Smallholder farmers' vulnerability to climate change in northwest Ethiopia

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Abstract

Purpose – The purpose of this paper is to investigate the vulnerability of smallholder farmers to climate change in northwest Ethiopia.

Design/methodology/approach – To achieve this aim, data was collected from a survey of 352 households, which were stratified into three groups: Lay Gayint (138 or 39%), Tach Gayint (117 or 33%) and Simada district (97 or 28%). To gain a deeper understanding of the vulnerability of these households, two approaches were used: the livelihood vulnerability index (LVI), consisting of 32 indicators, and the socioeconomic vulnerability index (SeVI), containing 31 indicators. Furthermore, qualitative data was obtained through focus group discussions conducted in six randomly chosen groups from the three districts, which were used to supplement the findings.

Findings – Both methods indicate that Simada is the most vulnerable district, followed by Tach Gayint and Lay Gayint. According to the SeVI approach, Simada district showed the highest level of sensitivity and exposure to climate-related hazards, as well as the lowest score for adaptive capacity. However, using the LVI approach, Simada district was found to have the highest sensitivity to climate effects and exposure to climate-related hazards, along with a higher adaptive capacity than both Lay Gayint and Tach Gayint districts.

Originality/value – Although there are numerous studies available on the vulnerability of farmers to climate change, this particular study stands out by using and contrasting two approaches – the LVI and the SeVI – to assess the vulnerability of households in the study area. Previous research has indicated that

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no single approach is sufficient to evaluate climate change vulnerability, as each approach has its own strengths and limitations. The findings of this study have significant implications for policymakers and development practitioners, as they can use the results to identify the households that are most vulnerable to climate change. This will enable them to design adaptation options that are tailored to the specific needs of each community and that will effectively address the risks of current and future climate change.

Keywords Climate change, Vulnerability, Livelihoods, Socioeconomics, Smallholders, Ethiopia

Paper type Research paper

1. Introduction

The occurrence of extreme events that negatively affect the livelihoods of smallholder farmers in developing countries is increasing due to climate change (Balaganesh *et al.*, 2020; Farid *et al.*, 2019: GebreMichael, 2020). The vulnerability of smallholder farmers' livelihoods to climate change partly arises from their geographic position in vulnerable landscapes, their socioeconomic characteristics, extreme dependence on natural resources and policies that limit their ability to adapt to changing climates (Jamshidi *et al.*, 2019). In sub-Saharan Africa, extreme climate events like drought make it difficult for people to raise crops and keep cattle (Negatu *et al.*, 2011; Pironon *et al.*, 2019). This difficulty is primarily due to Africa's weak socioeconomic background, which has an impact on the continent's ambitions for achieving the sustainable development goals (Chirambo, 2018; Kumi, 2019).

Ethiopia stands out as one of the sub-Saharan African countries that is most affected by climate-related hazards, with significant adverse effects on its agriculture sector (Kamali *et al.*, 2018; Sietz *et al.*, 2017). The vulnerability of Ethiopia's agricultural system is attributed to its dependence on smallholder rain-fed agriculture (Yalew *et al.*, 2018). According to various projections, extreme weather patterns such as droughts, floods and hot days and nights will continue to occur more frequently and intensely (Liou and Mulualem, 2019; Nikulin *et al.*, 2018). Despite the fact that climate change is a global phenomenon, its vulnerability is specific to particular regions. As a result, several scholars have proposed localized assessments of climate change vulnerability (Ahsan and Warner, 2014; Tessema and Simane, 2021; Yesuf *et al.*, 2008). Hahn *et al.* (2009) suggested the testing of climate change vulnerability at the community level, which would enable the comparison of the vulnerability of communities within a district or region and the prioritization of adaptation measures specific to local needs. Thus, it is essential to comprehend the vulnerability context at the local level to implement effective and relevant adaptation measures. In other words, local-level studies assist in identifying context-specific factors (Eriksen *et al.*, 2005) that must be considered to ensure that interventions benefit vulnerable groups. Studies conducted in Ethiopia, such as those by Simane *et al.* (2016) and Teshome (2016), provide evidence that smallholder farmers in the country are highly susceptible to the impacts of climate change and variability. For example, Gebreegziabher *et al.* (2019) discovered that the majority of farmers in the Nile Basin of Ethiopia are vulnerable to climate change. Moreover, a study by Simane *et al.* (2016) focusing on agroecosystem-specific climate vulnerability analysis in the Choke Mountain area of the Blue Nile basin found that farmers in the Dega and Kolla agroecological zones exhibited greater vulnerability compared to those in the midland agroecological zone. Teshome (2016) also identified an increasing vulnerability to climate change risks among households in Dembia woreda, Northwest Ethiopia. Local-level studies are also helpful in tackling the challenges associated with developing dependable criteria that can be used for evaluating vulnerability and resilience toward climate change (Tessema and Simane, 2021). In addition, conducting a vulnerability assessment at a micro-level aid in identifying the populations and livelihoods that are the most susceptible in a particular region (Aryal *et al.*, 2014). As a result, conducting an empirical study on the vulnerability of households to climate change is imperative.

2. Materials and methods

2.1 Theoretical conceptualization

Indicator approaches are frequently used to evaluate vulnerability to climate change (Dendir and Simane, 2019; Ebrahim *et al.*, 2022; Gebreegziabher *et al.*, 2019; Oo *et al.*, 2018). Because it is easy to combine indicators to create an index, various vulnerability indexes have been developed (Oo *et al.*, 2018; Yesuf *et al.*, 2008). However, the definition of vulnerability is vague and inconsistent (Masuda *et al.*, 2019; Sam *et al.*, 2017) leading to the creation of different vulnerability indexes. Some experts even argue that vulnerability cannot be measured (Ahsan and Warner, 2014; Oo *et al.*, 2018). Tessema *et al.* (2019) maintain that an indicator approach can facilitate sensitivity analysis to calibrate vulnerability assessments within and among vulnerable areas by manipulating contributing factor scores.

