC_{schi} are the key elements for the household indexed by i ; $w_{MC_{schi}}$ is the weight of each key element, and n is the number of key elements in individually contributing factor. After calculating adaptation capacity, sensitivity, and exposure, the three contributing components are merged applying Eq. (7):

$$LVI - IPCC_h = (e_h - a_h) * s_h \quad (7)$$

where, $LVI - IPCC_h$ is the livelihood vulnerability index for household h stated in terms of the IPCC vulnerability paradigm, e_h is the estimated level of exposure for the household h (climate variability or natural hazard major component). The average standard deviation in monthly maximum and minimum rainfall and temperatures during the period of 11 year is used to measure climate variability (Adu et al., 2018; Etwire et al., 2013; Ashok and Sasikala, 2012; Hahn et al., 2009). Similarly, a_h is the computed adaptation capability value for household h (weighted average of key components such as socio-demographic profile, livelihood strategies, and social networks), then S_h is the computed sensitivity value for household h (weighted average of water, food, and health, key elements).

The LVI-IPCC Index ranges between 0 and 1 (least to most vulnerable). The LVI was estimated following the procedure of Hahn et al. (2009) and Adu et al. (2018). The data was analysed for the three regions (North, Central and Southern) region of Thaba-Nchu using the values of the 28 independent variables in the sub-elements. This gave rise to the values in the seven key elements which are natural hazards, climate change, access to water, and access to food, health, socio-demographic profile, livelihood strategies and social networks (Table 1).

Results and discussion

Households' livelihood vulnerability index

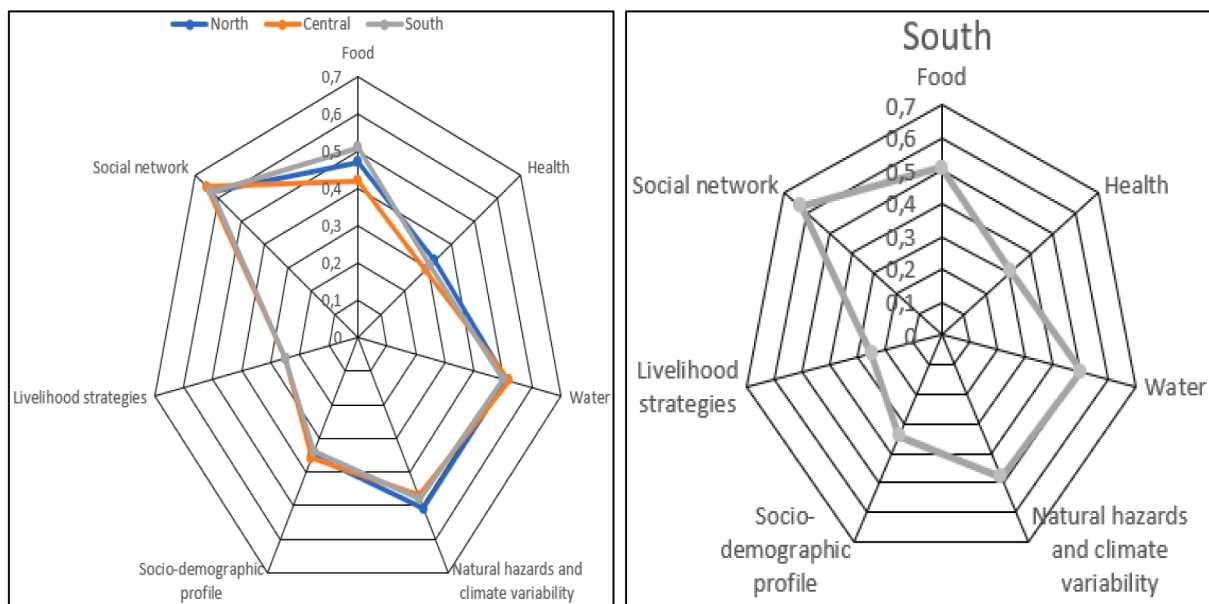
As indicated in Table 1, the vulnerability indices of the key element ranged between 0.245 and 0.653 for the three regions. The vulnerable indices in its absolute values are compared across the three strata. The vulnerability index of the LVI's food component revealed that Southern Thaba Nchu was most vulnerable to the effects of drought (0.513), followed by the North (0.467), and Central Thaba Nchu (0.420). Southern Thaba Nchu recorded a higher percentage (43%) of households whose food consumption pattern dropped due to drought in the previous year, followed by the Northern Thaba Nchu (36%) and Central Thaba (34%). Similarly, Southern Thaba Nchu recorded a higher percentage (77%) of the household whose choice of food preferences were affected because of drought followed by the Central (75%) and Northern Thaba Nchu (74%). When it comes to the proportion of households who do not preserve crops, Southern Thaba Nchu was the most vulnerable (34%), followed by the Northern Thaba Nchu (30%) and Central Thaba Nchu (17%).

