Environmental Systems Research

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Assessing smallholder farmers' vulnerability to climate change and coping strategies in South Kivu Province, eastern Democratic Republic of Congo

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Abstract

It is now well established that climate changes is affecting smallholder farmers and threatening agricultural production and livelihoods in South Kivu Province, eastern Democratic Republic of Congo (DRC), due to their limited capacity to cope with climate change. In the DRC, data on smallholder farmers' perceptions of climate change effects and related shocks remain limited. This study was carried out to assess smallholder farmers' vulnerability to climate change and their perceptions of related disruptions in livestock production in South Kivu Province. Specifically, the study assesses smallholder farmers' exposure, sensitivity, and adaptive capacity to climate change, as well as their perception of related shocks and the strategies they use to mitigate the shocks they experience. The study was conducted from May to October 2022 in five territories of South Kivu Province. Vulnerability was determined by considering the vulnerability index, potential impact index, and the adaptive capacity index. The findings revealed that livestock farmers in low-altitude zones are the most exposed and sensitive to the effects of climate change. However, their adaptive capacity is comparable to those of medium- and high-altitude zones. Most farmers believe that the observed effects of climate change and its impacts are due to poor agricultural and livestock practices. Their adaptive strategies include income diversification (57.6%), controlling livestock diseases (72%), adopting integrated production systems (65.2%), planting trees (56.9%), improving pasture management (45.5%), and using improved livestock breeds (41.3%). Despite their efforts, limited resources and access to technology constrain adaptation. This study highlights the critical role of farmers' attitudes and perceptions in shaping their adaptive behaviors. It underscores the need for localized interventions that integrate Climate Smart Agriculture (CSA) practices, built on traditional knowledge systems, to enhance resilience. These findings provide actionable insights for policymakers and practitioners aiming to improve the adaptive capacity of vulnerable communities in similar contexts.

Keywords Smallholder farmer, Exposure, Sensitivity, Adaptive capacity, Climate change, Cattle farms

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Introduction

Climate change poses a significant challenge to agriculture in the twenty-first century, particularly in Sub-Saharan Africa (SSA), where agricultural production heavily depends on rainfed systems and adaptive capacity is limited (Parry et al. 2007; Olsson et al. 2014). Smallholder farmers, who dominate agricultural production in SSA, are increasingly exposed to climate risks such as reduced rainfall, rising temperatures, and more frequent extreme weather events (Gbegbelegbe et al. 2017; Ayanlade et al. 2022). Projections indicate that temperatures in SSA could rise by 2 °C by 2050, with more frequent and intense droughts exacerbating agricultural vulnerabilities (Parry et al. 2007; Cairns et al. 2012). These climatic challenges threaten not only agricultural and livestock productivity but also the livelihoods of over 40% of the region's 360 million people, most of whom depend on smallholder farming (Ayanlade et al. 2022; Omotoso et al. 2023).

The Democratic Republic of Congo (DRC) exemplifies the challenges faced by smallholder farmers in SSA. In the DRC, 70% of the population lives in rural areas, heavily relying on agriculture and livestock for their livelihoods (Dove et al. 2021). Livestock, particularly cattle, contributes up to 9.2% of the gross domestic product (GDP) and is critical for household subsistence and income generation (Mugumaarhahama et al. 2021). However, the DRC is highly vulnerable to climate change due to factors such as widespread poverty, high population density, and persistent armed conflict (Cox 2011; Dove et al. 2021; Karume et al. 2022). In South Kivu Province, agriculture and livestock production are central to sustaining livelihoods. Cattle, in particular, play a pivotal role in household income, food security, and cultural practices (Mugumaarhahama et al. 2021).

The onset of climate change exacerbates existing vulnerabilities in South Kivu Province. Prolonged droughts, erratic rainfall patterns, and rising temperatures are driving ecological degradation, livestock herd depletion, food shortages, and population migration (Tarhule and Lamb 2003; Bele et al. 2010; Zizinga et al. 2017; Karume et al. 2022). Livestock populations in the DRC are declining due to stressors associated with climate variability, including inadequate husbandry practices and rural insecurity (Mugumaarhahama et al. 2021; Karume et al. 2022). These challenges underscore the urgent need for mitigation strategies to protect food security and reduce poverty in the region (Almeida et al. 2013).

Cattle production, in particular, is highly sensitive to the impacts of climate change, including reduced milk yield, impaired reproductive performance, increased disease incidence, and declining forage quality (Wheelock et al. 2010; Ahmed & Murtala 2023). Adverse effects on pastures and forage production, including shifts in floristic diversity, changes in dry matter yield, and reduced water-soluble carbohydrates, further impair livestock productivity (Bele et al. 2010). These vulnerabilities highlight the necessity of understanding smallholder farmers' adaptive capacities and their perceptions of climate change impacts.

Despite extensive research on climate change impacts, the existing literature on climate change in SSA largely focuses on biophysical and economic impacts. There is a critical gap in understanding smallholder farmers' perceptions of climate change and its influence on vulnerability and adaptation strategies. Perceptions, which are primarily shaped by lived experience and access to resources, are key to how farmers interpret risk and design adaptation strategies (Bryan et al. 2013; Sam et al. 2020; Chimi et al. 2022). As Chimi et al. (2022) point out, farmers' local perceptions of climate variability inform their adaptive behaviors, but these insights remain underexplored in studies conducted in South Kivu, where socio-ecological complexities add layers of vulnerability.

Recent studies, including those by Chimi et al. (2022) and Chimi et al. (2023), emphasize that vulnerability results from the interplay between exposure, sensitivity, and adaptive capacity. In their assessment of smallholder farmers' vulnerability to climate change in Cameroon, Chimi et al. (2023) show how factors such as resource availability, social capital and environmental stressors significantly influence vulnerability. Their work highlights the importance of integrating farmers' perceptions with quantitative assessments of vulnerability in order to design effective adaptation strategies.

South Kivu has special socioecological, economic, and cultural dynamic in comparison with similar regions or neighboring countries. The combination of persistent conflict, insecurity, high population density, and ecological degradation in this province leads to distinct vulnerabilities that cannot be fully addressed by referring to studies from other areas. These factors, combined with the cultural importance of livestock for household income, food security, and social practices, require specific research to capture the localized vulnerabilities that are lacking in the preexisting literature. Furthermore, there is a significant gap in the literature regarding how smallholder farmers in South Kivu perceive and respond to climate change, particularly when compared to regions such as Cameroon, where similar research (e.g., Chimi et al. 2022, 2023) has been conducted. The lived experiences and indigenous knowledge systems of South Kivu's farmers are critical for understanding vulnerability and designing effective adaptation strategies. This study aims to fill this gap by assessing the vulnerability of smallholder livestock farmers to climate change and their perceptions of related disruptions to cattle production in South Kivu Province, eastern DRC. Specifically, it evaluates farmers' exposure, sensitivity, and adaptive capacity to climate change while documenting their perceptions of climate-related shocks and adaptation strategies. By addressing this gap, the study seeks to inform evidence-based policy recommendations relevant to the specific context of South Kivu and thus contributes to the growing body of research on climate adaptation in SSA and offers actionable insights for developing targeted interventions that enhance the resilience of smallholder farming communities in the DRC.

Overview of climate change vulnerability assessment

Definition of vulnerability

Climate change vulnerability refers to the extent to which a system, such as a community, region, or sector, is susceptible to the adverse effects of climate change. It includes the system's exposure to these impacts, its sensitivity to them, and its ability to adapt and recover from them. Damage propensity or susceptibility makes agricultural livelihoods vulnerable to climatic disruptions (Lokonon 2018). According to Thornton et al. (2006), vulnerability is a complex concept that varies based on various factors including economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors. The assessment of vulnerability is challenging due to its multidimensional nature (Gitz and Meisebeck 2012). While there are multiple interpretations of vulnerability to climate change (Thornton et al. 2006; Reed et al. 2013), there is no consensus on its precise definition (Gallopín, 2006; Fellmann 2012). The most comprehensive and widely accepted definition of vulnerability comes from the Intergovernmental Panel on Climate Change (Parry et al. 2007; Olsson et al. 2014): "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes." The vulnerability of agricultural livelihood systems encompasses various aspects, such as their responsiveness to climatic disturbances and their limited capacity to adapt to them (Olsson et al. 2014). Consequently, vulnerability is determined by the type, magnitude, and rate of climate variability that a system experiences, as well as its adaptive capacity (Smit & Wandel 2006; Reed et al. 2013; Chinwendu et al. 2017; Lokonon 2018; Huong et al. 2018; Jamshidi et al. 2019).

Choice of framework

Approaches to conceptualizing vulnerability in the climate change literature typically fall into three main categories (Žurovec et al. 2017):

- The endpoint approach defines vulnerability as the extent of damage that a system may experience due to a specific climate-related event or hazard (Kelly and Adger 2000). This approach focuses primarily on hazard assessments and their consequences, often overlooking the role of human systems in influencing the outcomes of such events, hence the term physical or biophysical vulnerability. It emphasizes outcome indicators rather than the state of a system before the hazard event occurs (Žurovec et al. 2017).
- The starting point approach considers vulnerability as a state determined by the inherent characteristics of a system before it faces a hazard event. Social vulnerability, resulting from the social and economic characteristics of a system, is considered an inherent characteristic (Adger and Kelly 1999; Žurovec et al. 2017).
- The integrated approach, aligned with the Olsson et al. (2014) definition from the Third Assessment Report (TAR), combines both external biophysical elements, such as exposure to climate variability, and internal social dimensions, such as a system's sensitivity and adaptive capacity (Füssel and Klein 2006; Žurovec et al. 2017).

Components of vulnerability

Considering that the vulnerability of a given region or system involves both external, biophysical aspects and internal, socioeconomic factors, the vulnerability of agricultural livelihoods to climate-related disturbances is understood as their susceptibility or propensity to experience adverse impacts (Olsson et al. 2014). We decided to construct a vulnerability index using the indicator method, which is consistent with the IPCC definition of vulnerability. This methodology allows for the assessment of both socioeconomic and biophysical variables that contribute to vulnerability. As outlined by Olsson et al. (2014), vulnerability to climate change and variability is defined based on three fundamental components: (1) exposure, (2) sensitivity, and (3) adaptive capacity. According to the framework introduced by Füssel and Klein (2006), exposure and sensitivity together represent the potential impacts, while adaptive capacity represents the ability of the system to cope with these impacts. Thus, vulnerability can be quantified using the following mathematical formula:

$$\nu = f(PI, AC) \quad (1)$$

$$PI = f(E, S) \quad (2)$$

where ν is the vulnerability index, PI is the potential impact, AC is the adaptive capacity, E is the exposure, and S is the sensitivity. Thus, vulnerability can be defined as a function of biophysical and social indicators, which are the three components of vulnerability.

Exposure, sensitivity, and adaptive capacity emerge as the central components that shape vulnerability and require thorough investigation (Huong et al. 2018). According to the framework proposed by the IPCC, sensitivity and adaptive capacity are intrinsic factors, whereas exposure refers to an extrinsic element (Füssel 2007). A visual representation in Fig. 1 shows the intricate relationships between these three components in a structured way. This definition has received considerable support from the scientific community (Tao et al. 2011).

Exposure

Exposure refers to the extent to which a system is subject to significant physical changes associated with climate change (Parry et al. 2007; Jamshidi et al. 2019). In the context of this research, exposure refers to the presence of agricultural livelihood systems in regions and environments that may experience adverse impacts (Olsson et al. 2014). As highlighted by Islam et al. (2013), exposure indicators include the frequency of severe events, the degree of land degradation, and variations in temperature and precipitation.

Sensitivity

Sensitivity represents the degree to which an agricultural livelihood system is affected by or responds to climate change, either positively or negatively (Olsson et al. 2014). Sensitivity considers both detrimental and beneficial outcomes, as certain agricultural livelihood systems may benefit from climatic disruptions (Lokonon 2018). These impacts may be direct (e.g., changes in crop yields due to changes in temperature mean, range, or variability) or indirect (e.g., damages from increased instances of coastal flooding due to sea level rise) (Parry et al. 2007).