Vulnerability studies serve several significant functions, including monitoring vulnerability changes over time and space, identifying the contributing processes, outlining plans for vulnerability reduction and assessing the effectiveness of these plans in different social and ecological contexts (Alam *et al.*, 2017; Mulugeta *et al.*, 2019; Salman *et al.*, 2022). However, quantifying vulnerability is a complex task due to various factors, such as the impact of multiple factors on vulnerability, nonlinear interactions among them and a lack of knowledge about their weights. To measure household vulnerability to climate change, different studies have used the livelihood vulnerability index (LVI (Hahn *et al.*, 2009) and the socioeconomic vulnerability index (SeVI) (Ahsan and Warner, 2014). Previous research has shown that no single approach is sufficient to assess climate change vulnerability, as each method has its own strengths and limitations (Oo *et al.*, 2018; Sam *et al.*, 2017). For instance, the LVI method assigns equal importance to all indicators, which may not accurately reflect the effects of climate change on households' vulnerability (Hahn *et al.*, 2009; Yesuf *et al.*, 2008). Furthermore, certain economic and social indicators that do not align with the LVI components cannot be used in the LVI method (Oo *et al.*, 2018; Sam *et al.*, 2017). However, these indicators can be applied to the SeVI domain to calculate households' socioeconomic vulnerability separately.

A comprehensive assessment of household livelihood profiles can provide appropriate information for this purpose, provided it is analyzed from the social and economic perspective of the region in question (Ahsan and Warner, 2014; Mekonen and Berlie, 2021; Oo *et al.*, 2018). Such approaches can provide policymakers and developmental organizations with sufficient information regarding the demographic, social, livelihood, health, water, food and climate hazard aspects contributing to households' vulnerability. This, in turn, enables them to formulate effective adaptation strategies and policies within the limits of available resources. To obtain a complete understanding of the vulnerability of households to climate change and variability in the study area, we used and compare two methods: the LVI and SeVI methods, considering the abovementioned factors.

2.2 Study area

The study area is located in the South Gondar Administration Zone of the Amhara National Regional [2] State of Ethiopia and includes Tach Gayint, Lay Gayint and Simada districts, referred to as Woredas in Amharic (Figure 1). Lay Gayint is situated in the *High Dega* (3,200–3,700 m asl) agro-ecological zone, whereas Tach Gayint and Simada are found in the *Dega* (2,300–3,200 m asl) and *Woyna Dega* (1,500–2,300 m asl) zones, respectively (Hurni *et al.*, 2016). The average annual rainfall ranges from 788 mm in Simada to 1,096 mm in Lay Gayint, and the mean annual temperature ranges from 14.4°C in Lay Gayint to 18.2°C in Simada. The *Kiremt* season, the main rainy season, occurs from June to mid-September, whereas the *Belg* season, the minor rainy season, lasts from March to May (Endalew and Sen, 2020). The area has a bimodal precipitation system that allows for two harvesting

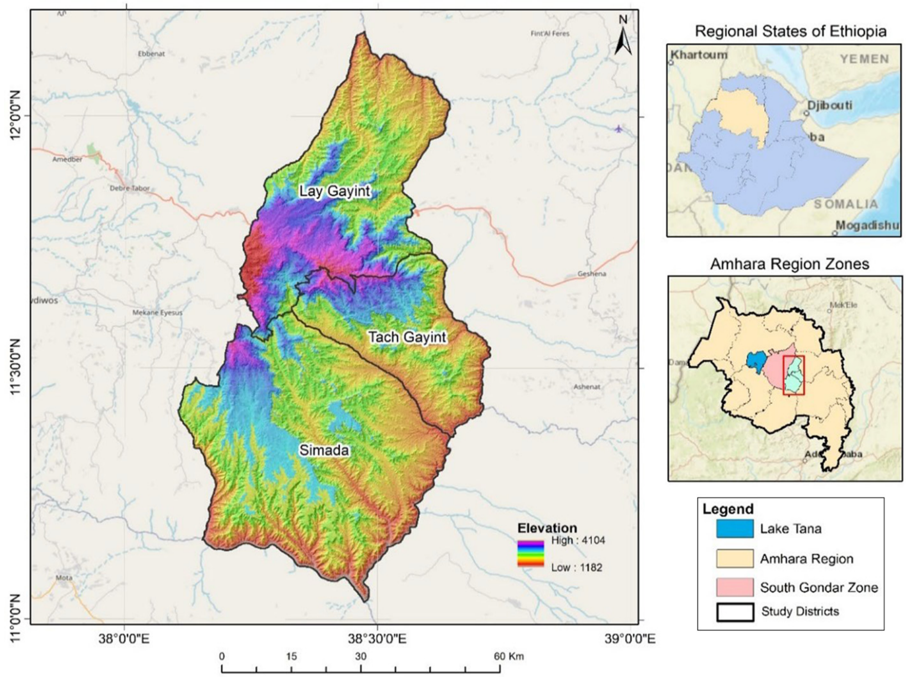


Figure 1.
Map of the study area

Source: Authors own creation using QGIS software (2022) (https://data.humdata.org/dataset/cod-ab-eth)

seasons, the main and secondary, locally known as *Meher* and *Belg*, respectively. However, the *Belg* harvest is often hindered by the short, highly variable and frequently inadequate rainy season (Endalew and Sen, 2020).

2.3 Sampling techniques and procedures

The study used a multi-stage sampling technique that combined purposive and random sampling methods to select both the study area and sample households. First, Lay Gayint, Tach Gayint and Simada districts were purposively selected from the South Gondar Zone due to their frequent exposure to climate extremes, particularly droughts. Next, three kebeles [1] were selected at random, one from each agro-ecological zone, based on the assumptions that smallholder farmers in different zones possess varying livelihood resources, indigenous knowledge and skills. Finally, the researchers identified a sample of households from each target kebele using sampling frames obtained from the respective sample kebele administrative offices. The study's sample size was determined using the formula provided by Kothari (Kothari, 2004) as follows:

$$n = \frac{Z^2 * p * q * N}{e^2(N-1) + Z^2 * p * q}$$

The total sample size (n) was determined using the proportional-to-size formula with the following parameters: $n = 4{,}203$, $p = 0.5$, $q = 0.5$, $e = 5\%$ and $Z = 1.96$ for a 95% confidence interval. The total number of households was $n = 4{,}203$, comprising 1,644 from Lay Gayint, 1,404 from Tach Gayint and 1,155 from Simada. The resulting sample size was $n = 352$, with sample sizes of 138, 117 and 97 for Lay Gayint, Tach Gayint and Simada, respectively. The sample size at each kebele was determined using a simple random sampling technique with a probability proportional to size as follows:

$$ni = \frac{n \times Ni}{\sum Ni}$$

where ni refers to the number of households in the ith kebele, whereas Ni represents the total number of households in the ith kebele. A calculated sample size, denoted by n, was used to determine the number of households to be included in the survey. Before conducting the survey, respondents provided informed consent, and no personally identifiable information was collected during data collection.