The second important component was health, which had four sub-elements. When all the sub-elements were considered, Central Thaba Nchu was estimated to be the least vulnerable (0.285), followed by

South (0.305) and Northern (0.330). Southern Thaba Nchu had the highest susceptibility (0.50) in terms of the percentage of households with poor health due to drought, followed by Central (0.48), and Northern Thaba Nchu was somewhat better (0.42). The proportion of households where a member of the family had to skip school or work due to drought, was greater in the Northern Thaba Nchu (0.58) followed by Central (0.37) and Southern Thaba Nchu (0.36). Central Thaba Nchu was the least vulnerable (0.28) in term of the percentage of household that experienced anxiety and depression due to drought followed by the North (0.29) and Southern Thaba Nchu (0.33). North and Southern Thaba Nchu were more vulnerable (0.03) than Central Thaba Nchu in terms of the average time it takes a household to have access to health care facility (0.01). According to the World Bank (2010), insufficient access to health care has the tendency of worsening the health of smallholder farming household, making them more vulnerable to harsh weather conditions.

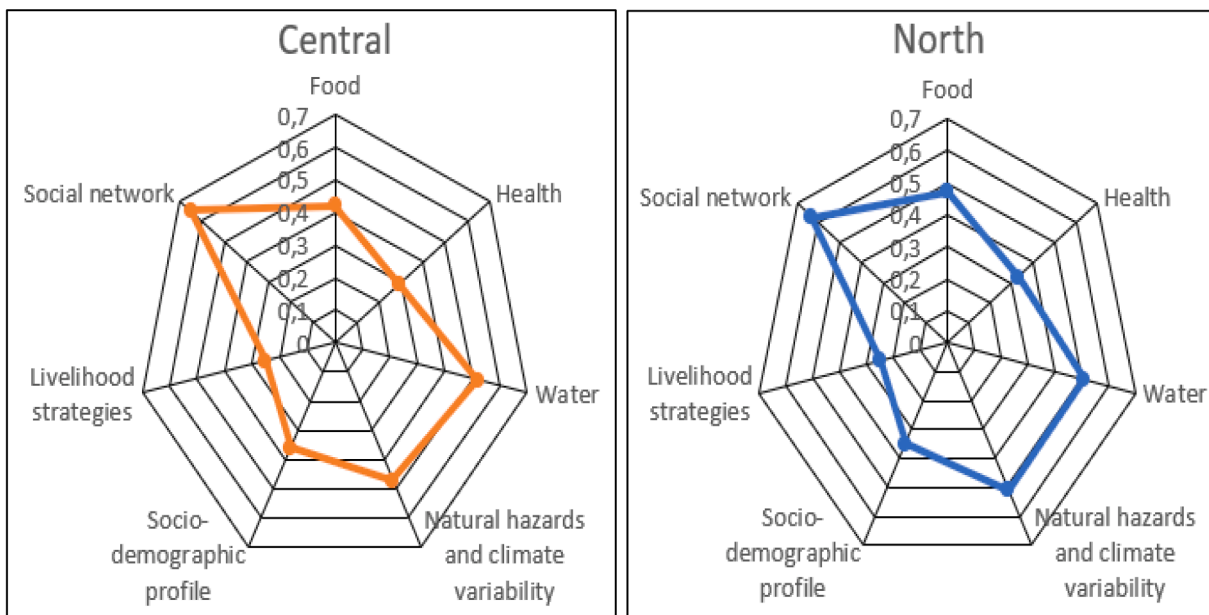
Water was the third essential component, with four subcomponents. According to the vulnerability index of water element of the LVI, Southern Thaba Nchu was less vulnerable (0.503) than Northern Thaba Nchu (0.510) and Central Thaba Nchu (0.517). Central Thaba Nchu reported a higher percentage (76%) of households who experiencing variability in water supply during the last 5 years, followed by the Southern Thaba Nchu and Northern Thaba Nchu with 75% and 72%, respectively. Central Thaba Nchu recorded a higher percentage (69%) of households that abandoned farming owing to water constraint in the previous year, followed by Northern Thaba Nchu (64%) and Southern Thaba Nchu (61%). This result implies that more than half of the smallholder farming households have been forced out of their sources of livelihood by drought, which may necessitate their migration to urban areas for greener pastures. Drought is a serious environmental shock for several homes in rural SSA, it undermines livelihoods and well-being (Jarawura, 2021). Droughts caused by climate change are increasing fears that they would exacerbate migration out of rural areas. Southern Thaba Nchu recorded a higher percentage (51%) of the household who experienced water conflict in the past than North (48%) and Central Thaba Nchu (44%). More households in Northern Thaba Nchu (0.20) reported making use of rainwater harvesting in their homes as compared with those in Central Thaba Nchu (0.18) and South Thaba Nchu (0.14), respectively. This is to say that only about (17.33%) of farmers on average in Thaba Nchu is making use of rainwater harvesting. Rainwater harvesting is broadly considered as a viable alternative source of fresh water that may be harvested and used in dry and semi-dried environments (Ali et al., 2020; Toosi et al., 2020).