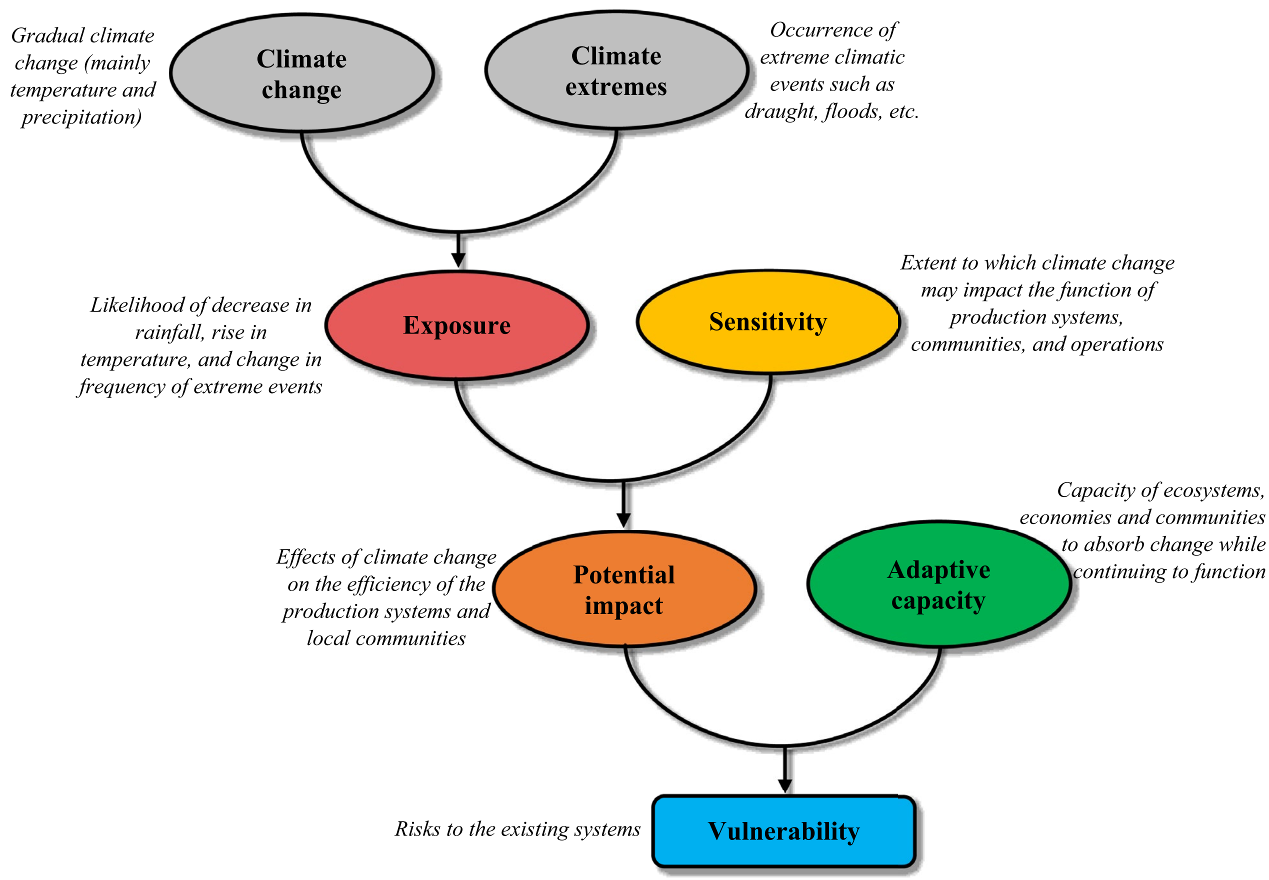

Fig. 1 Relationship among the three components of vulnerability (exposure, sensitivity, and adaptive capacity). Adapted from Jamshidi et al. (2019)

Adaptive capacity

The adaptive capacity of an agricultural livelihood system refers to its ability to respond to outcomes, seize opportunities, or adapt to climatic disturbances (Olsson et al. 2014). The concept of adaptive capacity encompasses both behavioral and technological adaptations (Jamshidi et al. 2019). According to the IPCC framework, vulnerability and adaptive capacity are considered incompatible. According to this model, reduced vulnerability to climatic shocks is associated with more robust adaptive capacity. However, higher adaptive capacity does not always translate into lower vulnerability. Thus, agricultural livelihood systems may be highly resilient to climatic shocks but also have significant adaptive capacity. Conversely, low adaptive capacity could reduce vulnerability. Given that susceptibility can be exploited in the face of climatic shocks, certain farmers may benefit from such events (Lokonon 2018). Here, v is the vulnerability index, PI is the potential impact, AC is the adaptive capacity, E is the exposure, and S is the sensitivity. Thus, vulnerability can be defined as a function of biophysical and social indicators that comprise the three elements of vulnerability.

Material and methods

Study area

This study was conducted between May and October 2022 and covered five of the eight territories in the South Kivu Province, located in the eastern part of the DRC (Figure 2). The territories included are Kabare, Kalehe, Mwenga, Uvira, and Walungu. These territories are defined as second-level administrative divisions at the national level, after the province. The province of South Kivu is located between 1° 36′ and 5° 00′ south latitude and between 26° 47′ and 29° 20′ east longitude, with elevations ranging from 773 to 3000 m above sea level (m.a.s.l.). South Kivu covers an area of 69,130 km^2 and has an average annual temperature of 19 °C. The selected areas represent the three agroecological zones present in the province: low, medium, and high altitude. These areas have a hilly tropical environment, characterized by grassy savannas crossed by numerous streams, and experience a bimodal rainfall pattern ranging from 1300 to 1800 mm. The soils in these areas are identified as depleted and eroded clay soils. Despite the noted climatic variations in the study area, the presence of the lake, river, and forest plays a role in regulating rainfall and temperature. Lake Kivu borders the territories of Kalehe, Kabare, and Kalehe, while significant parts of Walungu, Kabare, and Kalehe are within the boundaries of the Kahuzi-Biega National Park (KBNP).

The predominant sources of income for the inhabitants of the aforementioned regions include agriculture, animal husbandry, fishing, and small businesses. In particular, cattle, goats, and chickens are the most important livestock species raised for subsistence purposes. The urban center of Bukavu serves as the main market for these areas and receives direct food supplies from them (Mondo et al. 2019). These regions have high population densities, exceeding 300 individuals per square kilometer. Within the ethnic communities inhabiting these areas, cattle have notable cultural and societal significance, in addition to serving as a means of subsistence and financial support. Cattle play a central role in important ceremonial events such as weddings, where they are offered as dowries. In addition, the fermentation of cow's milk from these cattle is used to make a highly prized white cheese known locally as *mashanza*, which is highly valued by the indigenous population.

Sampling and data collection

A total of 1000 cattle farms were included in the data collection process, ensuring an equal distribution of 200 farms in each of the five selected territories. Stratified random sampling was considered to ensure equal representation of farms in each of the five selected territories. In this way, different types of experiences and perspectives were captured in each area, limiting regional bias.

A standardized survey was administered to farm managers. The household was chosen as the primary unit of analysis, as most agricultural decisions—including those related to production, investment, and consumption—are made at this level. The survey collected data on socio-demographic characteristics, farmers' exposure to climate change impacts, livestock management practices, and adaptive strategies.

In-depth, semi-structured interviews were conducted with farm managers to gather qualitative insights into the vulnerability of livestock farmers to climate change. These interviews allowed respondents to share detailed experiences and perspectives while providing flexibility to explore additional topics as needed. The interviews were conducted in local languages to facilitate effective communication and ensure accurate data collection.

In addition to primary data, supplementary information on climate-related risks, livestock production challenges, and adaptive practices was obtained from existing literature, as well as governmental and non-governmental reports. This approach ensured a comprehensive understanding of the region's vulnerability to climate change and its impact on livestock production. Figure 3 summarizes the research process used in this study.

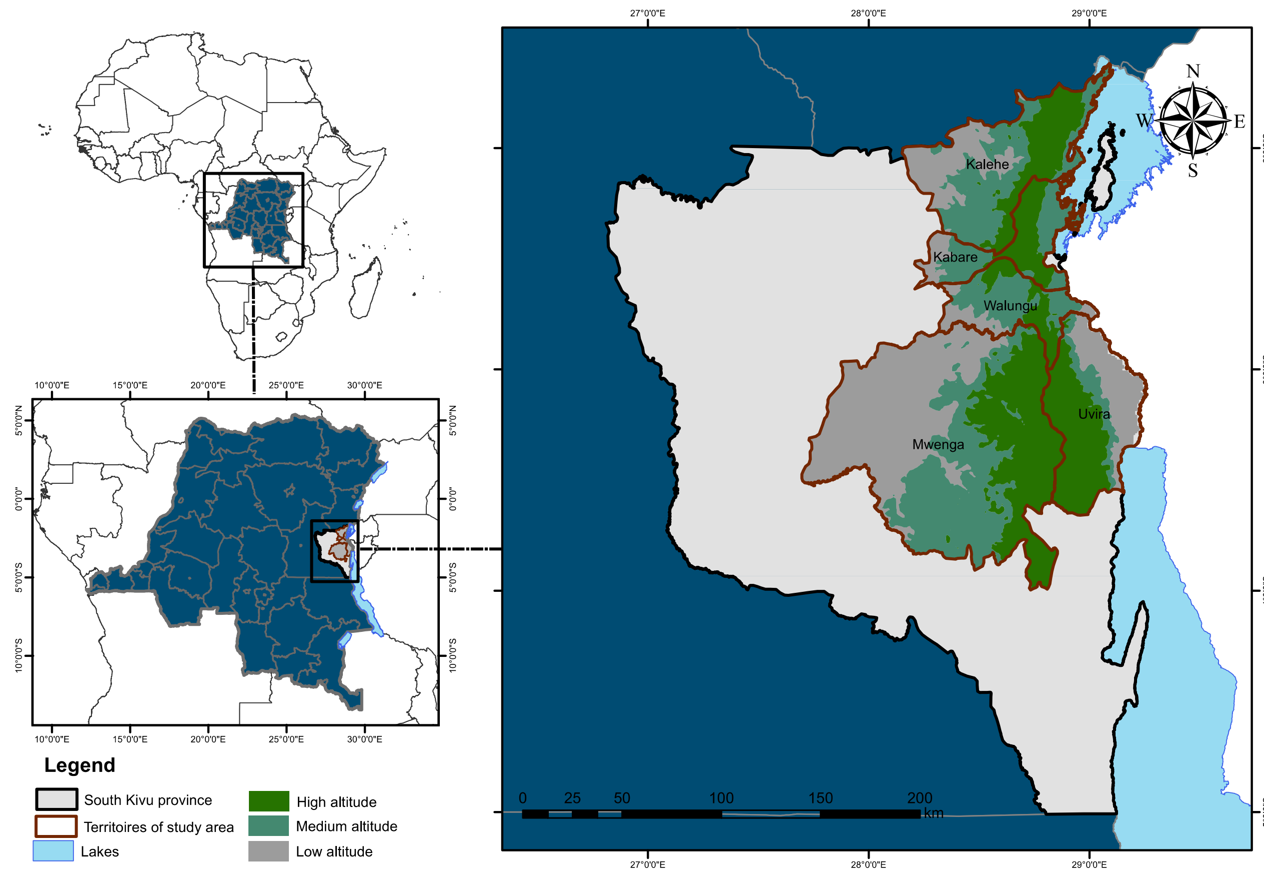

Fig. 2 Map of the study area

Data analysis

The data collected during the study were analyzed using both quantitative and qualitative methods to ensure comprehensive insights into the socio-economic characteristics of pastoralists in South Kivu Province. Survey responses were coded in Microsoft Excel and entered into R for statistical analysis. Descriptive statistics, such as means, standard deviations, and percentages, were used to summarize collected data. Cross-tabulations were performed to compare these characteristics across different agroecological zones.

Empirical approach to vulnerability assessment

Vulnerability assessment can be conducted at different levels, including regional, national, subnational, community, and even household or individual levels (Jamshidi et al. 2019). It provides a framework for identifying the social, economic, and environmental factors that contribute to disasters (Zarafshani et al. 2016) and plays a critical role in adaptation strategies to reduce their adverse impacts (Corobov et al. 2013). Assessing vulnerability to climate change and related impacts can be essential for increasing the resilience of smallholder livestock farmers (Mallari and Ezra 2016); however, vulnerability is a complex and multidimensional concept that includes social,

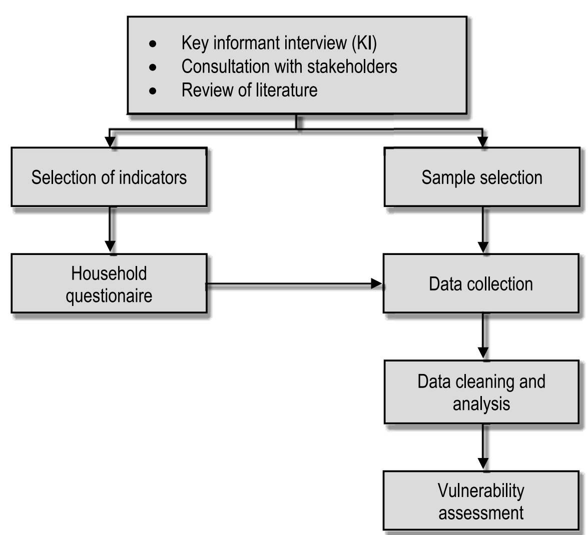

Fig. 3 Overall research framework

economic, physical, and environmental factors that can be interpreted and approached differently (Adger et al. 2005). There are a variety of methods and approaches for assessing vulnerability to climate change, which are often used to guide policy development to mitigate climate-related risks (Füssel and Klein 2006; Reed et al. 2013). Vulnerability assessments can consider social vulnerability, environmental vulnerability, or the interplay between the two (Füssel 2007). Due to different conceptualizations of vulnerability, there are numerous, sometimes overlapping, methods for assessing vulnerability (Pearson et al. 2011). In this study, we constructed a vulnerability index using the indicator method, which is consistent with the IPCC definition of vulnerability. As outlined by Olsson et al. (2014), vulnerability to climate change and variability is defined based on three fundamental components: exposure, sensitivity, and adaptive capacity.

Choice of vulnerability indicators A holistic comprehension of the three elements of vulnerability—exposure, sensitivity, and adaptive capacity—is critical in assessing the vulnerability of agricultural livelihood systems to climate-induced shocks. The use of indicators is one strategy that is used to measure vulnerability (Lokonon 2018), acting as proxies (Adger et al. 2005; Žurovec et al. 2017). Our research considers rural households as vulnerable systems affected by climate change and variability. This is based on the premise that a significant proportion of rural households depend on agriculture and livestock for their income or as a key element of their livelihood (Berjan et al. 2014; Žurovec et al. 2017). Livestock production is particularly vulnerable to climate variability, with the impacts worsening as variability increases. Therefore, the selected indicators should cover the physical aspects of climate change, the existing environmental conditions affected by climate change, and the socio-economic context that shapes the adaptive capacity in rural areas (Žurovec et al. 2017).

The indicator approach involves establishing a set of indicators and identifying relevant ones through expert assessment, principal component analysis (PCA), or correlation with past extreme events (Gbetibouo and Ringler 2009). Thus, both indicators and selection procedures are critical in vulnerability assessment.