2.4 Sources of data and methods of collection

The study used two data sets:

(1) quantitative data obtained from a survey of 352 households; and

(2) qualitative data collected through six focus group discussions (FGDs).

The quantitative data were used to develop the SeVI and the LVI by characterizing households in terms of their sensitivity, exposure and adaptive capacity to climate change and variability. The qualitative data were used to complement and support the quantitative analysis. FGD participants were selected based on their years of farming experience, voluntary participation and knowledge of the influence of climate change on their livelihoods. For this purpose, two FGDs, each with 8–12 participants were conducted in each kebele. The sample included both men and women between the ages of 25 and 75 with many years of local knowledge and farm experience.

2.5 Analytical model and index formulation

Vulnerability indexes are based on major components as an aggregate of different subcomponents. In the case of equally weighted indicators, or equal importance, a standardization approach needs to be followed to minimize the erroneous estimation of different subcomponents and to avoid selection biases and missing data problems. However, in the case of unequally weighted indicators, many methodological approaches can be used to avoid the uncertainty of equal weighting of the different indicators used (Yesuf *et al.*, 2008). Methodological approaches in a number of studies include the use of expert judgment (Jamshidi *et al.*, 2019), principal component analysis (Datta and Das, 2019) or correlation with past disaster events (Negatu *et al.*, 2011). In this study, the method of conceptualization and standardization of indicators and aggregation of the selected indicators is used. In addition, this study explores the vulnerability of households using two indexes: the LVI consists of 32 indicators: adaptive capacity (12 indicators), sensitivity (14 indicators) and exposure (6 indicators) (Tables 4–6). The SeVI, on the other hand, comprises 31 indicators: adaptive capacity (7 indicators), sensitivity (16 indicators) and exposure (8 indicators) (Tables 1–3). Furthermore, climate exposure, sensitivity and adaptive capacity were calculated and depicted with spider and triangular diagrams and were discussed separately. In the following section, the two indexes used to assess households' vulnerability are presented.

2.5.1 Socioeconomic vulnerability index. Ahsan and Warner (2014) used the SeVI as a tool to evaluate household vulnerabilities through analysis of various social and economic relationships, whereas considering the three dimensions of climate change (adaptive capacity, sensitivity and exposure) as defined by the Intergovernmental Panel on Climate

Table 1. Adaptive capacity components, sub-component indexes of SeVI in the study area

IPCC dimension	Domain	Indicators/variables	Lay Gayint	Tach Gayint	Simada
Adaptive capacity	Demographic	Dependency ratio	0.64	0.74	0.67
		Percentage of female headed households	0.07	0.18	0.21
		Average year of farming experiences	0.46	0.48	0.45
		Weighted average score (st. dev.)	0.39 (0.29)	0.47 (0.28)	0.44 (0.23)
	Social	Percentage of households with no assistance from PSNP	0.65	0.73	0.77
		Percentage of households not in contact with neighbor farmers	0.15	0.18	0.21
		Percentage of households not receiving assistance from relatives/friends	0.81	0.71	0.73
		Percentage of households without access to information (radio, television)	0.96	0.92	0.89
		Weighted average score (st. dev.)	0.64(0.35)	0.64(0.32)	0.65(0.30)

Source: Authors' own survey (2022)

Table 2. Sensitivity components, Sub-component indexes of SeVI in the study area

IPCC dimension	Domain	Indicators/variables	Lay Gayint	Tach Gayint	Simada
Sensitivity	Economic	Percentage of households not receiving any off-farm income	0.74	0.73	0.91
		Percentage of households not receiving any nonfarm income	0.69	0.76	0.89
		Percentage of households borrowing money from informal money lenders	0.38	0.37	0.46
		Percentage of households borrowing money from credit association	0.58	0.61	0.55
		Percentage of households reporting that they could not solve financial problems by themselves	0.82	0.89	0.97
		Weighted average score (st. dev.)	0.64 (0.17)	0.67 (0.19)	0.76 (0.23)
	Physical	Percentage of households not undertaking irrigation practices	0.86	0.82	0.81
		Percentage of households reporting poor fertility of farmland	0.58	0.50	0.47
		Percentage of households reporting that crop production was affected by climatic shocks	0.84	0.92	0.96
		Average walking time to water sources (min)	0.60	0.66	0.72
		Percentage of households not having paved roads in the area	0.88	0.96	0.93
		Percentage of households who reported chronic illness	0.15	0.22	0.33
		Percentage of households not applying sufficient fertilizer	0.64	0.58	0.73
		Percentage of households not applying chemical insecticides	0.63	0.66	0.76
		Percentage of households not applying manure as fertilizer	0.77	0.74	0.65
		Average walking time to health centers (min)	0.31	0.49	0.51
		Percentage of households not having sanitary latrine	0.88	0.90	0.94
		Weighted average score (st. dev.)	0.65 (0.24)	0.68 (0.22)	0.71 (0.21)

Source: Authors' own survey (2022)