The fourth important component is climate variability and natural hazards. It is composed of six sub-elements. When all of the elements were considered, Northern Thaba Nchu had the highest vulnerability (0.505), followed by the South (0.483), and Central Thaba Nchu (0.472). With indices of 0.67, 0.61, and 0.55, respectively, approximately 67%, 61% and 55% of households in Central, Northern and Southern Thaba Nchu do not receive early warning climate service information pertaining to climate variability and natural hazards. Climate service information entails the creation, distribution, and contextualization of climate research-derived knowledge and information use in making of decision at all stages of the community (Vaughan and Dessai, 2014; Naab et al., 2019). Newnham et al. (2017) noted that early Warning Systems (EWSs) are important preventative methods for lowering the risk of loss connected with a natural disasters. EWSs set up rules for community members to follow in order to respond efficiently during drought. The purpose of EWSs is to alert people of approaching calamities so that they can take necessary precautions to preserve lives. With EWSs, households at risk of drought can take action to minimize or mitigate these risks and prepare for a successful response by receiving timely and effective information from designated institutions (Shrestha et al., 2021). Northern, Southern and Central Thaba Nchu recorded vulnerability to the average drought events with the indices of 0.96, 0.93 and 0.68, respectively. Southern Thaba Nchu was less vulnerable



a: Results of the key elements in north, central and south of Thaba Nchu

b: Results of the key elements in northern Thaba Nchu.



c: Results of the key elements in central Thaba Nchu

d: Results of the key elements in southern Thaba Nchu

Fig. 3. a: Results of the key elements in north, central and south of Thaba Nchu. b: Results of the key elements in northern Thaba Nchu. c: Results of the key elements in central Thaba Nchu. d: Results of the key elements in southern Thaba Nchu.

(0.02) in terms of the households who lost a family member due to climate variability and natural hazard, followed by the North (0.06) and Central Thaba Nchu (0.08). In the eleven-year period, the three regions had the same index for the monthly average minimum and maximum daily temperature, with 0.52 and 0.41, respectively. Moreover, the three regions recorded the same monthly average precipitation index 0.47, over the period 2010–2020.