An index can be characterized as "a composite measure of a social phenomenon that integrates different dimensions reflected by different indicators used as units of analysis". The assessment of vulnerability to a phenomenon requires a clear conceptual framework (Corobov et al. 2013). To improve the understanding of the determinants of vulnerability, a variety of indicators have been recognized for the three components of vulnerability in this study (Gbetibouo and Ringler 2009; Corobov et al. 2013; Bennett et al. 2014; Gizachew and Shimelis 2014; Pandey et al. 2015; Mallari and Ezra 2016; Lokonon 2018; Jamshidi et al. 2019). Identifying indicators of vulnerability is a daunting challenge (Downing et al. 2001). While several indicators are available to assess vulnerability to climate change (Fellmann 2012), the importance of specific indicators may vary across regions due to the location- and context-specific characteristics of vulnerability. In this study, a set of indicators was selected through expert focus group discussions, as outlined by Jamshidi et al. (2019). These indicators were further refined, taking into account the specific environmental and socioeconomic conditions of smallholder households in South Kivu Province. Table 1 presents the list of vulnerability indicators that were examined in this research.

Normalization of indicators To ensure comparability, all indicators used in this study were standardized to a range of 0 to 1. The standardization procedure followed the methodology used by the United Nations Development Program (UNDP) to calculate the Human Development Index. Before standardization, it was imperative to establish the functional link between the indicators and vulnerability. This validation ensures that the index values consistently have a positive association with vulnerability, where a higher value indicates greater vulnerability and vice versa. The functional associations with vulnerability for the indicators were identified from previous research (Žurovec et al. 2017). If vulnerability escalates simultaneously with an increase in the value of the indicator (positive correlation), thus showing a positive functional association with vulnerability, standardization was performed using the following equation (Eq. 3):

$$X_{ij} = I_{ij} \times \text{Max } I_j^{-1} \tag{3}$$

where X_{ij} is the normalized value of the jth indicator concerning the ith surveyed farmer, I_{ij} is the actual value of the jth indicator concerning the ith surveyed farmer, and Max I_j is the maximum value of the *jth* indicator concerning the *ith* surveyed farmer.

If the functional relationship with vulnerability is negative, i.e., if vulnerability decreases with an increase in the value of the indicator (negative correlation), the following equation was used (Eq. 4):

$$X_{ij} = \left(\text{Max } I_j - I_{ij}\right) \times \text{Max } I_j^{-1} \tag{4}$$

Calculation of the vulnerability index and weighting methods
After normalizing the indicators, the vulnerability index is computed for each farm household using the following equation (Eq. 5):

Table 1 Key indicators used for assessing vulnerability to climate shocks in South Kivu

Component	Code	Indicator	Nature	FR†
Exposure	EDRn	Decrease in precipitation during the last 20 years	Likert(1)	↑
	EHRn	Increase in frequency of heavy rains during the last 20 years	Likert(1)	↑
	ERRn	Change in rain frequency during the last 20 years	Likert(1)	↑
	EDSp	Increase in frequency of droughts during the last 20 years	Likert(1)	↑
	EITp	Increase in temperature during the last 20 years	Likert(1)	↑
	EFFl	Increase in flooding frequency during the last 20 years	Likert(1)	↑
	EHWd	Increase in frequency of heavy winds during the last 20 years	Likert(1)	↑
Sensitivity	SEEv	Losses due to extreme events during the last 20 years	Likert(1)	↑
	SPPd	Decline in pasture productivity during the last 20 years	Likert(1)	↑
	SISp	Occurrence of invasive species during the last 20 years	Likert(1)	↑
	SCYd	Decrease in crop yields during the last 20 years	Likert(1)	↑
	SPDP	Spread of diseases and parasites during the last 20 years	Likert(1)	↑
	SADi	Occurrence of new animal diseases during the last 20 years	Likert(1)	↑
	SAPd	Decrease in animal production during the last 20 years	Likert(1)	↑
Adaptative capacity	APCh	Proportion of kids and elders in the household	Continuous	↑
	APIl	The proportion of illiterates in the household	Continuous	↑
	AOFI	Possession of off-farm income	Dummy	↓
	AHIc	Monthly household income	Likert(2)	↓
	ALIm	Livestock and agriculture's importance in livelihoods	Likert(1)	↑
	AHSz	Household size	Discrete	↑
	AHHd	Herd size (in TLU)	Continuous	↓
	ALOw	Land ownership (in ha)	Continuous	↓
	AASv	Ability to save	Dummy	↓
	AREx	Livestock rearing experience	Discrete	↓
	ANSp	Number of reared species	Discrete	↓
	AACr	Access to agricultural credit	Dummy	↓
	AFAs	Financial assistance from a third party	Dummy	↓
	AHAg	Household head's age (years old)	Likert(3)	↑
	AHEd	Household head's education level	Likert(4)	↓
	ANPh	Number of telephones in the household	Discrete	↓
	AMAs	Membership in livestock farmers' associations	Dummy	↓
	ACEx	Number of contacts with extension workers	Discrete	↓
	AFLb	Use of family labor	Dummy	↓
	APLb	Use of paid labor	Dummy	↑
	ASOt	Solidarity with other herders	Dummy	↓
	AAEl	Access to electricity	Dummy	↓
	AAWt	Access to potable water	Dummy	↓
	ADMk	Distance from farmer's home to nearest market (in km)	Continuous	↑
	ADRd	Distance from farmer's home to the nearest road (in km)	Continuous	↑
	ARNb	Relatives and friends' households living nearby	Likert(5)	↓
	AMLo	Household money loaners	Likert(5)	↓
	ATNb	Trust in neighbors	Dummy	↓
	APCm	Participation in community activities	Dummy	↓

† FR: Functional relationship with vulnerability: ↑ = positive; ↓ = negative

(1) : Scores: 0 = nil; 1 = very low; 2 = Low; 3 = moderate; 4 = High; 5 = very high

(2) : Scores: 0 = nil; 1 $\leq$ 100$; 2 = 100–150$; 3 = 150–200$; 4 = 200–250$; 5 $\geq$ 250$

(3) : Scores: 0 $\leq$ 30; 2 = 30–40; 3 = 41–50; 4 = 51–60; 5 $\geq$ 60

(4) : Scores: 0 = illiterate; 1 = incomplete primary; 2 = primary; 3 = incomplete secondary; 4 = secondary; 5 = post-secondary

(5) : Scores: 0 = none; 1 $\leq$ 10; 2 = 10–20; 3 = 21–30; 4 = 31–40; 5 $\geq$ 40

$$\nu_i = \left(\sum_{j=1}^{n_e} W_{ej} \times X_{eij} + \sum_{j=1}^{n_s} W_{sj} \times X_{sij}\right) - \left(\sum_{j=1}^{n_a} W_{aj} \times X_{aij}\right) \quad (5)$$

where ν_i is vulnerability index concerning the ith surveyed farmer, X_{eij}, X_{sij} and X_{aij} are normalized indicators, respectively, of exposure, sensitivity, and adaptive capacity concerning the ith surveyed farmer; W_{ej}, W_{sj}, and W_{aj} are the weights assigned to the indicators of the exposure, the sensitivity, and the adaptive capacity; n_e, n_s and n_a are the number of indicators determining the exposure, the sensitivity, and the adaptive capacity, respectively (with $n = n_e + n_s + n_a$). One should notice that:

$$\sum_{j=1}^{n} W_j = 1 \quad (6)$$

Assigning appropriate weights to indicators and vulnerability components is crucial because they hold varying significance in assessing vulnerability (Jamshidi et al. 2019). One approach to address this is the indicator approach, where each indicator is assigned a weight as one of its attributes (Lokonon 2018). In Eq. 5, the challenge lies in determining the weights for the indicators. To reduce the uncertainty associated with weighting, the literature review identifies three methods (Gbetibouo and Ringler 2009): (i) equal weighting of all indicators (O'Brien et al. 2004; Deressa et al. 2008); (ii) dimension reduction techniques like factor analysis (FA) or principal components analysis (PCA) (Thornton et al. 2006; Deressa et al. 2008; Lokonon 2018; Jamshidi et al. 2019); and (iii) expert judgment (Moss et al. 2001; Brooks et al. 2005). Different variables influence vulnerability unequally (Hebb and Mortsch 2007), so the equal weight method was not used in this study. In addition, because access to experts was limited, PCA was applied.

Given that vulnerability is a multidimensional concept (Vincent and Cull 2014), the principal components obtained through PCA were utilized to construct the sub-indices. To maximize the representation of variability in the dataset, the decision on the number of principal components to retain was based on Kaiser's criterion, retaining all PCs exceeding an eigenvalue of 1 (Köbrich et al. 2003). The weight assigned to each component is determined by the proportion of variance it explains (Lokonon 2018). The weight of each principal component was calculated using Eq. 7 as follows:

$$W_k = V_k \times \left(\sum_{k=1}^{p} V_k\right)^{-1} \quad (7)$$

where V_k is the inertia captured in the kth component, and p is the number of retained principal components. W_k is the weight of the kth component from PCA.

The indicators' weights are computed using Eq. 8 as follows:

$$W_j = Z_{jk} \times W_k \quad (8)$$

Z_{jk} is the loading of the jth indicator on the kth component from PCA.

Once exposure (E), sensitivity (S), and adaptive capacity (AC) are calculated, the three contributing factors are combined using the following equation to compute the vulnerability:

$$\nu_i = (E_i + S_i) - AC_i \quad (9)$$

Upon completion of the ν_i calculation, households were categorized into three groups based on their ν_i values. The first group was identified as minimal vulnerability, meaning that the household is vulnerable but able to sustain itself without external assistance. The next group, known as moderate vulnerability, consists of households that need immediate but temporary external assistance to recover from a crisis. Finally, there is the high vulnerability group (the third group), which consists of households facing dire circumstances and requiring the highest level of expertise to recover (Jamshidi et al. 2019).

Results

Socio-economic characteristics of cattle farmers in the South-Kivu

Results in Table 2 present the socio-economic profile of the heads of livestock farmers' households in the three AEZs of South-Kivu province.

The results presented in Table 2 show that the vast majority (85.2%) of livestock farmers' households are headed by married men (66.1%). It is noteworthy to mention that a significant proportion (57.3%) of these household heads fall within the age interval of 40–60 years and have a significant level of expertise of more than 10 years in the area of livestock rearing (69.1%). In addition, a significant proportion of these household heads have no formal education (39.8%). The main source of livelihood for these households is agriculture and livestock husbandry (65.2%), often serving as their main occupation on a full-time basis (61.3%). The level of participation in livestock associations tends to vary by geographical region. Specifically, residents living in lowlands show a higher level of participation in such associations compared to their counterparts living in medium and high altitudes. The results presented in Table 3 illustrate the specific characteristics that characterize livestock farmers' households

Table 2 Profile of household heads among livestock farmers in South-Kivu Province

Variables	AEZs			Total
	High altitude	Medium altitude	Low altitude	
Gender of the household head				
Female	11.2	17.2	14.5	14.8
Male	88.8	82.8	85.5	85.2
Age of the household head				
Under 30 years old	7.4	12.6	9.5	10.4
30–40 years old	16.3	18.8	11.8	16.2
40–50 years old	29.8	22.2	31.7	26.9
50–60 years old	26.7	32.7	30.2	30.4
Over 60 years old	19.8	13.7	16.8	16.2
Experience in livestock farming				
Under 5 years	8.5	16.2	10.3	12.5
5–10 years	15.5	19.7	19.1	18.4
10–15 years	20.9	20.8	23.7	21.6
15–20 years	22.1	22.2	22.1	22.2
Over 20 years	32.9	21.1	24.8	25.3
Marital status				
Single	8.5	8.9	8.0	8.6
Divorced	5.8	7.3	8.0	7.1
Married	73.3	64.3	62.2	66.1
Widowed	12.4	19.5	21.8	18.2
Education level				
Nonformal education	39.5	39.4	40.8	39.8
Primary	32.9	19.9	19.1	23.2
Secondary	21.3	27.9	31.3	27.1
University	6.2	12.8	8.8	9.9
The main source of income				
Agriculture-livestock	81.0	57.4	62.6	65.2
Small trade	15.2	29.6	27.5	25.2
Public service	2.7	8.7	6.9	6.6
NGO work	1.2	4.1	3.1	3.0
Time allocated to herding				
Partial	35.7	41.4	37.0	38.7
Full	64.3	58.6	63.0	61.3
Association membership	18.2	30.0	42.0	30.1

in the three agro-ecological zones (AEZs) of the province of South Kivu.

In the three AEZs, the composition of livestock farmers households shows an average of 11.3 ± 4.3 persons living in dwellings constructed mainly of non-durable (37.2%) or semi-durable (40.1%) materials. Approximately 40% of these households are composed of individuals belonging to vulnerable age groups, such as children and the elderly, while approximately 30% of the population is illiterate. These households typically own an average of 1.7 ± 5.3 hectares of land, which is mainly used for crop cultivation purposes. The monthly income of these households rarely exceeds $200, with a significant portion (44.8%) coming from off-farm activities. Despite the limited access to agricultural credit among this rural population, the degree of access varies among the different AEZs, with farmers located in the highlands facing the greatest challenges in obtaining such financial support (Table 3). Several interrelated factors can be highlighted in relation to the problems faced by highlands' farmers in accessing financial support (agricultural credit). One of the most important is geographical isolation, as high-altitude areas tend to be deep in the countryside and poorly connected to the nearest cities, where formal credit institutions such as banks and microfinance services are usually located. Moreover, there are also artificial gaps, with fewer financial service providers in the high-altitude areas due to the high logistical challenges and costs of serving these areas.

Cattle production systems in South-Kivu province

Table 4 presents the summary of the livestock production systems in the three AEZs.