Table 3. Exposure components, sub-component indexes of SeVI in the study area

IPCC dimension	Domain	Indicators/variables	Lay Gayint	Tach Gayint	Simada
Exposure	Exposure to climatic hazards	Percentage of households reporting receipt of warning information from the government	0.07	0.23	0.29
		Percentage of households reporting loss of farmland due to severe erosion	0.45	0.59	0.49
		Percentage of households reporting problems with agricultural production due to climate shocks	0.74	0.96	0.98
		Average number of drought events in the past 10 years	0.36	0.49	0.59
		Average number of flood events in the past 10 years	0.36	0.41	0.36
		Percentage of households reporting losses to physical assets due to climate-related hazards	0.59	0.64	0.79
		Percentage of households reporting loss of livestock due to recent disaster	0.57	0.66	0.85
		Average rainfall perception index (%)	0.70	0.92	0.97
		Weighted average score (st. dev.)	0.48 (0.22)	0.61 (0.25)	0.67 (0.27)

Source: Authors' own survey (2022)

Table 4. Adaptive capacity components, sub-component indexes of LVI in the study area

IPCC dimension	Major components	Sub-components	Lay Gayint	Tach Gayint	Simada
Adaptive capacity	Sociodemographic profile	Percentage of female headed households in the sample	0.07	0.18	0.21
		Percentage of households with orphans	0.42	0.11	0.16
		Percentage of households not attending school	0.54	0.50	0.55
		Dependency ratio	0.64	0.67	0.72
		Weighted average score (St. dev.)	0.42 (0.25)	0.37 (0.26)	0.41 (0.27)
	Livelihood strategies	Percentage of households reliant on agriculture as the main source of income	0.93	0.95	0.91
		Percentage of households not undertaking irrigation practices	0.83	0.82	0.81
		Percentage of households without family members working in a different community	0.76	0.87	0.89
		The inverse of agricultural livelihood diversification index (1/ # livelihoods +1)	0.38	0.06	0.06
		Weighted average score (st. dev.)	0.72 (0.23)	0.68 (0.41)	0.67 (0.41)
	Social networks	Percentage of households not receiving extension services	0.33	0.34	0.13
		Percentage of households not involving in social groups	0.18	0.23	0.07
		Percentage of households not receiving any climate change training	0.96	0.97	0.68
		Percentage of households not receiving assistance from relatives/friends	0.81	0.71	0.4
		Weighted average score (st. dev.)	0.57 (0.37)	0.56 (0.34)	0.32 (0.28)

Source: Authors' own survey (2022)

Table 5. Sensitivity components, subcomponent indexes of LVI in the study area

IPCC dimension	Major components	Subcomponents	Lay Gayint	Tach Gayint	Simada
Sensitivity	Water	Average walking time to water sources (min)	0.58	0.66	0.72
		Percentage of households using a natural water source	0.79	0.92	0.94
		Percentage of households reporting water conflicts	0.07	0.13	0.39
		Percentage of households not having consistent drinking water supply	0.71	0.81	0.87
		Weighted average score (st. dev.)	0.54 (0.32)	0.63 (0.35)	0.73 (0.24)
	Food	Percentage of households who did not save crops	0.74	0.8	0.87
		Average number of months households struggle to find food	0.37	0.39	0.41
		Percentage of households who did not save seed	0.72	0.74	0.79
		Percentage of households dependent on family farm for food	0.94	0.96	0.95
		The inverse of crop diversity index (1/# crops +1)	0.38	0.06	0.16
		Weighted average score (st. dev.)	0.63 (0.25)	0.59 (0.36)	0.64 (0.34)
	Health	Percentage of households reporting chronic illness	0.15	0.22	0.43
		Percentage of households where a member missed work/ school due to illness	0.06	0.11	0.19
		Percentage of households who could not afford prescribed health services	0.52	0.62	0.78
		Percentage of households without a sanitary latrine	0.78	0.90	0.94
		Average walking time to health centers (min)	0.31	0.49	0.51
		Weighted average score (st. dev.)	0.36 (0.29)	0.47 (0.32)	0.57 (0.30)

Source: Authors' own survey (2022)

Table 6. Exposure components, sub-component indexes of LVI in the study area

IPCC dimension	Major components	Sub-components	Lay Gayint	Tach Gayint	Simada
Exposure	Climate variability & related hazards	Mean standard deviation in monthly precipitation (1981–2018)	0.38	0.41	0.42
		Percentage of households reporting loss of livestock due to recent disaster	0.57	0.66	0.85
		Average number of flood events in the past 10 years	0.46	0.49	0.52
		Average number of drought events in the past 10 years	0.36	0.49	0.59
		Percentage of households reporting losses to physical assets due to climate-related hazards	0.59	0.64	0.79
		Percentage of households with family members injured in recent climate related hazards	0.32	0.34	0.47
		Weighted average score (St. dev.)	0.45 (0.22)	0.51 (0.31)	0.61 (0.34)

Source: Own survey (2022)

Change (IPCC) (IPCC, 2001). As the individual indicators are measured on diverse scales, standardization is required for each of them:

$$\text{Indicator index score (IIS)}_d = \frac{X_d - X_{min}}{X_{max} - X_{min}} \tag{1}$$

The indicator value for a district, denoted by X_d, is calculated using the highest value ($X_{\max}$) and lowest value ($X_{\min}$) of the indicator. After obtaining the indicator index value, the next step is to calculate the domain vulnerability score by combining the weighted values of all indicators within the same domain. This is done by aggregating the values using equation (2), as described by Ahsan and Warner (2014), McEntire *et al.* (2010) and Urothody and Larsen (2010):

$$\text{Domain vulnerability score (DVS)d } = \frac{\sum_{j=1}^{n} (\text{WIS})_{jd}}{\sum_{j=1}^{n} (\text{Average weight })_{jd}} \tag{2}$$

In this context, $(\text{DVS})_d$ represents the domain scores for the vulnerability index in district d and j represents the number of indicators within the specified range. Once the domain values for the vulnerability indices are calculated, the various vulnerability dimensions can be obtained by dividing the sum of the domains under adaptive capacity, sensitivity and exposure by the number of domains analyzed. This calculation is denoted as:

$$DM_{kd} = \frac{\sum_{j=1}^{n} DVS_{jd}}{n} \tag{3}$$

The number of domains under adaptive capacity, sensitivity and exposure is denoted by k. The calculation of the SeVI for district d follows the method outlined by Ahsan and Warner (2014) and can be obtained from the following equation:

$$\text{Socioeconomic vulnerability index } (SeVI)d = \frac{DM_{acd} + DM_{sd} + DM_{ed}}{3} \quad (4)$$

The overall vulnerability index for district d is determined by the average effects of adaptive capacity, sensitivity and exposure, with the SeVI having a direct relationship with sensitivity and exposure but an inverse relationship with adaptive capacity (Ahsan and Warner, 2014; Asfaw *et al.*, 2018; Ford *et al.*, 2006). To assess household socioeconomic vulnerability, we selected 31 indicators based on previous studies (Adhav *et al.*, 2021; Ahsan and Warner, 2014; Asfaw *et al.*, 2018; Balaganesh *et al.*, 2020; Oo *et al.*, 2018; Sam *et al.*, 2017), a field survey and consultations with local experts. The SeVI ranges from 0 (least vulnerable) to 1 (most vulnerable).