The fifth major component was the socio-demographic profile, which had four subcomponents. Central Thaba Nchu had the highest vulnerability (0.363) on the socio-demographic profile measure, followed by Northern Thaba Nchu (0.348) and Southern Thaba Nchu (0.348). With regards to dependency ratio, Central Thaba Nchu was less vulnerable (0.14) than the South (0.18) and Northern Thaba Nchu (0.19),

respectively. This could be attributable to the fact that the percentage of individuals under the age of 15 and over the age of 65 who were dependents was higher in the north and south of Thaba Nchu than in the Central. Central Thaba Nchu respondents indicated a greater proportion of male-headed households (0.62), followed by Northern Thaba Nchu (0.50) and Southern Thaba Nchu (0.48). According to Muthelo et al. (2019), less than half of the household heads were female in Thaba Nchu. The average age of female-headed households in Central Thaba Nchu was (0.48) compared to (0.47) and (0.44) in the North and South Thaba Nchu, respectively. The average age reported from the three regions was 46 years old. More than a 23% of household heads lacked basic education in the three regions. As observed by Etwire et al. (2013), formal education helps smallholder farming households better

Table 2
LVI-IPCC for the North, Central and Southern Thaba Nchu.

| Contributing factors | Key contributors | Key element values | | | Number of sub-element per key element | Contributing factor value | | | LVI-IPCC value | | |
|----------------------|---|--------------------|---------|-------|---------------------------------------|---------------------------|---------|-------|----------------|---------|-------|
| | | North | Central | South | | North | Central | South | North | Central | South |
| Sensitivity | Food | 0.467 | 0.420 | 0.513 | 3 | 0.432 | 0.409 | 0.434 | 0.052 | 0.029 | 0.041 |
| | Health | 0.330 | 0.285 | 0.305 | 4 | | | | | | |
| | Water | 0.510 | 0.517 | 0.503 | 4 | | | | | | |
| Exposure | Natural hazards and climate variability | 0.505 | 0.472 | 0.483 | 6 | 0.505 | 0.471 | 0.483 | | | |
| Adaptive capacity | Socio-demographic profile | 0.348 | 0.363 | 0.338 | 4 | 0.390 | 0.399 | 0.386 | | | |
| | Livelihood strategies | 0.245 | 0.248 | 0.245 | 4 | | | | | | |
| | Social network | 0.630 | 0.653 | 0.633 | 3 | | | | | | |

understand the challenges that concern them and, as a result, look for viable solutions in the right areas. Lack of education makes smallholder farming families more exposed to climatic pressures because they lack access to information.

The sixth major component, livelihood strategies, is made up of four sub-elements (households, practicing freelancing, the household that depends only on agriculture, agricultural livelihood diversification index, and the household that participates in farm-based insurance). When all the sub-components were aggregated, Northern and Southern Thaba Nchu showed the same level of vulnerability to livelihood strategies (0.245) than Central Thaba Nchu (0.248). The Central Thaba Nchu had about 67% of households who depend solely on agriculture for a living, while the North and Southern Thaba Nchu have 62% and 60%, respectively. Based on the average agricultural livelihood diversification, the Southern Thaba Nchu was the most vulnerable (0.36), followed by the North (0.27) and Central Thaba Nchu (0.25). These findings suggest that households in Central Thaba Nchu engaged in more diverse agricultural practices than those in Northern and Southern Thaba Nchu. The result also implies that the fewer agricultural practices a household engages in, the more vulnerable it is to climate shock. That is because diversifying agricultural operations (e.g., animal rearing, growing different crops, etc.) allows the household to shift to a higher revenue generation, which facilitates the adoption of climate change approach. Southern Thaba Nchu was found to be more vulnerable (0.01) in terms of the proportion of households who practice freelancing, followed by Central (0.04) and Northern Thaba Nchu (0.07). This indicates that fewer households have some individuals who work as freelancers (North with 7% Central with 4% and South with 1%). For farm insurance only 3%, 2% and 1% of the farming households in Central, Northern and Southern Thaba Nchu had purchase farm insurance as a risk mitigation strategy. One of the most important aspects of farm insurance is that it gives farmers the confidence to cultivate better crops and livestock, which can boost their overall productivity and raise their standard of life (Kumar et al., 2020). According to Mathithibane (2021), crop insurance is regarded as an effective risk management approach by fewer than 10% of farmers in South Africa.

