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Original Research

# Impact of Climate Change Vulnerabilities on Household Assets and Livelihood Capabilities in East Wollega Zone, Ethiopia

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## Abstract

*Ethiopia's East Wollega Zone is faced with climate change effects on rural livelihoods. This research assessed the effects on smallholder farmers' resources, adaptability, and resilience, and constraints to sustainable livelihoods, and proposed resilience strategies. In a mixed-method design, we surveyed 400 households in eight kebeles in four districts (Jimma Arjo, Diga, Kiremu, Gobu Sayo) using multistage sampling, covering lowland, midland, and highland districts. Survey information, focus group interviews, interviews, observations, and climate data were analyzed using the Livelihood Vulnerability Index (LVI), LVI-IPCC, ANOVA, PCA using STATA version 17, and thematic analysis. Results showed midlands with the highest exposure (0.38, LVI-IPCC: -0.142), lowlands with the highest sensitivity (0.71) and lowest adaptive capacity (0.56, LVI-IPCC: -0.229), and highlands with enhanced resilience (0.62, LVI-IPCC: -0.124). Climate variations, including a 0.2°C rise in temperature per decade and a 30% fluctuation in rainfall, lowered food security and production. Education, farm scale, and cattle ownership enhanced resilience ($p < 0.01$), while poor infrastructure and market access enhanced lowland vulnerability. The study highlights the role of adaptive capacity in diminishing climate impacts, enabling integrated adaptation policies, better infrastructure, and economic diversification to enhance East Wollega's rural resilience.*

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## INTRODUCTION

Africa is among the most exposed continents to climate change, and effects are observed not only in environmental modifications but also in pervasive socio-economic issues such as poverty, health, and education (Diallo, 2023). The exposure is mainly because of exposure to climate pressures and low adaptive capacity, thus exacerbating food insecurity and livelihood instability. Rural communities practising rain-fed agriculture are particularly exposed to risks since climate variability endangers agricultural yields and food supplies (Tessema, 2019). Ethiopia, the second most populous country on the continent, is a good case in point. In Ethiopia, smallholder producers account for 95% of agricultural production based on rain-fed agriculture, making the sector particularly susceptible to environmental variability (Tesfaye et al., 2015). Soil erosion, rugged terrain, and more unstable rain patterns are factors that result in recurring food shortages and agricultural losses, increasing household exposure further (Birhanu et al. 2022).

In the last half-century, Ethiopia experienced increased average annual minimum temperatures at a rate of 0.2°C every decade, whereas trends in rain are extremely uncertain, fluctuating more than 30% in most instances (Tessema, 2019). These trends pose immediate threats to food security, especially during decisive growing seasons like Belg and Kiremt when crop failure becomes more likely under erratic rainfall (Bekuma et al., 2022). Despite the apparent risk, a huge knowledge gap still lingers as to the vulnerability of rural households in southwestern Ethiopia, especially their awareness of and adjustment to climatic stresses (World Bank, 2024; Gemeda et al., 2023). This gap weakens the building of effective climate adaptation plans that would increase resilience and reduce vulnerability (Portner et al., 2022).

The vulnerability of rural households can be described by the interaction of exposure, sensitivity, and adaptive capacity, as described in vulnerability assessment frameworks (Adger, 2006 & Hahn et al., 2009). Exposure is the extent to which households are subjected to climatic stresses, while sensitivity is their tendency to be affected by these stresses under socio-economic and environmental conditions (Cappelli et al., 2023). Adaptive capacity, on the other hand, illustrates the capacity of households to respond and adapt to these risks by utilizing available resources, social networks, and institutional support (Simane et al., 2016). Rain-fed farming and livestock production are the primary rural livelihoods in Ethiopia's East Wollega Zone (Bekuma et al., 2022). Traditional livelihood activities have been greatly affected by changing rainfall patterns, extended droughts, and sporadic flooding (Gemeda et al., 2021). Climate-related stressors have heightened competition for limited natural resources, thus exacerbating food security and sustainable livelihood issues.