2.5.2 Livelihood vulnerability index. The LVI development applied the methods introduced by Hahn *et al.* (2009) with some modifications of indicators to suit the study area context. LVI indices were structured into three dimensions, namely, sensitivity, exposure and adaptive capacity, which were defined based on the IPCC's description of vulnerability. Vulnerability refers to the extent to which a system is capable of dealing with or susceptible to the negative impacts of climate change, including its variability and extremes. Meanwhile, adaptive capacity pertains to the system's ability to manage and adjust to climate change, enabling it to minimize potential damage, seize opportunities or deal with the consequences. Finally, sensitivity describes the degree to which a system is positively or negatively influenced by climate-related stimuli.

The LVI in this study comprises of seven primary components, including sociodemographic profile, livelihood strategies, social networks, water, nutrition, health, natural hazards and climate variability and associated hazards, which are standardized using the same method as the SeVI. The indicators were developed by reviewing existing literature (Asfaw *et al.*, 2021; Balaganesh *et al.*, 2020; Hahn *et al.*, 2009; Oo *et al.*, 2018; Sahana *et al.*, 2021), conducting a field survey and consulting with local experts to assess household vulnerability. To calculate vulnerability, a balanced weight approach was used, where each subcomponent contributes equally, which is preferred over an unbalanced weight approach (Hahn *et al.*, 2009; Oo *et al.*, 2018; Pandey and Jha, 2012; Sullivan *et al.*, 2002). The LVI is calculated by assigning equal weight to each of its subcomponents, resulting in a simpler and more accessible interpretation process for policy advisors. However, as the number of subcomponents varies across the main components, each main component contributes a different weight to the overall vulnerability score. The calculation of LVI involves standardizing the subcomponents of each main component using equation (1) and then averaging them:

$$M_d = \frac{\sum_{i=1}^{n} indexS_d i}{n} \quad (5)$$

After deriving the subcomponents of district d for each of the seven principal components, denoted by M_d, the subcomponents can be indexed through i with n as the number of subcomponents in each principal component. The average LVI can then be calculated using the following formula:

$$LVI_d = \frac{\sum_{i=1}^{7} -W_{id} M_{id}}{\sum_{i=1}^{7} -W_{id}} \quad (6)$$

where LVI_d is the LVI for district d, i is the index of households in district d and W_{id} denotes the number of subcomponents that make up each main component. Furthermore, the contributing factors (sensitivity, exposure and adaptive capacity) can be constructed as the following equation:

$$CF_d = \frac{\sum_{i=1}^{n} W_{id} M_{id}}{\sum_{i=1}^{n} W_{id}} \quad (7)$$

The contributing factor for district *d* is denoted by CF_d. The main components for district *d* are represented by *Mid*, indexed by *i*. The weight of each main component in each contributing factor is denoted by W_{id}. The LVI is a measure of vulnerability scaled between 0 (least vulnerable) and 1 (most vulnerable). Once sensitivity, exposure and adaptive capacity have been calculated using either vulnerability indicator method, the vulnerability index ($IPCC_d$) can be determined:

$$LVI(IPCC_d) = (e_d - a_d)^{*} S_d \quad (8)$$

where vulnerability index ($IPCC_d$) is the LVI and SeVI for district "*d*" quantified applying the IPCC vulnerability framework. Decomposed, "*e*, *a* and s" are the calculated sensitivity, exposure and adaptive capacity for district "*d*". In our study, the vulnerability index ($IPCC_d$) was scaled from −1 (least vulnerable) to 1 (most vulnerable).

3. Results and discussion

3.1 Socioeconomic vulnerability

The values for the individual indicators that constitute the SeVI and are distributed across the five domains are presented in Tables 1–3. A brief discussion of each domain and subdomain is provided and the vulnerability of households based on the SeVI approach is presented in the subsequent sections.

3.1.1 Demographic vulnerability. Tach Gayint had the highest dependency ratio (score: 0.74) among households, whereas Lay Gayint had the lowest (score: 0.64). This aligns with the findings of Khan (2012) and Oo *et al.* (2018) that populations with higher proportions of children and elderly individuals are more vulnerable to natural hazards due to limited protective capacity. Notably, Simada had the highest percentage of female-headed households (score: 0.21), whereas Lay Gayint had the lowest (score: 0.07). Overall, Tach Gayint was found to be the most vulnerable in this domain, with a weighted average score of 0.47 (±0.28), compared to Simada and Lay Gayint with scores of 0.44 (±0.23) and 0.39 (±0.29), respectively.

3.1.2 Social vulnerability. Simada had the highest social vulnerability score of 0.65 (±0.30) compared to Lay Gayint and Tach Gayint, which had scores of 0.64 (±0.35) and 0.64 (±0.32), respectively. Farmer-to-farmer extension has been identified as a proxy for social capital and farmer-to-farmer relationships, where information and farming technologies are shared among farmers (Oo *et al.*, 2018; Tessema *et al.*, 2013). In this study, about 21% of Simada's households reported no social relationships with neighboring farmers; this is higher than in Lay Gayint (15%) and Tach Gayint (18%). In this study, the majority of households (75%) received no support from relatives or friends during difficult times. In addition, the majority of households (92%) stated that they did not receive any information from radio or television. The lack of access to information and social capital increases the vulnerability of poor households to climate change-related risks, which underscores the need to improve access to information and social capital (Oo *et al.*, 2018; Tessema and Simane, 2021).