The seventh major component was the social network, which was made up of three sub-components. When all of the sub-elements in the three regions were pooled, the Northern Thaba Nchu was the least susceptible (0.630), followed by the Southern (0.633) and Central Thaba Nchu (0.653). About 83% of smallholder farming households in both North and Central Thaba Nchu were reported to have not received drought relief benefits from government compared to Southern Thaba Nchu (74%). This finding is consistent with the findings of Muthelo et al. (2019). The result also revealed that over 50% of the smallholder farming household has no access to extension services, which increases their vulnerability to drought by 55%, 58% and 60% for North, Central and Southern Thaba Nchu, respectively. Drought-resistant variety cultivation and modifying agricultural schedules are more likely to be implemented if extension services are available (Anik et al., 2021). Access to extension agents increases the probability of adaptation and the ability to apply a wider range of adaptive techniques (Boansi et al.,

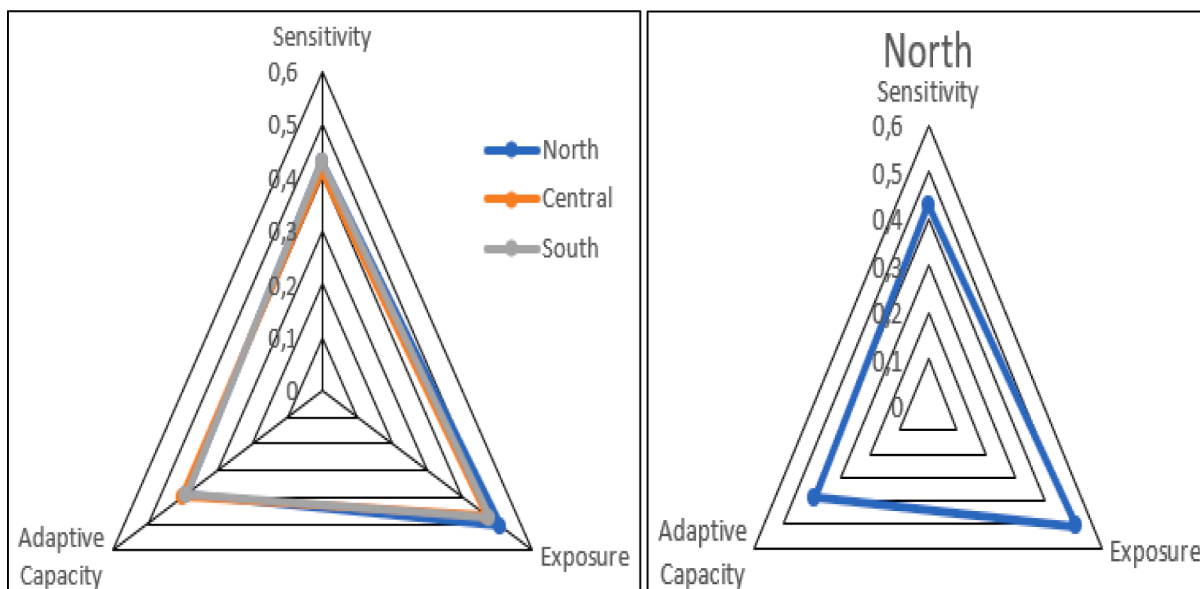
2017; Yegbemey et al., 2014), and it also gives information and guidance on adaptable techniques to the rural farming household (Muroyiwa et al., 2021). Northern Thaba Nchu was less vulnerable (0.51) when it comes to the percentage of the households that do not belong to farm association if compared to Central and Southern Thaba Nchu with 0.55 and 0.56, respectively. This implies that more than half of farmers (55.2%) are not members of any farmers' organization. Being a member of farmers' organization allows the farmer to have access to interventions such as product education to help run the farm more efficiently and productively. The organization also encourages farmers to share knowledge with one another (Phares et al., 2020).