Table 4 shows that the average number of livestock per farm is 14.6 ± 22.6 Tropical Livestock Units (TLU), including different species. Livestock production practices are predominantly extensive in medium and low altitude areas (72.7% to 93.3%), while semi-intensive is preferred in highlands (52%). The implementation of the semi-intensive system in highlands is likely driven by the more challenging climatic conditions (particularly temperature) in these areas, which necessitate greater attention and investment to ensure livestock productivity. The majority of cattle (82.5%) are grazed on common pastures (91.9%), where their diet consists mainly of fodder, occasionally supplemented with crop residues (90.8%) and rarely with agro-industrial by-products (13.2%). Farmers in low and medium-altitude areas often practice transhumance (69.4 to 100%) during the dry season, which is characterized by a shortage of food resources for the animals.

Cattle farmer's awareness of climate change in South-Kivu Province

Results related to farmers' awareness of climate change and the perceived causes are presented in Table 5.

The results presented in Table 5 show that a significant proportion of farmers (84.7%) are aware of climate change phenomena. Notably, farmers at lower altitudes have the highest level of awareness (95.8%). The perceived impacts of climate change are often linked to suboptimal agricultural and livestock management practices (56.7%),

Table 3 Socio-demographic characteristics of livestock farmers' households in South-Kivu province

Variables	AEZs			Total
	High altitude	Medium altitude	Low altitude	
Type of housing				
Durable	23.6	25.4	17.2	22.7
Semi-durable	45.3	36.4	41.2	40.1
Non-durable	31.0	38.2	41.6	37.2
Household size	11.6 ± 4.3	10.5 ± 4.2	11.6 ± 4.4	11.3 ± 4.3
Proportion of kids and elders	0.4 ± 0.2	0.4 ± 0.2	0.3 ± 0.2	0.4 ± 0.2
Proportion of illiterates	0.3 ± 0.3	0.3 ± 0.3	0.3 ± 0.2	0.3 ± 0.3
Landholding size (in ha)	1.6 ± 5.7	2.1 ± 6.3	1.2 ± 2.2	1.7 ± 5.3
Land tenure				
None	33.3	14.0	9.5	18.0
Lease	21.9	24.7	44.7	29.3
Ownership	45.0	61.3	45.8	52.7
Monthly household income				
Less than 100$	54.3	46.9	41.6	47.4
100–150$	29.1	23.1	33.2	27.5
150–200$	7.0	13.5	13.7	11.8
200–250$	6.2	10.5	8.4	8.8
More than 250$	3.5	5.9	3.1	4.5
Off-farm income	27.5	52.2	49.6	44.8
Access to agricultural credit	5.0	16.2	21.8	14.7

Table 4 Information on livestock production systems in South Kivu

Variables	AEZs			Total
	High altitude	Medium altitude	Low altitude	
Herd size (in TLU)	8.3 ± 7.3	15.4 ± 25.5	19.6 ± 25.8	14.6 ± 22.6
Livestock production system				
Extensive	34.9	72.7	93.3	70.2
Intensive	13.1	6.5	0.4	6.1
Semi-intensive	52.0	20.9	6.3	23.7
Grazing system				
Zero grazing	8.6	6.5	0.3	4.9
Herding	89.7	92.4	65.8	82.5
Free range in paddocks	1.7	1.1	33.9	12.6
Exploited pasturelands				
Community pasturelands	90.3	87.8	97.9	91.9
Private pasturelands	8.6	9.4	2.1	6.6
Community and private pasturelands	1.1	2.9	0.0	1.4
Transhumance	27.3	69.4	100.0	69.6
Use of agro-industrial byproducts	13.1	4.2	20.9	13.2
Use of crop residues	98.3	81.2	94.2	90.8

such as inadequate animal nutrition and intensive farming practices that lead to soil degradation. A significant number of farmers attribute climate change to the divine will (47.5%) or unspecified factors (29.9%), while a minority acknowledge the role of greenhouse gas emissions and deforestation (17.2% and 33%, respectively). In addition,

Table 5 Climate change awareness and their perceived causes among livestock farmers

Actions	AEZs			Total
	High altitude	Medium altitude	Low altitude	
Awareness of climate change occurrence	73.6	84.7	95.8	84.7
Causes of climate change				
God's will	55.0	39.6	53.4	47.5
End of the time	7.0	10.5	13.7	10.4
Deforestation	11.2	34.3	52.3	33.0
Desertification	3.1	4.6	14.9	7.0
Disobedience to customs	5.4	15.8	19.5	14.0
Poor practices in agriculture and animal husbandry	20.5	58.2	90.1	56.7
Greenhouse gas emissions	5.0	17.8	28.2	17.2
Unknown causes	38.0	30.0	21.8	29.9

farmers cite other causes such as failure to follow traditions (14%), apocalyptic beliefs (10.4%), and desertification (7%).

Exposure, sensitivity and adaptive capacity of cattle farmers in South-Kivu province

Figure 4A shows that the exposure index (EI) is highly correlated with the first principal component (PCA1) obtained from the PCA analysis of exposure indicators. PCA1 captures 22.5% of the total exposure inertia and primarily represents the occurrence of extreme climate events, of which it captures a significant proportion. It is strongly correlated with the frequency of the occurrence of heavy winds (EHWd), the frequency of the occurrence of droughts (EDSp), the frequency of the occurrence of heavy rains (EHRn), and the frequency of the occurrence of floods (EFFl). The second component (PCA2) characterizes the change felt in climatic variables, essentially change in temperature (EITp), rainfall change (EDRn), and change in raining frequency (ERRn). This last component is very weakly correlated with the exposure index. This shows that exposure to climate change is mainly reflected in exposure to extreme climate events. It is less felt in the climatic variables. In terms of farmers' exposure, those at low altitudes are the most exposed to the occurrence of extreme climatic events. Those at high altitudes are the least exposed.

Figure 4B shows that the first component (PCA1, from the PCA on sensitivity indicators) is highly correlated with the sensitivity index (SI). This component captures almost 25.7% of the total inertia of sensitivity to the effects of climate change. It characterizes the negative impact of climate change on livestock production systems. Indeed, this component is strongly correlated with lower livestock productivity in terms of meat and milk (SAPd), lower crop yields (SCYd), the spread of diseases and parasites in livestock (SPDP), the occurrence of new animal diseases (SADi) and lower pasture productivity (SPPd). However, losses due to extreme climatic events (SEEv) and the occurrence of invasive plant species (SISp) are strongly correlated with the second principal component (PCA2), which is not at all correlated with the sensitivity index. This shows that these two phenomena do not reflect the farmers' sensitivity to climate change at all. Once again, we see that farmers in the lowland zone mostly score positively on PCA1, indicating that they are the most sensitive to climate change. Farmers in the other two AEZs have almost similar levels of sensitivity that are lower than of the ones at low altitudes.

Figures 4C and D indicate that in terms of adaptive capacity, its index (ACI) is correlated with the first two principal components (PCA1 and PCA2, capturing 26.1% of total inertia) derived from the PCA on adaptive capacity indicators. On these two principal components, and even including the third principal component (PCA3, accounting for 7.4% of total inertia), we cannot differentiate between farmers in the three AEZs; they are confused about the principal planes derived from these axes. In other words, farmers in all three AEZs have similar adaptive capacities. In all three AEZs, the households with the greatest adaptive capacity are those whose heads are better educated (AHEd). This category of farmers is more open to membership of farmers' associations (AMAs), which opens them up to a greater number of contacts with extension agents (ACEx) and assistance from other farmers (ASOt) when needed. These are the households with a high level of income (AHIc), obtained in particular through off-farm economic activities (AOFI), which allows them to save (AASv) and gives them the advantage of easy access to agricultural credit (AACr) and easy access to financial support from a third party (AFAs). They are financially

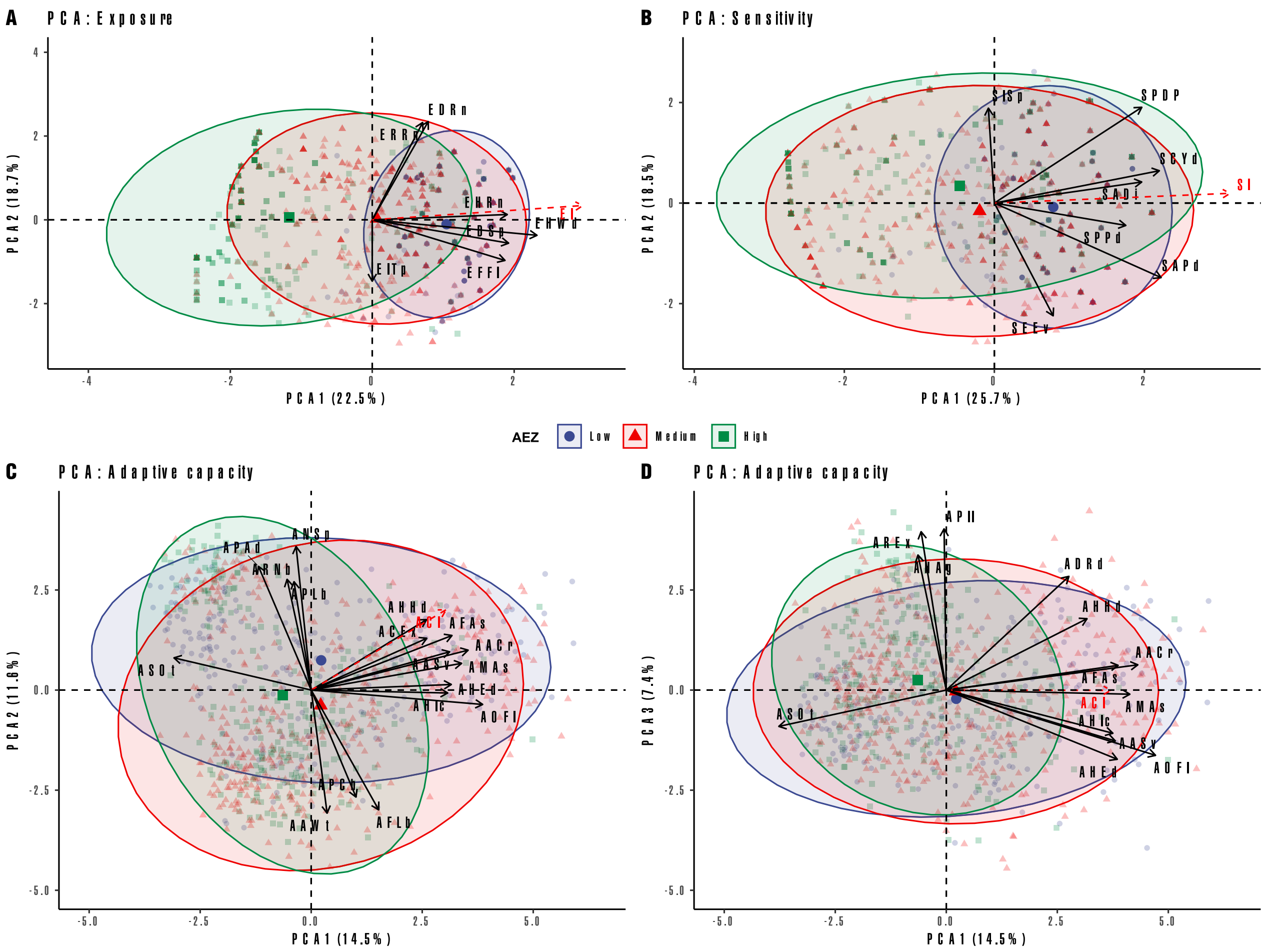

Fig. 4 PCA outputs of the indicators of exposure (**A**); indicators of sensitivity (**B**); and the components of adaptive capacity (**C** and **D**)

better off than other farmers and have the largest herds in terms of livestock units (AHHd).

The farmers' vulnerability scores and their components in the three AEZs are summarized in Fig. 5.

Results in Fig. 5 confirm the trends observed in Fig. 4, showing that lowland livestock farmers are the most exposed and sensitive to the effects of climate change. In terms of adaptive capacity, farmers in the three AEZs are comparable. They have the same adaptive capacity. With the highest exposure and sensitivity scores, lowland farmers have the highest vulnerability scores. In brief, the higher the altitude, the less farmers are exposed, sensitive, and vulnerable to the climate change effects.

Figure 6 shows the distribution of the levels of vulnerability in the three AEZs of the South-Kivu province.

Figure 6 demonstrates that the level of vulnerability is not depending on the household head's gender. Whether the household is led by a male or a female, the distribution of vulnerability is the same. Additionally, awareness of climate change does not appear to influence the level of vulnerability of farmers' households. Though a relatively high proportion of the least vulnerable households are among the unaware category, both aware and unaware households exhibit similar levels of vulnerability. However, it is noteworthy that the proportion of highly vulnerable farmers in the high-altitude zone is significantly lower compared to the other two AEZs, where this category represents over 60% of farmers. Conversely, the least vulnerable farmers are predominantly found in the high-altitude zones and are scarce in the low-altitude zone.

The results in Table 6 identify the main socio-economic factors that have an impact on the vulnerability of livestock farmers to climate change.