3.1.3 Economic vulnerability. Lay Gayint was found to be the least economically vulnerable, with an average score of 0.64 (± 0.17), whereas Simada was identified as the most vulnerable with a score of 0.76 (±0.23) in this domain. In Simada, 91% of households had no off-farm income, the corresponding values in Lay Gayint and Tach Gayint were 74% and 73%, respectively. Moreover, the majority of households (78%) reported that they do not receive any nonfarm income and have limited access to credit. Households require agricultural credits before the beginning of cultivation periods and usually borrow from moneylenders at higher interest rates during the growing seasons. Higher agricultural input prices, low yield returns and a lack of production consistency owing to climate change are the reasons for increasing debt (Oo *et al.*, 2018).

3.1.4 Physical vulnerability. The majority of households (65%) explained they did not apply sufficient fertilizer due to the lack of access to credit and the higher cost. Moreover, the majority of households (72%) did not use manure as fertilizer due to a shortage of resources for composting. In addition, the absence of paved roads in the area hindered the movement and interaction of households for various purposes. Sanitation was also a concern, with the highest percentage of households (90%) lacking sanitary latrines in the study area. According to weighted average scores, Simada was the most vulnerable with a score of 0.71 (±0.21), followed by Tach Gayint with 0.68 (±0.22) and Lay Gayint with 0.65 (±0.24).

3.1.5 Climate variability and related hazards. According to the study, Simada had the highest vulnerability score of 0.67 (±0.27) in relation to climate variability and related hazards, whereas Lay Gayint had the lowest vulnerability score of 0.48 (±0.22). Furthermore, households in Simada reported the highest percentage (97%) of increased rainfall variability, compared to Tach Gayint (92%) and Lay Gayint (70%). The majority of households (80%) reported that climate information and warnings from government organizations are limited. The impacts of climate variability and change, such as droughts, floods, loss of arable land, reduction in agricultural production and livestock deaths, were reported to have triggered household vulnerability across the study area.

3.2 Livelihood vulnerability index

The values for the individual indicators of the LVI, distributed over its seven components, are presented in Tables 4–6. A brief discussion of each component is also provided and the vulnerability of households based on the LVI approach is presented in the following sections.

3.2.1 Sociodemographic profile. In this study, the percentage of female-headed households in Simada was found to be the highest (21%) compared to Tach Gayint (18%) and Lay Gayint (7%). Tessema *et al.* (2019) suggested that female-headed households are more vulnerable than male-headed households due to sociocultural barriers that limit their access to resources. Moreover, Asmamaw *et al.* (2020) revealed that male-headed households with a low dependence ratio and an average family size that does not exceed the national average are less sensitive to climate change and variability. Furthermore, Simada was found to be relatively vulnerable compared to Tach Gayint and Simada in terms of dependency ratio. Consistent with this study, Masuku and Manyatsi (2013) found that large family sizes are more likely to have large dependents, making the household more vulnerable to climatic shocks. Around 53% of the respondents in the study area were unable to read and write, making them particularly exposed to the detrimental effects of climate change. Education enhances a household's ability to comprehend extension services and adopt alternative solutions during times of crisis (Etwire *et al.*, 2013). The research showed that Lay Gayint had the highest sociodemographic vulnerability score of 0.42 (±0.25) compared to Simada (score: 0.41 (±0.27)) and Tach Gayint (score: 0.37 (±0.26)) districts, as shown in Table 4. The increased vulnerability of Lay Gayint's sociodemographic profile was mainly attributed to the higher proportion of households with orphans (42%) in comparison to Simada (16%) and Tach Gayint (11%).

3.2.2 Livelihood strategies. The study found that Lay Gayint is the most vulnerable to livelihood strategies, with a score of 0.72 (±0.23), whereas Simada is the least vulnerable, with a score of 0.67(±0.41). In Tach Gayint, 95% of households rely on agriculture as their primary source of income, compared to 93% in Lay Gayint and 91% in Simada. Due to the lack of alternative income opportunities, households are forced to seek employment in other communities. The agricultural diversity index, which evaluates crops, livestock, agroforestry and off-farm activities, can enhance adaptive capacity (Hahn *et al.*, 2009; Tessema and Simane, 2021). The study highlights that households relying on a single source of income are more vulnerable to hazards and less able to meet their needs during crises. Several studies have demonstrated that households relying on a single source of income (i.e. agriculture) are more vulnerable to hazards and less capable of meeting their needs during crises (Adu *et al.*, 2018; Alam *et al.*, 2017; Belay *et al.*, 2017; Oo *et al.*, 2018). However, Dendir and Simane (2019) and Dendir and Birhanu (2022) found that diversifying livelihoods is not a guaranteed strategy for reducing vulnerability. This is because various cross-cutting factors, such as the market, access to credit and the availability of technology, affect the entire livelihood system. As a climate-sensitive sector, rain-fed agriculture is particularly vulnerable to extreme weather events. Unfortunately, 82% of households in the study area lack access to irrigation water, which exacerbates their dependence on rain-fed agriculture.

3.2.3 Social networks. Lay Gayint had the highest vulnerability score of 0.57 (±0.37) in terms of social network components, followed by Tach Gayint with the second-highest score of 0.56 (±0.34), whereas Simada had the lowest score of 0.32 (±0.28). The study found that social support programs, such as the PSNP, could help mitigate food security challenges, but approximately 33% of respondents in the study area were not PSNP beneficiaries. In addition, households' involvement in social groups was not strong enough to reduce the impact of climate-related hazards. However, indigenous social networks such as "Equib", "Idir" and "Wonfel" played a crucial role in agricultural activities, information exchange and crisis management, and were important inputs for improving the economic performance of smallholder farmers. Focus group discussants reported a recent decrease in their social networks, which increases their vulnerability to climate change and instability. Previous research has shown that social networks can enhance local communities' adaptive capacity and reduce their vulnerability to climate change (Dapilah *et al.*, 2020; Son and Kingsbury, 2020; Thompson and Scoones, 2009). The majority of households (97%) in the study area did not receive any climate change training, which is crucial for improving their knowledge and anticipation of natural disasters (Amos *et al.*, 2015). Access to climate change training is also important for enhancing productivity and rural development (Alam *et al.*, 2017).