The findings of this study reveal that the three regions that comprise Thaba Nchu in Mangaung District are sensitive to the effects of climate change, albeit the vulnerabilities vary depending on location: the north, central or southern region. These variations are consistent with earlier studies such as Adu et al. (2018), who revealed that Wenchi Municipality was more vulnerable to climate change and variability than Techiman Municipality in Ghana. At Bolivian Altiplano region, Valdivia et al. (2010) study finds greater vulnerability to climate change in northern Altiplano than central Altiplano communities. These findings agree also with some past studies on household vulnerability to environmental hazards, human capital, and social capital in the context of diverse livelihood frameworks (Uy et al., 2011; Dorward et al., 2009). The findings also showed that smallholder farming household were vulnerable to the main features of Carney's (1999) livelihood vulnerability framework. Climate variability and natural hazards, livelihood methods, food, water, socio-demographic profile, health, and social network are the major elements of Carney's (1999) livelihood frameworks. For the North, Central, and Southern Thaba Nchu, the overall livelihood indices of the seven key elements were 0.430, 0.418, and 0.425, respectively. However, the results obtained from the key elements suggested that smallholder farming households in Thaba Nchu are somewhat resilient to shocks resulting from livelihood strategies which may need fewer support to help deal with this shock.

Fig. 3(a, b, c, and d) summarized the outcomes of all the key elements. The vulnerability spider diagram has a scale ranging from 0 to 0.7 (least to most vulnerable). Based on social networks, water, socio-demographic profile and livelihood strategies, Central Thaba Nchu was most vulnerable. North Thaba Nchu was most vulnerable to changing climate, natural hazard, and health issues. With regards to food, southern Thaba Nchu was the most vulnerable.

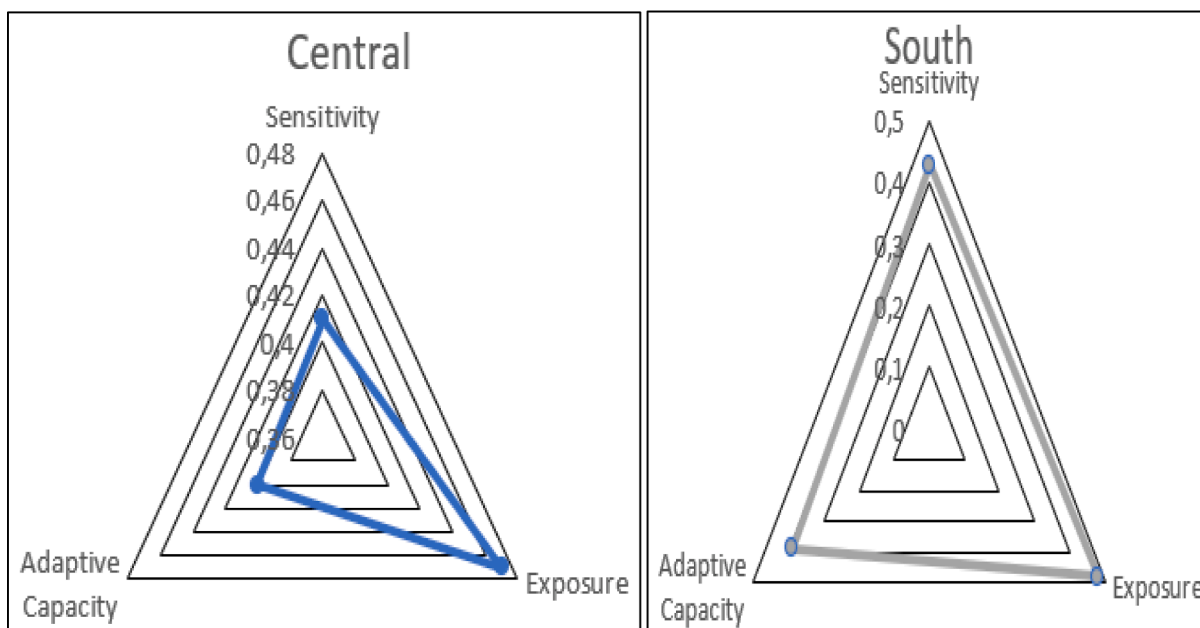
Livelihood vulnerability index – Intergovernmental panel on climate change (LVI-IPCC)