The results presented in Table 6 show that enhancing the adaptive capacity of farming households to the impacts of climate change requires several actions. These include reducing the workload by utilizing family labor ($p = 0.000$), strengthening social ties among farmers by avoiding social isolation from relatives and

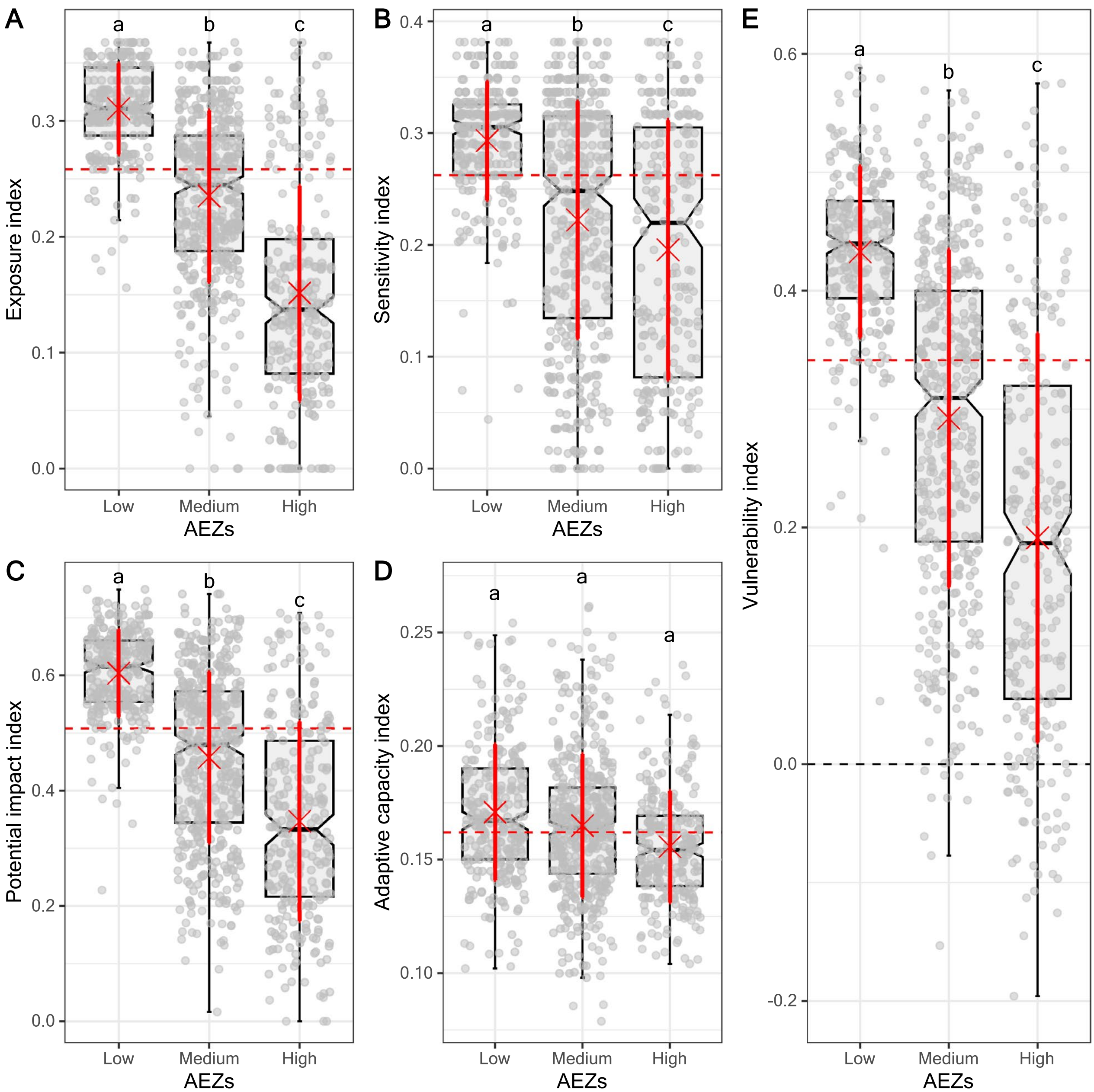

Fig. 5 Scores of Exposure (**A**), Sensitivity (**B**), Potential impact (**C**), Adaptive capacity (**D**), and Vulnerability (**E**) of livestock farmers and scores related to components of vulnerability

friends ($p=0.000$), strengthening solidarity with fellow farmers ($p=0.000$), and actively engaging in community activities ($p=0.002$). However, even with strengthened social ties, households remain vulnerable if they include a significant number of vulnerable individuals such as children and the elderly ($p=0.012$). In addition, living in easily accessible areas ($p=0.006$), in houses with access to electricity ($p=0.000$), and having at least one telephone ($p=0.001$) are also indicators of the resilience of farming households to climate change. Increasing household resilience to climate change impacts can also be achieved by improving access to land resources (increasing land ownership, $p=0.000$), increasing herd size ($p=0.039$), diversifying livestock species ($p=0.045$), and reducing household dependence on agriculture and/or livestock for livelihoods ($p=0.009$). In addition, external financial support to livestock farmers serves as an additional factor in

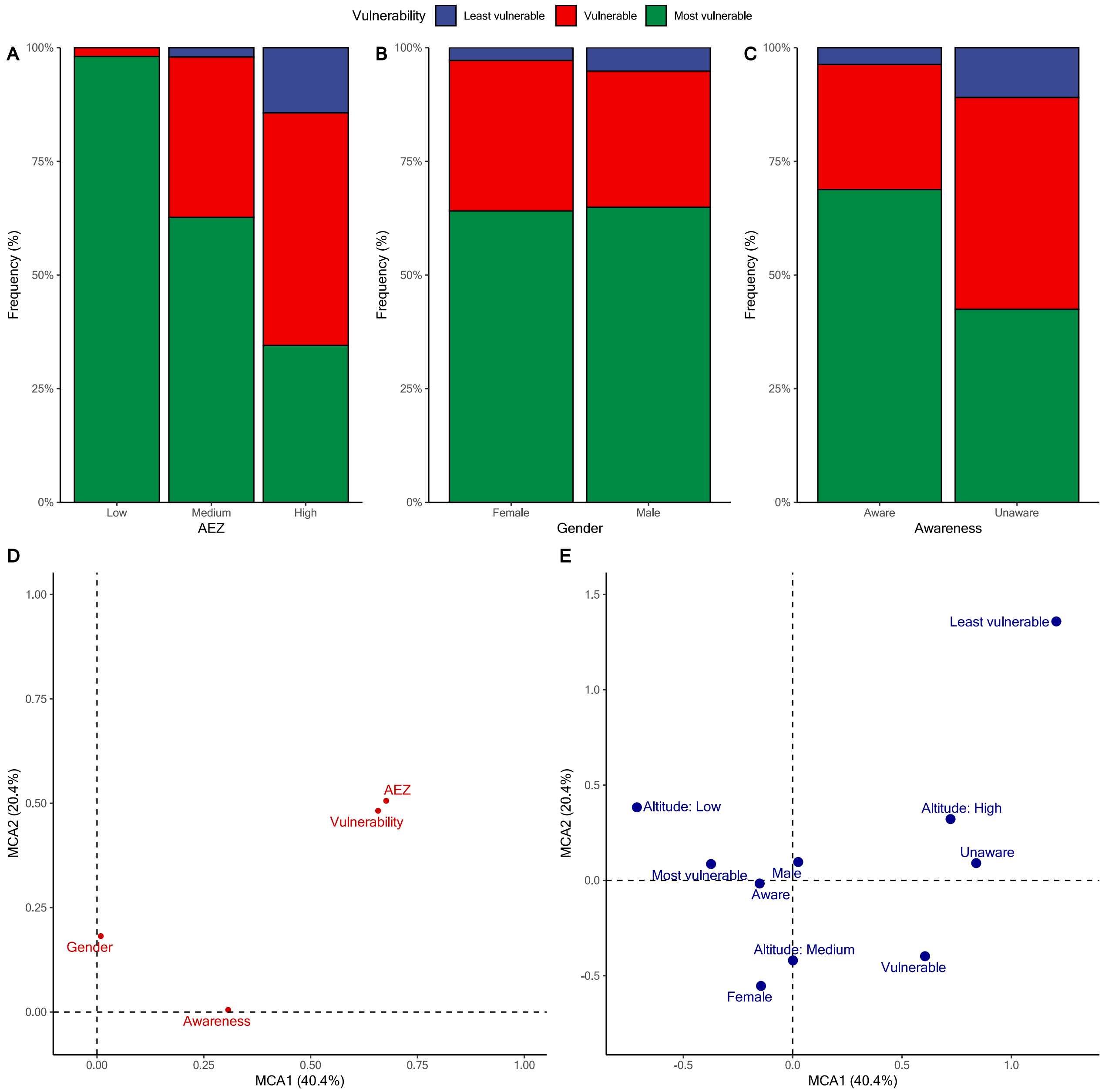

Fig. 6 Distribution of the three vulnerability thresholds based on agroecological zones: **A** AEZs, **B** gender, and **C** awareness. **D** and **E** display the biplots of variables and individuals after conducting an MCA analysis. The analysis considers four factors: the vulnerability threshold, agroecological zones, gender, and awareness

strengthening their capacity to adapt to the impacts of climate change.

Table 7 shows the strategies implemented by farmers to mitigate the effects of climate change.

As shown in Table 7, a variety of mitigation strategies are being adopted by farmers to cope with the adverse effects of climate change. Notably, farmers residing in the lowland region show a higher adoption rate of mitigation measures compared to their counterparts in the other two AEZs. Their main approaches include seeking divine intervention through prayer (71.3%) as a means of mitigating the effects of climate change. There is also a concerted effort among farmers to diversify household income sources (57.6%) to reduce dependence on agriculture and/or livestock for subsistence. They also advocate increased investment in livestock (60.5%), disease and parasite control (72%), adoption of integrated production systems (65.2%), cultivation of improved fodder

Table 6 Linear regression between vulnerability index and adaptive capacity indicators among livestock farmers

Indicators	β	SE	t	Pr(>|t|)	VI	Rank
Intercept	0.572	0.045	12.777	0.000***	–	–
Proportion of kids and elders in the household	1.354	0.538	2.517	0.012*	2.517	11
The proportion of illiterates in the household	−0.960	0.597	−1.607	0.108	1.607	16
Possession of off-farm income(1)	0.456	0.437	1.043	0.297	1.043	20
Monthly household income(1)	−0.526	0.619	−0.849	0.396	0.849	22
Livestock and agriculture's importance in livelihoods	1.224	0.464	2.637	0.009**	2.637	10
Household size	−0.559	0.539	−1.038	0.300	1.038	21
Herd size(1)	2.407	1.162	2.072	0.039*	2.072	12
Landholding size(1)	7.639	1.889	4.044	0.000***	4.044	5
Ability to save(1)	0.384	0.329	1.168	0.243	1.168	18
Livestock rearing experience(1)	−0.340	0.486	−0.699	0.485	0.699	25
Number of reared species(1)	1.206	0.601	2.009	0.045*	2.009	13
Access to agricultural credit(1)	−0.006	0.508	−0.012	0.991	0.012	29
Financial assistance from a third party(1)	1.729	0.463	3.736	0.000***	3.736	6
Household head's age	0.022	0.554	0.039	0.969	0.039	28
Household head's education level(1)	−0.528	0.460	−1.147	0.252	1.147	19
Number of telephones in the household(1)	1.302	0.390	3.337	0.001***	3.337	7
Membership in livestock associations(1)	0.656	0.346	1.895	0.058†	1.895	15
Number of contacts with extension workers(1)	1.521	0.786	1.935	0.053†	1.935	14
Use of family labor(1)	1.547	0.310	4.995	0.000***	4.995	3
Use of paid labor	−0.248	0.312	−0.794	0.428	0.794	23
Solidarity with other herders(1)	2.142	0.324	6.618	0.000***	6.618	2
Access to electricity(1)	1.602	0.329	4.865	0.000***	4.865	4
Access to potable water(1)	0.400	0.325	1.227	0.220	1.227	17
Distance from farmer's home to the nearest market	0.411	0.538	0.765	0.445	0.765	24
Distance from farmer's home to the nearest road	−1.504	0.549	−2.741	0.006**	2.741	9
Relatives and friends' households living nearby(1)	3.522	0.508	6.935	0.000***	6.935	1
Household money loaners(1)	0.271	0.445	0.608	0.543	0.608	26
Trust in neighbors(1)	0.219	0.443	0.495	0.621	0.495	27
Participation in community activities(1)	0.999	0.326	3.060	0.002**	3.060	8

Residual SE = 0.138, DF = 927 | R^2 = 0.307, Adjusted R^2 = 0.286 | F-statistic = 14.18, p-value = 0.000 | VI: Variable importance

(1) : These indicators have a negative functional relationship with vulnerability. Their coefficients should be interpreted accordingly | *** → highly different from 0; ** → very different from 0; * → different from 0

varieties (48.6%), intensified erosion control (58.9%) and tree planting (56.9%) to counter the adverse effects of climate change. In addition, adopting superior livestock breeds (41.3%), diversifying livestock species (51.6%), improving pasture management (45.5%), expanding grazing areas (48.5%), preserving fodder in silos (35.4%), improving animal feeding practices (37. 8%), use of crop residues and agro-industrial by-products (41.8%), fighting bush fires (49.7%) and maintaining traditional rituals (36.8%) are among the strategies implemented, with a predominant presence in lowland areas.

Discussion

Agriculture and livestock farming as key livelihoods

The findings of this study highlight the significance of agriculture and livestock farming as key livelihood assets for rural farmers' households in South Kivu. Similar to other sub-Saharan African regions, agriculture, and livestock farming are the primary sources of income for household heads, upon which they rely to support their families' needs (Davis et al. 2017; Mugumaarhahama et al. 2021). However, despite their involvement in this sector, these households struggle to earn a monthly income of $150, on average, for an average household size of 11 individuals. Moreover, the majority of them have no additional source of income. This indicates that ~90% of these households live in extreme poverty, earning

Table 7 Implemented strategies to mitigate the effects of climate change by South Kivu livestock farmers

Actions	AEZs			Total
	High altitude	Medium altitude	Low altitude	
Diversification of income sources	51.9	60.6	58.0	57.6
Increasing funds allocated to livestock	69.8	57.9	55.7	60.5
Adoption of improved animal breeds	23.3	38.4	63.7	41.3
Diversification of reared animal species	32.6	45.3	80.9	51.6
Parasites and diseases control	59.7	67.7	91.2	72.0
Better pasturelands management	19.0	39.1	82.1	45.5
Increasing the amount of land used for grazing	26.7	42.8	79.4	48.5
Forage cultivation and adoption of improved forages	23.3	43.0	82.8	48.6
Forage conservation (Silage)	17.8	36.6	50.8	35.4
Practice of integrated farming systems	57.4	55.8	88.5	65.2
Improvement of livestock feeding practices	21.7	38.0	53.4	37.8
Valorization of crop residues and agro-industrial by-products	15.9	36.8	75.6	41.8
Planting trees	41.5	50.1	83.6	56.9
Stepping up erosion control	36.4	61.3	77.1	58.9
Fighting bush fires	21.7	48.7	79.0	49.7
Traditional rites	12.8	34.6	64.1	36.8
Prayers	57.0	72.5	83.2	71.3

less than $1 per person per day. These estimates align with the findings of Tambo and Mockshell (2018) who observed that rural households in SSA typically experience poverty, with an average annual household income of $711 (less than $100 per month) for approximately seven individuals in the household.