3.2.4 Water. Simada has been identified as the most vulnerable with a weighted average score of 0.73 (±0.24) based on water indicators. Tach Gayint follows with a score of 0.63 (±0.35), whereas Lay Gayint is considered the least vulnerable with a score of 0.54 (±0.32). In the study area, the majority of households (88%) rely on natural water sources, and roughly 80% of households do not have consistent access to drinking water. Moreover, Simada has a higher percentage of households (39%) that have reported conflicts over water resources compared to Tach Gayint (13%) and Lay Gayint (7%). Access to water is an important factor that influences vulnerability (Gentle *et al.*, 2014). The average time it takes to reach a water source in Simada is higher than in Lay Gayint and Tach Gayint, adding more burdens on women and children responsible for fetching water for domestic use. According to the results of the focus group discussants, people rely on rivers and streams for their daily drinking and household water needs.

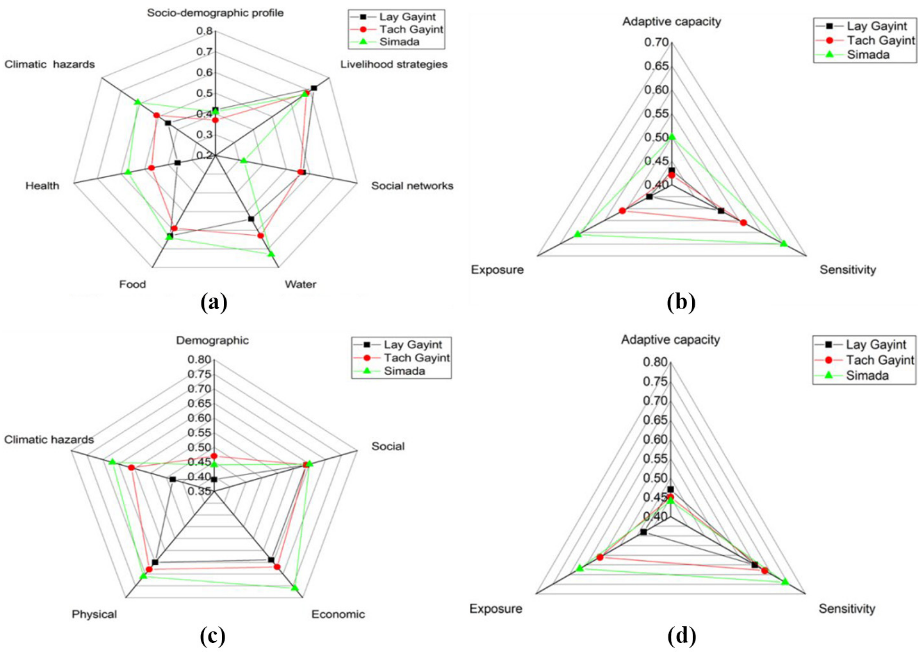
3.2.5 Food. The food vulnerability of Simada, Lay Gayint and Tach Gayint was evaluated, with Simada found to be the most vulnerable (score: 0.64 ± 0.34)), whereas Tach Gayint had a lower vulnerability score of 0.59 (±0.36). The study found that farming was the primary occupation for households in the study area, with an average of 96% of households in Tach Gayint relying on agriculture, compared to 95% in Simada and 94% in Lay Gayint. Difficulty in obtaining food was reported by households in the study area, with households in Simada experiencing, on average, 2.9 months per year of struggling to provide adequate food, whereas Tach Gayint and Lay Gayint experienced 2.7 months and 2.6 months, respectively. The challenging periods for obtaining food were reported to occur mainly during the *Kiremt* season (June to September), and households who did not keep food or save seeds were found to be the most vulnerable. In this study, nearly 80% and 75% of households did not save crop and seed due to the subsistence nature of agriculture in the study area.

3.2.6 Health. The health vulnerability of the study area was assessed, with Simada being the most vulnerable, having a weighted average score of 0.57 (±0.30). However, Tach Gayint was found to have a greater vulnerability for the health component with a score of 0.47 (±0.32), compared to Lay Gayint, which had a score of 0.36 (±0.29). The greatest distance to health services was found to be in Simada, taking an average of 190 min, followed by Tach Gayint at 180 min and Lay Gayint at 120 min. Inadequate access to health services also tends to reduce the health status of smallholder farming households, making them more vulnerable to extreme climatic conditions (Adu *et al.*, 2018). Béné (2009) and Pironon *et al.* (2019) have suggested that the increased vulnerability of rural households to climate change could be linked to health problems. In the study area, 87% of households lacked sanitary latrines, which is concerning as inadequate sanitation can lead to child mortality, diarrheal diseases and death. Simada was also found to be more vulnerable to having households with family members suffering from chronic illnesses (43%), compared to Tach Gayint (22%) and Lay Gayint (15%). Furthermore, households in Simada reported relatively higher rates of family members missing school or work due to illness (19%), compared to Tach Gayint (11%) and Lay Gayint (6%).

3.2.7 Climate variability and related-hazards. Simada was found to be the most vulnerable [score: 0.61 (±0.34)] in terms of climate variability and related hazards, followed by Tach Gayint [score: 0.51 (±0.31)] as the second most vulnerable and Lay Gayint [score: 0.45 (±0.22)] as the least vulnerable. Livelihoods of households in the study area were impacted by loss of livestock and physical assets, with drought and flooding affecting 48% and 49% of households, respectively. Focus group discussants revealed that persistent drought and unpredictable rainfall patterns are significant challenges that hinder farmers' livelihoods. Lack of climate awareness among the local people, government unpreparedness before natural hazard events and weak rehabilitation and resettlement processes were cited as the reasons for loss of livestock and physical assets (Ahsan and Warner, 2014; Oo *et al.*, 2018). As such, it is essential to implement climate change awareness programs, preventive measures and climate change mitigation and adaptation strategies in the study area.