The LVI-IPCC was evaluated by categorizing the seven key elements into three sets: adaptive capacity, sensitivity, and exposure. Adaptive capacity and sensitivity were composed of the sum of three key element scores each, whereas exposure was composed of the value of only one key component score (Table 2). The LVI-IPCC estimations for the North, Central and Southern Thaba Nchu were 0.052, 0.029 and 0.041, respectively (Table 2). Generally, with regards to climate variability and



a: LVI-IPCC vulnerability triangular diagram for north, central and south of Thaba Nchu

b: LVI-IPCC vulnerability triangular diagram for northern Thaba Nchu



c: LVI-IPCC vulnerability triangular diagram for central Thaba Nchu

d: LVI-IPCC vulnerability triangular diagram for southern Thaba Nchu

Fig. 4. a: LVI-IPCC vulnerability triangular diagram for north, central and south of Thaba Nchu. b: LVI-IPCC vulnerability triangular diagram for northern Thaba Nchu. c: LVI-IPCC vulnerability triangular diagram for central Thaba Nchu. d: LVI-IPCC vulnerability triangular diagram for southern Thaba Nchu.

change, Northern Thaba Nchu was the most vulnerable, followed by South and Central Thaba Nchu. The IPCC description of vulnerability, which considers adaptive capacity, sensitivity, and exposure, is depicted in Fig. 4(a, b, c, and d) as a vulnerability triangle with a scale ranging from 0 to 0.6 (low to high contributing factor).

The vulnerability triangle clearly shows that smallholder farming households in Central Thaba Nchu are less exposed and sensitive to climate variability and change, considering food, health, water, natural hazards, and climate change condition of the households in the region. However, considering the livelihood strategies, social networks, and

socio-demographic profile, farming households in Central Thaba Nchu were more vulnerable with regards to household adaptation capacity.

Conclusion and recommendation

The African continent is commonly considered to be extremely vulnerable to the changing climate and climate variability. The intrinsic vulnerability has fuelled a call to action in the need to provide climate services that aid in the development of adaption strategies to mitigate the effects of changing climate. It is therefore imperative to examine

livelihood vulnerability to climate variation for practitioners and policymakers to develop sustainable adaptation interventions to improve resilience. Climate service information permits national, regional and local climate projections for impact adaptation and mitigation. To achieve these objectives, climate information must be adapted to the needs and expectations of end users. The current study used LVI to investigate the vulnerability of smallholder farming households to changing climate in Thaba Nchu, with focus on access to water resources and usage. Primary and secondary data were used, where the primary data came from 301 smallholder farming households, and it was supplemented by secondary data on temperature and rainfall from 2010 to 2020. The North, Central, and Southern Thaba Nchu, were subjected to a comparative analysis.

According to the empirical findings, farming households in Central Thaba Nchu were more vulnerable based on water, socio-demographic profile, livelihood strategies and social network. Similarly, North Thaba Nchu was more vulnerable to health risks, climate change, and natural hazard. More also, Southern Thaba Nchu was more vulnerable based on food component of LVI. The overall Livelihood vulnerability index calculated from the key elements shows that smallholder farming households in Northern Thaba Nchu are more vulnerable to the changing climate, with an index of 0.430 compared to 0.425 in Southern Thaba Nchu and 0.418 in Central Thaba Nchu. The LVI-IPCC index further revealed that smallholder farming families in Northern Thaba Nchu were more vulnerable with an index of 0.052 than those in Southern Thaba Nchu with 0.041, and Central Thaba Nchu 0.029. According to the findings of this study, climate change is occurring in Thaba Nchu Mangaung District of the Free State province of South Africa, and smallholder farming households are suffering as a result of this occurrence.