Challenges of livestock farming in South Kivu
In the context of extensive livestock farming, characterized by communal grazing on pastures, there is limited improvement in the socio-economic situation and household income of farmers (Mugumaarhahama et al. 2021). Smallholder cattle farms face challenges such as low productivity resulting from insufficient investments, leading to high production costs about yield. Additionally, the low genetic potential of predominantly local breeds and poor feeding practices, relying primarily on inexpensive forage without supplementation, contribute to low productivity (Sottie et al. 2008; Hemme et al. 2010; Baenyi et al. 2021; Balehegn et al. 2021). Furthermore, inadequate pasture management in communal areas hinders the fulfillment of animals' nutritional needs (Mugumaarhahama et al. 2021). Unfortunately, in addition to these existing challenges faced by livestock farmers, the impacts of climate change further exacerbate their situation (Godfray et al. 2010). Cattle production is particularly susceptible to the detrimental effects of climate change (Ayanlade and Ojebisi 2019).

Geographical variability in climate change impacts
Numerous studies have shown that although climate change is a global problem, its impacts are manifested differently in different regions. The significance of climate change impacts varies depending on the specific geographical zone, as evidenced by previous studies (Etwire et al. 2013; Jamshidi et al. 2019). Results of this research show that livestock farmers are exposed and sensitive to the effects of climate change depending on their geographical location. Farmers in low-altitude areas, characterized by a more arid climate, are the most exposed and sensitive to the effects of climate change compared to those in medium and high-altitude areas. A couple of scientific articles have highlighted critical impacts of climate change, including precipitation and water scarcity (Haden et al. 2012; Bagula et al. 2022), pest and disease outbreaks (Niles et al. 2015), extreme temperature fluctuations, changes in rainfall patterns (Kabir et al. 2016), and declining crop yields and erratic rainfall (Vani and Kumar 2016). In this research, at low altitudes, exposure to climate change is more likely to consist of exposure to extreme climatic events, such as the increasing frequency of heavy winds, dry spells, heavy (abnormal) rainfall, and floods. Gbegbelegbe et al. (2017) highlighted in their analysis that a large number of research efforts in East Africa have identified declining rainfall, rising temperatures, and increased occurrences of dry spells and flooding as the major climatic hazards facing smallholder farmers. These findings are in line with our study which

reports the exposure of farmers to these climatic risks. They corroborate also the findings by Chikoore and Jury (2021), Thoithi et al. (2021), and Wainwright et al. (2021).

Livestock productivity and climate change

Exposure to the above-mentioned climate risks is associated with negative impacts on livestock productivity, reflecting farmers' vulnerability to climate change. For example, in this study, livestock farmers reported the spread of animal diseases and parasites and the emergence of new animal pathologies as a result of climate change. These results corroborate the findings by Kimaro and Chibinga (2013) who reported changes in the frequency and distribution of diseases due to climate change in Eastern Africa. More studies link climate change to changes in the spread of pathogens and the populations of vectors and animal hosts that are sensitive to changes in temperature and precipitation (Gale et al. 2009; Semenza et al. 2008; Rust and Rust 2013). Furthermore, Kimaro and Chibinga (2013) reported pasture shortages and water scarcity in drought areas resulting from climate change. These authors link climate change to a decline in the quantity and quality of pastures which are also experienced by farmers of South-Kivu province where community pastures constitute the main grazing lands.

Climate change has the potential to affect the availability of forage crops and the quality of forage, as shown by various studies (Rust and Rust 2013; Reidsma et al. 2015). This is mainly due to its effects on pasture growth and constituents, resulting in changes in the grass-to-legume ratio, variations in forage quality due to changes in water-soluble carbohydrates and nitrogen concentrations, and variations in dry matter yield (Wilkinson et al. 2019). Economically, these effects are reflected in a decline in both livestock productivity and food crop yields. Livestock productivity is also directly impacted by climate change by increasing heat stress in animals. Heat stress influences growth, reproduction performance, milk production, wool production, animal health, and welfare (Tarhule and Lamb 2003; Bele et al. 2010; Oyhantçabal et al. 2010; Wheelock et al. 2010; Kimaro and Chibinga 2013; Rust and Rust 2013; Joy et al. 2020). Heat stress leads to reduced feed intake and results in poor growth performance, although indigenous cattle are heat tolerant to high temperatures (Oyhantçabal et al. 2010; Wheelock et al. 2010; Joy et al. 2020).

Economic and food security impacts

Climate change and its associated impacts are indirectly affecting the availability of local food on the market, leading to an imbalance between supply and the ever-increasing demand resulting from the region's robust demographic expansion (Bosire et al. 2019). As a result, there has been a noticeable increase in food imports, exacerbating poverty and food insecurity. The impact of climate change on global food security is profound and has been highlighted in several studies (Rosegrant and Cline 2003; Parry et al. 2004; Schmidhuber and Tubiello 2007). Moreover, a correlation between poverty, vulnerability to climate change, and previous research findings is evident (e.g. Shewmake 2008; Deressa et al. 2008, 2009a, b; Islam et al. 2013; Alam et al. 2017; Lokonon 2018; Jamshidi et al. 2019). Undoubtedly, climate change stands out as a significant obstacle to poverty reduction and food security improvement, especially in sub-Saharan Africa (Alam et al. 2017; Hassan and Tularam 2018; Hassan and Nhemachena 2008).

Household vulnerability and resilience

The results of this study show that having a large proportion of vulnerable age groups (kids and elders) in the household weakens its resilience to the effects of climate change. However, living near a large number of relatives and friends reduces household vulnerability. Since most of these relatives and friends are also farmers, they help each other in conducting labor-demanding activities, so the main labor used is family-based. This solidarity is not limited to the family circle but extends to the whole community. All this contributes to making them more resilient to the effects of climate change. Furthermore, several studies indicated that poor and landless households and large-sized families are mostly affected by climate shocks. In addition, factors such as low level of education, age of the household head, small livestock herd size, small landholding size, low per capita income of the household, and low access to agricultural credit contribute to vulnerability (Deressa et al. 2008; Senbeta and Olsson 2009; Jan et al. 2012; Etwire et al. 2013; Nkondze et al. 2013; Asfaw et al. 2015; Chinwendu et al. 2017; Lokonon 2018; Jamshidi et al. 2019). Findings from this study show that in each of the three AEZs, the households with the greatest adaptive capacity are led by individuals with higher levels of education. Then, education seemed to correlate with vulnerability. Less vulnerability is associated with a high literacy rate as demonstrated in other previous studies (e.g., Deressa et al. 2008; Etwire et al. 2013; Chinwendu et al. 2017; Lokonon 2018). Through a higher level of education, farmers have access to information in terms of appropriate adaptation strategies that can be developed to cope with climate change (Lokonon 2018).

Adaptive capacity and coping strategies

Findings reveal that highly educated farmers are more receptive to joining farmers' associations, which affords them greater access to extension agents and assistance from other farmers in rearing activities when required. The more farm households have access to extension services, the they are better off in terms of vulnerability to climate change, and this aligns with previous studies (e.g. Asfaw et al. 2015; Lokonon 2018). These are the households with a high level of income, primarily derived from non-farm economic activities, which enables them to save and facilitate easy access to agricultural credit and third-party financial support. They are better off financially than other producers and have the greatest herds in terms of animal husbandry units. Furthermore, these results show that living close to roads, having access to electricity, owning larger plots (Chinwendu et al. 2017; Jamshidi et al. 2019), and a greater diversity of livestock species, and having one or more telephones in the household are all indicators of a better financial situation that characterize the households of the least vulnerable farmers. We can also see that households with this favorable financial situation are those whose livelihoods are less dependent on agriculture and/or livestock.

According to Gbegbelegbe et al. (2017), smallholder farmers in SSA have shown evidence in the past of being able to adapt to climatic risks. However, the magnitude and pace of climate change is unprecedented. Farmers can effectively manage the negative effects of climate change by adapting their agricultural practices, according to empirical evidence (Füssel 2007; Arunrat et al. 2017). Similar to other countries in SSA, the DR Congo seeks viable alternatives to address the detrimental effects of climate change on community livelihoods (Karume et al. 2022).

Smallholder farmers in DRC have adopted a range of adaptation strategies and practices to mitigate the adverse effects of climate change (Bele et al. 2010; Nsombo et al. 2012; Wright et al. 2014; Karam et al. 2022; Karume et al. 2022). In the South Kivu province, as evidenced by the results of this research, livestock farmers are taking measures to cope with climate change. In particular, farmers in the low-altitude zones show greater engagement in formulating climate change mitigation strategies than their counterparts in the other two AEZs. To reduce their dependence on agriculture and/or livestock for their livelihoods, these farmers seek to diversify their household income. They also advocate increased investment in the livestock sector, the management of animal diseases and parasites, the adoption of integrated production systems, the cultivation of fodder—especially high-quality fodder varieties—the intensification of erosion control measures, and afforestation as a means of countering the adverse effects of climate change, they face. Nevertheless, Partey et al. (2018) found that smallholder farmers' initiatives to combat climate change have yielded only marginal results.

Adoption of climate-smart agriculture

Climate-smart agriculture (CSA) was presented as one of the alternative and innovative approaches to sustainably increase the productivity of crops, livestock, fisheries, and forestry production systems and to enhance rural people's livelihoods and incomes. It has been demonstrated that CSA accomplishes this while also contributing to climate change mitigation efforts (Lipper et al. 2014; Karume et al. 2022; Waaswa et al. 2021). Karume et al. (2022) found evidence of progress in the adoption of CSA-like practices by farmers in DRC. They observe that communities adopting these practices are building on traditional knowledge systems and adapting introduced technologies to local conditions. The reported returns from the use of these practices are encouraging, suggesting their future applicability. As Karume et al. (2022), we advocate the integration of CSA into curricula and the training of a new generation of CSA-sensitive human capital at all levels of education, but especially at the public sector, extension, and community levels, as well as at the national and international levels.

Policy implications and recommendations

This research emphasizes the urgent need for climate change adaptation policies focused on enhancing the adaptive capacity of smallholder livestock farmers in South Kivu Province. Key policy actions identified include improving access to education and agricultural extension services, integrating Climate-Smart Agriculture (CSA) practices, and expanding extension services in vulnerable lowland areas. Policies should also enhance financial stability by improving access to agricultural credit and financial aid, extending microfinance facilities to smallholder farmers, and providing investment subsidies for climate-resilient technologies. Promoting the diversification of livelihoods through vocational training, support for small businesses, and incentives for non-agricultural economic activities is crucial for increasing household income stability and reducing vulnerability. Strengthening social networks and community adaptation initiatives, such as farmers' associations and cooperatives, is essential for building resilience and facilitating knowledge sharing, resource pooling, and access to funding and expertise.

The study further recommends incorporating climate change considerations into local and national planning to develop comprehensive models addressing vulnerability at the systemic level. Policymakers should use empirical evidence from this study and others to prioritize interventions in the most affected areas, ensuring that national action plans are coordinated with international climate agreements and aligned with global commitments. These strategies will help create a resilient agricultural sector capable of adapting to climate variability and securing sustainable livelihoods for smallholder farmers.

Limitations of the study

Despite its valuable insights, the study has limitations. It is limited in the sense that it is based on farmers' perceptions, which might not always be consistent with the objective climate data. The main focus was only on the livestock farmers, the interaction with other farming systems was not considered, such as crop production. Geographic coverage is limited to the agroecological zones of South Kivu; hence, probably the generalization of the findings to the other provinces in the DRC is limited. It assesses farmers' vulnerability to climate change using the AR5 framework, which is widely used but may not fully capture local-level dynamics or recent improvements in climate modeling and impact assessment. It also doesn't consider other wider socioeconomic and policy contexts, such as market access, extension services, and government support, which also affect farmers' adaptive capacity. Future research should be done with the integration of long-term climatic data, while the interaction of farming-across sectors and scope-should be widened to increase the generalizability of the findings. However, this study lays a very firm foundation for understanding and addressing the impacts of climate change among livestock farmers in the region, presenting critical insights to inform targeted interventions and adaptive strategies.

Conclusions

This study carries out an in-depth analysis of the vulnerability of smallholder livestock farmers in South Kivu Province to climate change, with a focus on exposure, sensitivity, and adaptive capacity. The results show that lowland farmers are the most vulnerable due to high exposure to extreme climatic events and high sensitivity to such impacts as outbreaks of diseases and reduction of pasture productivity. In contrast, farmers in high-altitude zones have lower levels of vulnerability despite comparable adaptive capacities across regions. These results underscore the nuanced interplay between geographic location, socio-economic factors, and climate change impacts.

The study emphasizes that education, financial resources, and social networks are some of the most determining factors in adaptive capacity. Households headed by better-educated individuals and households with off-farm income, financial assistance, and extension services show greater resilience. The strategies also include integrated farming systems, improved pasture management, and adoption of CSA practices in order to mitigate climate change impacts.