The five underlying livelihood capitals of human, social, physical, financial, and natural are critical in influencing resilience to climate shocks. Limited access to productive resources, weak market infrastructure, and environmental degradation reduce adaptive capacity and increase vulnerability at rural household levels. Scarcity of land and water resources is the most important key to agrarian challenges since climate change-induced exacerbated scarcity increases within-community competition. Disruptions in agriculture erode vital social networks upon which families depend for coping and crisis management (Bouteska et al., 2024). It is imperative to learn about how such pressures influence rural livelihoods to ensure that proper strategies are formulated that increase community resilience (Asrat & Simane, 2018).

This research thus focuses on the East Wollega Zone to evaluate the effects of climate change on household resources and their ability to adapt. By providing information on such interactions, the research seeks to inform policies and programs that can enhance the resilience of vulnerable groups.

The study has four key objectives. First, it gauges the impacts of climate change on household resources, such as land, livestock, and stocks of food, and how they influence adaptation and food security. Second, it analyzes how households adapt to environmental hazards, especially those arising from drought and floods, that affect agricultural productivity. Third, it analyzes market access barriers, financial support, and social protection, which are needed for effective adaptation. Lastly, it identifies the critical resilience barriers and makes policy suggestions for promoting sustainable livelihoods and improving access to resources.

In resolving these, the research improves a broader understanding of vulnerability and resilience in climate-stressed rural communities. Results will provide policymakers, scholars, and development practitioners with important inputs in developing well-focused initiatives that improve rural resilience and insulate communities from upcoming challenges. The study was carried out in the East Wollega Zone of the Oromia National Regional State of Ethiopia, which spans 14,102.5 km² of land with 289 rural kebeles and 17 districts. The zonal capital, Nekemte, is located 328 km west of Addis Ababa. East Wollega is situated geographically between 8°31'20" N and 10°22'30" N latitudes and 36°06'00" E and 37°12'00" E longitudes. The area shares borders with the Amhara Region to the north and Jimma Zone to the south, among other neighboring zones (Figure.1). Despite the socioeconomic and environmental issues, the region faces, it needs to be assessed to appreciate the role of climate change in developing resilience-strengthening interventions (Bekuma et al., 2022).