The following recommendations are made by the study. First, funders, non-governmental organizations, and government organizations in the province should prioritize Central Thaba Nchu, which is the most vulnerable in terms of key contributing component. This might be accomplished through steps such as the installation of rainwater harvesting tanks and the building of more boreholes, which would reduce inconsistency in water supply and water conflicts. The proposal above is derived from the fact that Central Thaba Nchu was more vulnerable to water scarcity, with a higher proportion of the farming households reporting irregularity in water availability. Second, in terms of households that rely solely on agriculture as a source of income, extension agents should encourage farming households to diversify their sources of income, engage in freelancing, and become heavily involved in farm-based insurance to combat the negative effects of climate change.

Thirdly, although Central Thaba Nchu is more vulnerable in term of social network in its' key element value (0.653), the three regions should be given adequate support by donors, non-governmental organization, and government in this area of social network. This is because majority of the smallholder farming household does not receive drought relief benefit from the government. Changing climate can jeopardize the well-being of the smallholder farming household, whose livelihoods rely primarily on agriculture, unless those strategies are implemented. Considering the modest vulnerability of smallholder farming homes to changing climate, it is essential that measures are designed to track how climate change would probably influence farming households' livelihoods.

This study contributes to the discussion about livelihood vulnerability by showcasing the vulnerability of smallholder farming households in Thaba Nchu to changing climate and variability. This research used household level data to supply an experimental contribution on the vulnerability of smallholder farming households in Thaba Nchu, to changing climate, and some other livelihood variables (food, health

Table 1A

Number of selected households using Yamane's formula: $n = N / (1 + N(e)^2)$; N= number of households, e = error term=10%.

| Areas | Community names | Number of Household | Calculated number of participants (n) |
|---------------------|-----------------|---------------------|---------------------------------------|
| North of Thaba Nchu | Rakhoi | 78 | 44 |
| | Ratabane | 72 | 42 |
| | Longridge | 35 | 26 |
| | Middeldeel | 114 | 53 |
| | | | 165 |
| South of Thaba Nchu | Noga's Post | 99 | 50 |
| | Eureka | 39 | 28 |
| | Yorksford | 47 | 32 |
| | | | 110 |
| Central Thaba Nchu | Thubisi | 96 | 49 |
| | Total | | 324 |

Sources: (<http://www.mangaung.co.za/wp-content/uploads/2022/05/Final-Updated-MRDP-20.03.04.pdf>).

facilities, socio-demographic profile, livelihood strategies, social networks, and water access). Also, the study examined and ascertained the significant changes in levels of vulnerability across the three regions' key elements. However, because our data was limited to a specific region in Mangaung District, Free State Province of South Africa, the outcome needs to be interpreted as restricted to this region till additional extensive data becomes obtainable.

Limitation of the study

All research has limitations, regardless of who is conducting it: senior academics with decades of experience, undergraduate, masters, or PhD students. Just like every other article, this one has a limitation. Temperature and rainfall were the two main climate variables in the secondary data used for this analysis. However, the authors recommend that future research should include heat waves, wind (because air circulation and weather patterns can exacerbate drought), and relative humidity as some of the climate factors that impact the efficacy of concrete degradation mechanisms. Moreover, future studies could be extended to other drought prone areas in South Africa. A pool of empirical evidence on household vulnerability to drought in South Africa will enhance a comprehensive planning and implementation of strategies to mitigate the effects of occurrence of natural hazards such as drought.

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Data availability

The dataset and code used to analyse the dataset are available from the corresponding author upon request.

Authors contribution

AAO conceived and planned the research idea, applied for funding, supervised the project, oversaw the data analysis and led in the drafting of the manuscript. GD-A proposed the methodology and supervised the data analysis, participated in the drafting of the article. CCO was responsible for data management, analysis and drafting of the first draft. All authors read and agreed on the final draft of the manuscript.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ogundeji Abiodun reports financial support was provided by National Research Foundation.

Appendix 1

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