The localized nature of vulnerability and the socio-economic contingencies of adaptive capacity are concerns to which this study brings its contribution. In general, the findings from this study will be of interest primarily to policy and practice aiming at enhancing the resilience of smallholder farming systems. Identifying effective adaptation strategies and their socio-economic drivers, this study thus provides valuable input to develop targeted interventions and policies addressing specific challenges that vulnerable farming communities are faced with.

Furthermore, this study sets the stage for future research by pointing out the need for methodological advancements, deeper sociocultural analyses, and exploration of emerging technologies. This research furthers the broader goal of constructing sustainable and resilient agricultural systems in the face of climate change by bridging the gap between empirical findings and practical applications.

Acknowledgements
The Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) and the Global Research Alliance on Agricultural Greenhouse Gases (GRA) are acknowledged for providing the financial support that made possible this research through a Graduate Research Grant #RU/2020/GRG/08. Farmers are also acknowledged for their cooperation during data collection.

Author contributions
Conceptualization: P.C.A., Y.M., V.B.M. and K.K.; methodology: P.C.A., Y.M., V.B.M., A.B. and T.M.; Data collection: Y.M., V.B.M., A.B. and T.M.; data curation: Y.M., V.B.M., G.B.C., A.B. and T.M.; writing-original draft: P.C.A., Y.M., V.B.M., J.M.M., G.B.C.; writing-review and editing: P.C.A., Y.M., V.B.M., J.M.M., G.B.C., A.B., T.M., E.M.B., R.B.B.A., S.P.B., S.B.B., K.K.; supervision: E.M.B., R.B.B.A., S.P.B., K.K. All authors read and approved the final manuscript.

Funding
Not applicable.

Availability of data and materials
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 21 July 2024 Accepted: 29 January 2025
Published online: 10 February 2025

References

Adger WN, Kelly PM (1999) Social vulnerability to climate change and the architecture of entitlements. Mitig Adapt Strat Glob Change 4(3–4):253–266. https://doi.org/10.1023/A:1009601904210

Adger WN, Arnell NW, Tompkins EL (2005) Successful adaptation to climate change across scales. Glob Environ Chang 15(2):77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005

Ahmed A, Murtala M (2023) Effects of climate change on community-based grazing lands management: a case study of the border between Nigeria and Niger Republic. Glob J Earth Environ Sci 8(1):1–8. https://doi.org/10.31248/gjees2022.129

Alam MM, Siwar C, Talib BA, Wahid AN (2017) Climatic changes and vulnerability of household food accessibility. Int J Clim Change Strat Manag 9(03):387–401. https://doi.org/10.1108/ijccsm-06-2016-0075

Almeida JP, Montúfar R, Anthelme F (2013) Patterns and origin of intraspecific functional variability in a tropical alpine species along an altitudinal gradient. Plant Ecol Divers 6(3–4):423–433. https://doi.org/10.1080/17550874.2012.702137

Arunrat N, Wang C, Pumijumnong N, Sereenonchai S, Cai W (2017) Farmers' intention and decision to adapt to climate change: a case study in the Yom and Nan basins, Phichit province of Thailand. J Clean Prod 143:672–685. https://doi.org/10.1016/j.jclepro.2016.12.058

Asfaw S, McCarthy N, Paolantonio A, Cavatassi R, Amare M, Lipper L (2015) Diversification, climate risk and vulnerability to poverty: evidence from rural Malawi. In: 2015 CONFERENCE, August 9–14, 2015, Milan, Italy. https://doi.org/10.22004/ag.econ.230216

Ayanlade A, Ojebisi SM (2019) Climate change impacts on cattle production: analysis of cattle herders' climate variability/change adaptation strategies in Nigeria. Change Adapt Socio-Ecol Syst 5(1):12–23. https://doi.org/10.1515/cass-2019-0002

Ayanlade A, Oluwaranti A, Ayanlade OS, Borderon M, Sterly H, Sakdapolrak P, Jegede MO, Weldemariam LF, Ayinde AF (2022) Extreme climate events in sub-Saharan Africa: a call for improving agricultural technology transfer to enhance adaptive capacity. Climate Services 27:100311. https://doi.org/10.1016/j.cliser.2022.100311

Baenyi PS, Joseph JO, Ochieng JW, Tiambo CK, Tarekegn GM, Machuka EM, Kabange D, Musale K, Ciza AM, Kizungu RV, Pelle R (2021) Typology, management, and smallholder farmer-preferred traits for selection of Indigenous goats (*Capra circus*) in three agroecological zones in the Democratic Republic of Congo. J Appl Anim Res 49(1):423–430. https://doi.org/10.1080/09712119.2021.1995393

Bagula EM, Majaliwa JGM, Mushagalusa GN, Basamba TA, Tumuhairwe JB, Mondo JGM, Musinguzi P, Mwimangire CB, Chuma GB, Egeru A, Tenywa MM (2022) Climate change effect on water use efficiency under selected soil and water conservation practices in the Ruzizi Catchment, Eastern D.R. Congo. Land 11(9):1409. https://doi.org/10.3390/land11091409

Balehegn M, Ayantunde A, Amole T, Njarui D, Nkosi BD, Müller FL, Meeske R, Tjelele TJ, Malebana IM, Madibela OR, Boitumelo WS, Lukuyu B, Weseh A, Minani E, Adesogan AT (2021) Forage conservation in sub-Saharan Africa: review of experiences, challenges, and opportunities. Agron J 114(1):75–99. https://doi.org/10.1002/agj2.20954

Bele Y, Mulotwa E, De Semboli BB, Sonwa D, Tiani A (2010) Afrique centrale : les effets du changement climatique dans le Bassin du Congo; la nécessité de soutenir les capacités adaptatives locales. http://hdl.handle.net/10625/45639

Bennett NJ, Dearden P, Murray G, Kadfak A (2014) The capacity to adapt?: communities in a changing climate, environment, and economy on the northern Andaman coast of Thailand. Ecol Soc. https://doi.org/10.5751/es-06315-190205

Berjan S, Jovanovic M, Mrdalj V, Paspalj M, Matovic F, Driouech N, El-Bilali H, Abouabdillah A (2014) Rural livelihood diversification in south-eastern Bosnia: influence of household financial management. Int J Environ Rural Dev 5(2):17–22

Bosire CK, Rao EJO, Muchenje V, Van Wijk M, Ogutu JO, Mekonnen MM, Auma JO, Lukuyu B, Hammond J (2019) Adaptation opportunities for smallholder dairy farmers facing resource scarcity: integrated livestock, water, and land management. Agr Ecosyst Environ 284:106592. https://doi.org/10.1016/j.agee.2019.106592

Brooks N, Adger WN, Kelly PM (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob Environ Chang 15(2):151–163. https://doi.org/10.1016/j.gloenvcha.2004.12.006

Bryan E, Ringler C, Okoba B, Roncoli C, Silvestri S, Herrero M (2013) Adapting agriculture to climate change in Kenya: household strategies and determinants. J Environ Manage 114:26–35. https://doi.org/10.1016/j.jenvman.2012.10.036

Cairns J, Sonder K, Zaidi P, Verhulst N, Mahuku G, Babu R, Nair S, Das B, Govaerts B, Vinayan M, Rashid Z, Noor J, Devi P, Vicente FS, Prasanna B (2012) Maize production in a changing climate. In: Advances in agronomy, pp 1–58. https://doi.org/10.1016/b978-0-12-394275-3.00006-7

Chikoore H, Jury MR (2021) South African drought, deconstructed. Weather Clim Extremes 33:100334. https://doi.org/10.1016/j.wace.2021.100334

Chimi PM, Mala WA, Fobane JL, Essouma FM, Mbom JA II, Funwi FP, Bell JM (2022) Climate change perception and local adaptation of natural resource management in a farming community of Cameroon: a case study. Environmental Challenges 8:100539. https://doi.org/10.1016/j.envc.2022.100539

Chimi PM, Mala WA, Abdel KN, Fobane JL, Essouma FM, Matick JH, Pokam EYN, Tcheferi I, Bell JM (2023) Vulnerability of family farming systems to climate change: The case of the forest-savannah transition zone, Centre Region of Cameroon. Res Glob 7:100138. https://doi.org/10.1016/j.resglo.2023.100138

Chinwendu OG, Sadiku SOE, Okhimamhe AO, Eichie J (2017) Households vulnerability and adaptation to climate variability induced water stress on downstream Kaduna River Basin. Am J Clim Chang 06(02):247–267. https://doi.org/10.4236/ajcc.2017.62013

Corobov R, Sîrodoev I, Koeppel S, Denisov N, Sîrodoev G (2013) Assessment of climate change vulnerability at the local level: a case study on the Dniester River Basin (Moldova). Sci World J. https://doi.org/10.1155/2013/173794

Cox TP (2011) Farming the battlefield: the meanings of war, cattle and soil in South Kivu, Democratic Republic of the Congo. Disasters 36(2):233–248. https://doi.org/10.1111/j.1467-7717.2011.01257.x

Davis B, Di Giuseppe S, Zezza A (2017) Are African households (not) leaving agriculture? Patterns of households' income sources in rural Sub-Saharan Africa. Food Policy 67:153–174. https://doi.org/10.1016/j.foodpol.2016.09.018

Deressa T, Hassan RM, Ringler C (2008) Measuring Ethiopian farmers' vulnerability to climate change across regional states, Research briefs 15(5) AMH, International Food Policy Research Institute (IFPRI). https://ideas.repec.org/p/fpr/resbrf/15(5)amh.html

Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M (2009a) Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob Environ Chang 19(2):248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Deressa T, Hassan RM, Ringler C (2009) Assessing household vulnerability to climate change: the case of farmers in the Nile Basin of Ethiopia (No. 935). International Food Policy Research Institute (IFPRI)

Dove M, Lang Y, Zermoglio F, Johnston J (2021) Climate risk country profile: Congo, Democratic Republic. The World Bank Group, World Bank, Washington

Downing TE, Butterfield R, Cohen S, Huq S, Moss R, Rahman A et al (2001) Vulnerability indices: climate change impacts and adaptation. UNEP Policy Series, UNEP, Nairobi, 15.

Etwire PM, Al-Hassan RM, Kuwornu JKM (2013) Application of livelihood vulnerability index in assessing vulnerability to climate change and variability in Northern Ghana. J Environ Earth Sci 3(2):157–170

Fellmann T (2012) The assessment of climate change-related vulnerability in the agricultural sector: Reviewing conceptual frameworks. In: Meybeck A, Lankoski J, Redfern S, Azzu N, Gitz V (eds) Building resilience for