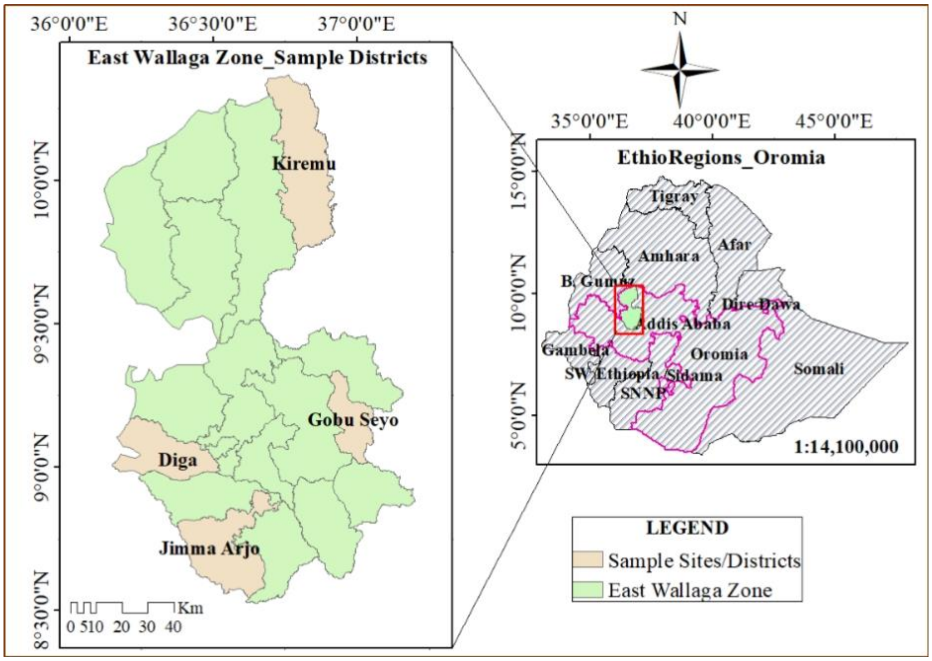

**Figure 1.** *Location map of the study area.*

## MATERIALS AND METHODS

### Sample Size and Sampling Design

A representative and systematic sample approach was used to investigate how climate change affects household livelihood diversification and food security. At various levels, multistage random sampling was used. The East Wollega Zone was chosen purposively because of its varied agroecology and the recent development of climate change (rising temperatures and unpredictable rainfall). Based on their agro-ecologic characteristics, the districts of Jimmaa Arjo, Diga, Kiremu, and Gobu Sayo were chosen from among the 21 zones of Oromia Regional State, having a total estimated population of 1,847,649: comprising 918,529 males and 929,120 females (CSA, 2023).

By agroecology, districts, and kebeles, the stratified sample approach matched the zone's geographic and socioeconomic characteristics. East Wollega has three distinct agroecological zones: low (less than 1400 masl), middle (1400–2000 masl), and high (2000–3000 masl). Kebeles were chosen by stratified random selection after being divided into these zones. Eight kebeles were chosen, including two from low altitude, four from intermediate altitude, and two from high altitude.

Random samples were taken from the agroecological zones in each of the eight kebeles (Table 1). Households of smallholder farmers served as the analytical unit.

**Table 1**

*Total households of Kebele(ganda) and sample size*

| No | District | Kebeles (Ganda) | Total Male HH | Total Female HH | Sample Male HH | Sample female HH | Total |
|---|---|---|---|---|---|---|---|
| 1 | Jimma Arjo | Haraa | 930 | 420 | 50 | 22 | 72 |
| | | Hindhee | 713 | 397 | 38 | 21 | 59 |
| 2 | Kiremu | Burka Soruma | 627 | 285 | 33 | 15 | 48 |
| | | Tokuma Kokofe | 778 | 111 | 41 | 6 | 47 |
| 3 | Diga | Arjo Q/bulaa | 612 | 114 | 33 | 6 | 39 |
| | | Bikila | 458 | 167 | 24 | 9 | 33 |
| 4 | Gobbu Sayo | Ongobo Bakanisa | 1003 | 255 | 53 | 14 | 67 |
| | | Sombo Kejo | 510 | 124 | 27 | 8 | 35 |
| Total | | | N=7,526 | | 299 | 101 | n=400 |

*Source: (E/W/Z/Agricultural office, 2014) and own calculation for sample households (n)*

Kebeles and districts with varying food security and livelihood levels were chosen randomly. Lists of households were acquired from the zonal agriculture office and other pertinent offices. Kothari's formula, which is appropriate for a stratified sample of a finite population to guarantee an accurate calculation, was used to estimate the sample size (Kothari, 2004).

$$n = \frac{Z^2 .p.q.N}{e^2(N-1)+Z^2\,pq} \qquad (1)$$

Where q = 1 - p; p = 0.50 was presumed to supply the maximum sample size so that q = 0.5; and Z = represented the value of the standard variation at a specified confidence level. Z-score (1.96); n = sample size; e = intended margin of error, which is 5% (0.05); N = total population. The margin of error utilized was 5%. From the total of 7,526 houses across all Kebeles, 400 made up the necessary sample size. Based on the proportionality of each Kebele's household size, the sample size for each kebele was chosen. Finally, household heads were selected for the questionnaire using a random sample procedure.