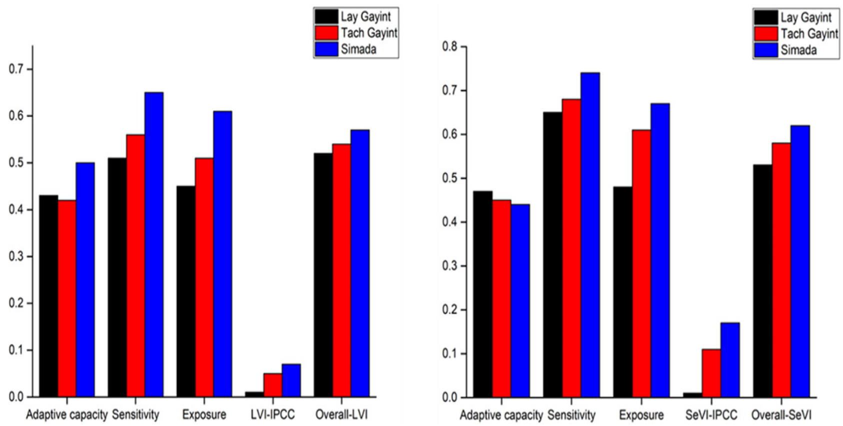
4. Overall vulnerability assessment based on the socioeconomic vulnerability index and livelihood vulnerability index methods

The calculated results of the major components and domains of the LVI and SeVI are presented in spider diagrams and the contributing factor scores are depicted in a triangular diagram in Figure 2. In this section, we compare and briefly discuss the vulnerability of households using both the LVI and SeVI methods. Our findings, based on the weighted averages in Figure 3, show that indicators such as water, food, health and climate-related hazards are determining indicators of sensitivity and exposure in the Simada as compared to the Lay Gayint and Tach Gayint based on the LVI method. Likewise, based on the SeVI method, Simada is more sensitive and exposed than Lay Gayint and Tach Gayint in terms of social, economic, physical



Source: Own survey (2022)

Figure 2.
Major components (spider diagram) and contributing factors (triangle diagram) of LVI (a and b) and SeVI (c and d) in the study area



Source: Own survey (2022)

Figure 3.
Overall vulnerability scores and major component scores for LVI and SeVI approaches in the study area

and climate-related hazards. This means that there could be higher socioeconomic and livelihood vulnerabilities in Simada. The study reveals that Simada has lower scores for health and water indicators compared to Lay Gayint and Tach Gayint due to weaker sanitation facilities, physical infrastructure and health services, as well as persistent water availability problems. The overall IPCC vulnerability index scores in both methods highlight that households in Simada are more vulnerable than those in Lay Gayint and Tach Gayint as they are more exposed to climate-related hazards. On the other hand, the overall IPCC vulnerability index scores demonstrate that Lay Gayint is the least vulnerable. Moreover, the overall vulnerability scores pointed to the vulnerability of Simada, as shown in Figure 3.

Overall, the study districts (Lay Gayint, Tach Gayint and Simada) are one of the most climate-related hazard-prone areas in South Gondar zone and suffers from the influence of climate change. In this study, we classified the degree of SeVI and LVI vulnerability as "very high" "high" "medium" and "low" (Oo *et al.*, 2018) (Table 7). Among the three districts, Simada is found to be the highest level of sensitivity and exposure to climate-related hazards with a medium adaptive capacity, making it more vulnerable than Lay Gayint and Tach Gayint. On the contrary, Lay Gayint appears to be the least vulnerable in terms of both the LVI and SeVI indexes with medium exposure to climate-related hazards.

5. Conclusions and implications

The research assessed household vulnerability to climate change in Lay Gayint, Tach Gayint and Simada using two vulnerability assessment methods. Two vulnerability assessment methods, LVI and SeVI, were used and compared. The study found that households in Simada were the most vulnerable due to limited access to basic amenities, lack of alternative income sources and heavy reliance on agriculture. The findings emphasize the need for effective disaster risk management strategies, adaptation measures and enhanced adaptive capacity. Using multiple vulnerability assessment methods proved effective in understanding household vulnerability, identifying district-specific indicators for future assessments. Immediate action is crucial, including implementing policies supporting disaster risk management, diversifying income sources and reducing agriculture dependence. Education, training and support services should enhance households' adaptive capacity. The study has limitations, such as potential biases in assessment methods and district-specific findings. Future research should broaden the study's scope, validate findings, explore vulnerability variations and assess the long-term effectiveness of adaptation strategies. Community engagement, stakeholder involvement and effective communication are vital for successful implementation. Education and awareness campaigns are needed to enhance understanding and promote adaptation and resilience. Although focused on specific districts, the study's findings have global relevance. Climate change impacts and vulnerability are universal challenges and the identified strategies can

Table 7. Comparison of the degree of LVI and SeVI vulnerability scores in the study area

LVI	Adaptive capacity[a]	Sensitivity[b]	Exposure[c]	Overall LVI score[d]
Lay Gayint	Medium	High	Medium	High
Tach Gayint	Medium	High	High	High
Simada	High	Very high	Very high	High
SeVI				Overall SeVI score
Lay Gayint	Medium	Very high	Medium	High
Tach Gayint	Medium	Very high	Very high	High
Simada	Low	Very high	Very high	Very high

Notes: [a]Very high (>0.55), high (>0.5 and<0.55), medium (>0.4) and (<0.5) and low (<0.4). [b]Very high (>0.6), high (>0.5 and<0.6), medium (>0.5) and (<0.4) and low (<0.4). [c]Very high (>0.6), high (>0.5 and<0.6), medium (>0.4) and (<0.5) and low (<0.4). [d]Very high (>0.6), high (>0.5 and<0.6), medium (>0.4) and (<0.5) and low (<0.4)
Source: Authors' own survey (2022)

be applied elsewhere. Sharing experiences and best practices globally contributes to resilience and vulnerability reduction.

Notes

1. *Kebele* is the lowest administrative unit in Ethiopia.
2. *Regional* refers to one of the federating states of Ethiopia.

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