adaptation to climate change in the agriculture sector: proceedings of a Joint FAO/OECD Workshop 23–24 April 2012. Food and Agriculture Organization of the United Nations (FAO), p 37–53
Füssel HM (2007) Vulnerability: a generally applicable conceptual framework for climate change research. Glob Environ Chang 17(2):155–167. https://doi.org/10.1016/j.gloenvcha.2006.05.002
Füssel HM, Klein RJT (2006) Climate change vulnerability assessments: an evolution of conceptual thinking. Clim Change 75(3):301–329. https://doi.org/10.1007/s10584-006-0329-3
Gale P, Drew T, Phipps L, David G, Wooldridge M (2009) The effect of climate change on the occurrence and prevalence of livestock diseases in Great Britain: a review. J Appl Microbiol 106(5):1409–1423. https://doi.org/10.1111/j.1365-2672.2008.04036.x
Gallopín GC (2006) Linkages between vulnerability, resilience, and adaptive capacity. Glob Environ Chang 16(3):293–303. https://doi.org/10.1016/j.gloenvcha.2006.02.004
Gbegbelegbe S, Serem J, Stirling C, Kyazze F, Radeny M, Misiko M, Tongruksawattana S, Nafula L, Gakii M, Sonder K (2017) Smallholder farmers in eastern Africa and climate change: a review of risks and adaptation options with implications for future adaptation programmes. Clim Dev 10(4):289–306. https://doi.org/10.1080/17565529.2017.1374236
Gbetibouo GA, Ringler C (2009) Mapping South African farming sector vulnerability to climate change and variability: A subnational assessment (IFPRI Discussion Paper 00885). International Food Policy Research Institute. http://ifpri.org/publication/mapping-south-african-farming-sector-vulnerability-climate-change-and-variability
Gitz V, Meybeck A (2012) Risks, vulnerabilities and resilience in a context of climate change. In: Meybeck A, Lankoski J, Redfern S, Azzu N, Gitz V (eds) Building resilience for adaptation to climate change in the agriculture sector: proceedings of a joint FAO/OECD workshop 23–24 April 2012. Food and Agriculture Organization of the United Nations (FAO), p 19–36
Gizachew L, Shimelis A (2014) Analysis and mapping of climate change risk and vulnerability in Central Rift Valley of Ethiopia. Afr Crop Sci J 22(s4):807–818
Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327(5967):812–818. https://doi.org/10.1126/science.1185383
Haden VR, Niles MT, Lubell M, Perlman J, Jackson LE (2012) Global and local concerns: what attitudes and beliefs motivate farmers to mitigate and adapt to climate change? PLoS ONE 7(12):e52882. https://doi.org/10.1371/journal.pone.0052882
Hassan RM, Nhemachena C (2008) Determinants of African farmers' strategies for adapting to climate change: multinomial choice analysis. Afr J Agric Resour Econ 2(1):83–104. https://doi.org/10.22004/ag.econ.56969
Hassan OM, Tularam GA (2018) The effects of climate change on rural-urban migration in sub-Saharan Africa (SSA)—The cases of Democratic Republic of Congo, Kenya and Niger. InTech eBooks. https://doi.org/10.5772/intechopen.72226
Hebb A, Mortsch L (2007) Floods: mapping vulnerability in the Upper Thames watershed under a changing climate. Project Report XI, University of Waterloo, p 1–53. https://www.eng.uwo.ca/research/iclr/fids/publications/cfcas-climate/reports/vulnerability_mapping_report.pdf
Hemme T, Otté J, Initiative PPLP (2010) Status and prospects for smallholder milk production: a global perspective. In: Food and Agriculture Organization of the United Nations (FAO) eBooks. http://ci.nii.ac.jp/ncid/BB04863451
Huong NTL, Yao S, Fahad S (2018) Assessing household livelihood vulnerability to climate change: the case of Northwest Vietnam. Hum Ecol Risk Assess 25(5):1157–1175. https://doi.org/10.1080/10807039.2018.1460801
Islam MM, Sallu S, Hubacek K, Paavola J (2013) Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: insights from coastal Bangladesh. Reg Environ Change 14(1):281–294. https://doi.org/10.1007/s10113-013-0487-6
Jamshidi O, Asadi A, Kalantari K, Azadi H, Scheffran J (2019) Vulnerability to climate change of smallholder farmers in the Hamadan province, Iran. Clim Risk Manag 23:146–159. https://doi.org/10.1016/j.crm.2018.06.002
Jan I, Khattak MK, Khan MA, Hayat S, Rahim T (2012) Factors affecting rural livelihood choices in northwest Pakistan. Sarhad J Agric 28(4):681–688
Joy A, Dunshea FR, Leury BJ, Clarke IJ, DiGiacomo K, Chauhan SS (2020) Resilience of small ruminants to climate change and increased environmental temperature: a review. Animals 10(5):867. https://doi.org/10.3390/ani10050867
Kabir MI, Rahman MB, Smith W, Lusha MAF, Azim S, Milton AH (2016) Knowledge and perception about climate change and human health: findings from a baseline survey among vulnerable communities in Bangladesh. BMC Public Health. https://doi.org/10.1186/s12889-016-2930-3
Karam S, Seidou O, Nagabhatla N, Perera D, Tshimanga RM (2022) Assessing the impacts of climate change on climatic extremes in the Congo River Basin. Clim Change. https://doi.org/10.1007/s10584-022-03326-x
Karume K, Mondo JM, Chuma GB, Ibanda A, Bagula EM, Aleke AL, Ndjadi S, Ndusha B, Ciza PA, Cizungu NC, Muhindo D, Egeru A, Nakayiwa FM, Majaliwa JGM, Mushagalusa GN, Ayagirwe RBB (2022) Current practices and prospects of climate-smart agriculture in Democratic Republic of Congo: a review. Land 11(10):1850. https://doi.org/10.3390/land11101850
Kelly PM, Adger WN (2000) Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Clim Change 47(4):325–352. https://doi.org/10.1023/A:1005627828199
Kimaro EG, Chibinga OC (2013) Potential impact of climate change on livestock production and health in East Africa: a review. Livestock Research for Rural Development, 25(116). http://www.lrrd.org/lrrd25/7/kima25116.htm. Accessed 16 Apr 2024
Köbrich C, Rehman T, Khan M (2003) Typification of farming systems for constructing representative farm models: two illustrations of the application of multi-variate analyses in Chile and Pakistan. Agric Syst 76(1):141–157. https://doi.org/10.1016/s0308-521x(02)00013-6
Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T et al (2014) Climate-smart agriculture for food security. Nat Clim Change 4(12):1068–1072. https://doi.org/10.1038/nclimate2437
Lokonon BOK (2018) Farmers' vulnerability to climate shocks: insights from the Niger basin of Benin. Clim Dev 11(7):585–596. https://doi.org/10.1080/17565529.2018.1511403
Mallari N, Ezra CA (2016) Climate change vulnerability assessment in the agriculture sector: typhoon Santi experience. Procedia Soc Behav Sci 216:440–451. https://doi.org/10.1016/j.sbspro.2015.12.058
Mondo JM, Irenge AB, Ayagirwe RB, Dontsop-Nguezet PM, Karume K, Njukwe E, Mapatano SM, Zamukulu PM, Basimine GC, Musungayi EM, Mbusa HK, Kazamwali LM, Civava R, Mushagalusa GN (2019) Determinants of adoption and farmers' preferences for cassava varieties in Kabare Territory, Eastern Democratic Republic of Congo. J Rural Dev 7(2):44–52. https://doi.org/10.12691/ajrd-7-2-1
Moss RH, Brenkert AL, Malone EL (2001) Vulnerability to climate change: a quantitative approach. Pacific Northwest National Laboratory
Mugumaarhahama Y, Ayagirwe RBB, Mutwedu VB, Cirezi NC, Wasso DS, Azine PC, Karume K (2021) Characterization of smallholder cattle production systems in South-Kivu province, eastern Democratic Republic of Congo. Pastoralism 11:1–15. https://doi.org/10.1186/s13570-020-00187-w
Niles MT, Brown M, Dynes R (2015) Farmer's intended and actual adoption of climate change mitigation and adaptation strategies. Clim Change 135(2):277–295. https://doi.org/10.1007/s10584-015-1558-0
Nkondze MS, Masuku MB, Manyatsi A (2013) Factors affecting households vulnerability to climate change in Swaziland: a case of Mpolonjeni Area Development Programme (ADP). J Agric Sci. https://doi.org/10.5539/jas.v5n10p108
Nsombo BM, Thomas TS, Kyotalimy M (2012) East African agriculture and climate change: a comprehensive analysis—Democratic Republic of the Congo. https://reliefweb.int/sites/reliefweb.int/files/resources/aacccs_drcongo_note.pdf
O'Brien K, Leichenko R, Kelkar U, Venema H, Aandahl G, Tompkins H, Javed A, Bhadwal S, Barg S, Nygaard L, West J (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Chang 14(4):303–313. https://doi.org/10.1016/j.gloenvcha.2004.01.001
Olsson L, Opondo M, Tschakert P, Agrawal A, Eriksen S, Ma S, Perch L, Zakeldeen S (2014) Livelihoods and Poverty: climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the

Intergovernmental Panel on Climate Change, p 793–832. https://lup.lub.lu.se/search/publication/5bcb5b9f-e16b-4d4e-a8bc-d9096c560e5e
Omotoso AB, Letsoalo S, Olagunju KO, Tshwene CS, Omotayo AO (2023) Climate change and variability in sub-Saharan Africa: a systematic review of trends and impacts on agriculture. J Clean Prod 414:137487. https://doi.org/10.1016/j.jclepro.2023.137487
Oyhantçabal W, Vitale E, Lagarmilla P (2010) Climate change and links to animal diseases and animal production. pp 169–186. https://www.oie.int/fileadmin/Home/eng/Publications_%26_Documentation/docs/pdf/TT/2010_179-186_Oyhantcabal_A.pdf
Pandey R, Meena D, Aretano R, Satpathy S, Semeraro T, Gupta AK, Rawat S, Zurlini G (2015) Socio-ecological vulnerability of smallholders due to climate change in mountains: agroforestry as an adaptation measure. Change Adapt Socio-Ecol Syst. https://doi.org/10.1515/cass-2015-0003
Parry M, Rosenzweig C, Iglesias A, Livermore M, Fischer G (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Glob Environ Chang 14(1):53–67. https://doi.org/10.1016/j.gloenvcha.2003.10.008
Parry ML, Canziani OF, Palutikof JP, Van Der Linden PJ, Hanson CE (2007) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Summary for policymakers. https://www.cabdirect.org/abstracts/20083115494.html
Partey ST, Zougmoré RB, Ouédraogo M, Campbell BM (2018) Developing climate-smart agriculture to face climate variability in West Africa: challenges and lessons learnt. J Clean Prod 187:285–295. https://doi.org/10.1016/j.jclepro.2018.03.199
Pearson LJ, Nelson R, Crimp S, Langridge J (2011) Interpretive review of conceptual frameworks and research models that inform Australia's agricultural vulnerability to climate change. Environ Model Softw 26(2):113–123. https://doi.org/10.1016/j.envsoft.2010.07.001
Reed, Podesta G, Fazey I, Geeson N, Hessel R, Hubacek K, Letson D, Nainggolan D, Prell C, Rickenbach M, Ritsema C, Schwilch G, Stringer L, Thomas A (2013) Combining analytical frameworks to assess livelihood vulnerability to climate change and analyse adaptation options. Ecol Econ 94:66–77. https://doi.org/10.1016/j.ecolecon.2013.07.007
Reidsma P, Wolf J, Kanellopoulos A, Schaap BF, Mandryk M, Verhagen J, Van Ittersum MK (2015) Climate change impact and adaptation research requires integrated assessment and farming systems analysis: a case study in the Netherlands. Environ Res Lett 10(4):045004. https://doi.org/10.1088/1748-9326/10/4/045004
Rosegrant MW, Cline SA (2003) Global food security: challenges and policies. Science 302(5652):1917–1919. https://doi.org/10.1126/science.1092958
Rust J, Rust T (2013) Climate change and livestock production: a review with emphasis on Africa. South Afr J Anim Sci 43(3):255. https://doi.org/10.4314/sajas.v43i3.3
Sam AS, Padmaja SS, Kächele H, Kumar R, Müller K (2020) Climate change, drought and rural communities: understanding people's perceptions and adaptations in rural eastern India. Int J Disaster Risk Reduct 44:101436. https://doi.org/10.1016/j.ijdrr.2019.101436
Schmidhuber J, Tubiello FN (2007) Global food security under climate change. Proc Natl Acad Sci USA 104(50):19703–19708. https://doi.org/10.1073/pnas.0701976104
Semenza JC, Hall DE, Wilson DJ, Bontempo BD, Sailor DJ, George LA (2008) Public perception of climate change. Am J Prev Med 35(5):479–487. https://doi.org/10.1016/j.amepre.2008.08.020
Senbeta AF, Olsson JA (2009) Climate change impact on livelihood, vulnerability and coping mechanisms: a case study of West-Arsi Zone. Lund University, Lund, p 54
Shewmake S (2008) Vulnerability and the impact of climate change in South Africa's Limpopo River Basin. Soc Sci Res Netw. https://doi.org/10.2139/ssrn.1289844
Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Chang 16(3):282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008
Sottie ET, Darfour-Oduro KA, Okantah SA (2008) Comparative studies on growth traits of Sanga and Friesian-Sanga crossbred calves raised on natural pasture on the Accra Plains of Ghana. Trop Anim Health Prod 41(3):321–328. https://doi.org/10.1007/s11250-008-9192-8
Tambo JA, Mockshell J (2018) Differential impacts of conservation agriculture technology options on household income in sub-Saharan Africa. Ecol Econ 151:95–105. https://doi.org/10.1016/j.ecolecon.2018.05.005
Tao S, Xu Y, Liu K, Pan J, Gou S (2011) Research progress in agricultural vulnerability to climate change. Adv Clim Chang Res 2(4):203–210. https://doi.org/10.3724/sp.j.1248.2011.00203
Tarhule A, Lamb PJ (2003) Climate research and seasonal forecasting for west Africans: perceptions, dissemination, and use? Bull Am Meteor Soc 84(12):1741–1760. https://doi.org/10.1175/bams-84-12-1741
Thoithi W, Blamey RC, Reason CJC (2021) Dry spells, wet days, and their trends across southern africa during the summer rainy season. Geophys Res Lett. https://doi.org/10.1029/2020gl091041
Thornton PK, Jones PG, Owiyo T, Kruska RL, Herrero M, Kristjanson P, Notenbaert A, Bekele N and Omolo A, with contributions from Orindi V, Otiende B, Ochieng A, Bhadwal S, Anantram K, Nair S, Kumar V and Kulkar U (2006). Mapping climate vulnerability and poverty in Africa. Report to the Department for International Development, ILRI, Kenya. pp 171.
Vani CS, Kumar PBP (2016) A study on awareness levels and adaptation strategies for climate variability among farmers. Int J Environ Agric Biotechnol 1(2):190–194. https://doi.org/10.22161/ijeab/1.2.13
Vincent K, Cull T (2014) Using indicators to assess climate change vulnerabilities: are there lessons to learn for emerging loss and damage debates? Geogr Compass 8(1):1–12. https://doi.org/10.1111/gec3.12105
Waaswa A, Nkurumwa AO, Kibe AM, Kipkemoi JN (2021) Climate-smart agriculture and potato production in Kenya: review of the determinants of practice. Clim Dev 14(1):75–90. https://doi.org/10.1080/17565529.2021.1885336
Wainwright CM, Black E, Allan RP (2021) Future changes in wet and dry season characteristics in CMIP5 and CMIP6 simulations. J Hydrometeorol. https://doi.org/10.1175/jhm-d-21-0017.1
Wheelock J, Rhoads R, VanBaale M, Sanders S, Baumgard L (2010) Effects of heat stress on energetic metabolism in lactating Holstein cows. J Dairy Sci 93(2):644–655. https://doi.org/10.3168/jds.2009-2295
Wilkinson JM, Lee MRF, Rivero MJ, Chamberlain AT (2019) Some challenges and opportunities for grazing dairy cows on temperate pastures. Grass Forage Sci 75(1):1–17. https://doi.org/10.1111/gfs.12458
Wright H, Vermeulen S, Laganda G, Olupot M, Ampaire E, Jat M (2014) Farmers, food and climate change: ensuring community-based adaptation is mainstreamed into agricultural programmes. Climate Dev 6(4):318–328. https://doi.org/10.1080/17565529.2014.965654
Zarafshani K, Sharafi L, Azadi H, Van Passel S (2016) Vulnerability assessment models to drought: toward a conceptual framework. Sustainability 8(6):588. https://doi.org/10.3390/su8060588
Zizinga A, Kangalawe R, Ainslie A, Tenywa M, Majaliwa J, Saronga N, Amoako E (2017) Analysis of farmer's choices for climate change adaptation practices in south-western Uganda, 1980–2009. Climate 5(4):89. https://doi.org/10.3390/cli5040089
Žurovec O, Čadro S, Sitaula BK (2017) Quantitative assessment of vulnerability to climate change in rural municipalities of Bosnia and Herzegovina. Sustainability 9(7):1208. https://doi.org/10.3390/su9071208

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