## Data Collection Methods

The study employed a range of data sources and collection methods to achieve its objectives. Primary data were gathered through surveys, focus group discussions, interviews, and observations, while secondary data were sourced from organizations such as the Ethiopian NMA and CSA. The questionnaire addressed topics including food security, livelihood diversification, access, and livelihood assets. Enumerators efficiently collected quantitative data using a digitized version of the questionnaire on Kobo Toolbox. To ensure local accessibility, the English-language questionnaire was translated into Afan Oromo.

Focus group discussions, each with eight participants, explored the impacts of livelihoods and climate change. Semi-structured interviews with key informants, elders, officials, development agents, and displaced individuals aimed to collect qualitative data to support the triangulation of findings. Additionally, the researcher conducted seasonal visits to observe noticeable changes and validate data from other sources. Secondary data, including statistics, publications, and studies from organizations like CSA and NMA, facilitated the analysis of climate variability's effects on household resources and capabilities. All data collection tools were rigorously reviewed for accuracy, and STATA version 17 software was utilized for data analysis.

Quantitative data analysis employed models such as the Livelihood Vulnerability Index to assess the impacts of shocks and climate variability. Meanwhile, qualitative data from interviews and focus group discussions provided a deeper understanding of the research area and its socioeconomic context. By adopting a mixed-method approach, the researchers obtained reliable and comprehensive insights into how climate change affects rural livelihoods (Hahn et al., 2009; Etwire et al., 2013; Adu et al., 2018; Tessema & Simane, 2019 & Zeleke et al., 2023).

The Livelihood Vulnerability Index (LVI)

$$LVIhh = \frac{\begin{matrix} WSDPSDPH + WLSLSH + WHHh + WFFh \\ + WWWh + WNDCNDCh + WC \end{matrix}}{WSDp + WLS + WH + WSH + WF + WW + WNDC} \quad (2)$$

Where,

*WSDPSDPh* represents the weighted vulnerability associated with the Social and Demographic Profile (SDP) for the household (hh),

*WLSLSh* represents the weighted vulnerability associated with Livelihood Strategies (LS) for the specific household.

*WHHh* represents the vulnerability associated with Health (H) for the hh

*WFFh* represents the vulnerability associated with Food Security (FF) for the hh

*WWWh* represents the vulnerability associated with Water and Sanitation (WW) for the hh.

$WNDCNDC$h represents the vulnerability associated with natural disasters and climate variability.

$WC$ represents vulnerability associated with conflict.

Each of these elements is multiplied by a weight factor that represents its significance or importance in the overall vulnerability assessment (e.g., WSDP, WLS, WH). These weights are particular to the vulnerability analysis's goals and context.

The total of all the weight factors for each component makes up the denominator:

$$WSDP + WLS + WH + WSH + WF + WW + WNDC \quad (3)$$

By normalizing the index, this denominator makes sure that the LVI is simply comprehended and falls within a given range. It aids in scaling the index of the component weights that were selected. Therefore, each component must be normalized as an index using either equation (4) or equation (5) because each component is composed of several indications or subcomponents that are all evaluated on distinct scales (Etwire, 2018). Equation (4) was applied when a subcomponent had a positive relationship with vulnerability; equation (5) was applied when it had a negative relationship.

$$Indexshi = \frac{Sh - Smin}{Smax - Smin} \quad (4)$$

$$Indexshi = \frac{\mathrm{Smax} - \mathrm{Sh}}{\mathrm{Smax} - \mathrm{Smin}} \quad (5)$$

Where $S_{min}$ and $S_{max}$ represent the minimum and maximum values, respectively, and Sh is the observed sub-component of the household indicator. Equation (6) is used to average the sub-component indicators following standardization in order to determine the index of each main component:

$$Mh = \sum_{n=1}^{n} \frac{\mathrm{indexshi}}{\mathrm{n}} \quad (6)$$

The socio-demographic profile (SDP), livelihood strategies (LS), social networks (SN), health (H), food (F), water (W), natural hazards (NH), natural climatic variability (NDCV), conflict, and Mh are among the nine important elements. Index shi represents the sub-components, indexed by I, that comprise each major component for the household h, where n is the number of sub-components in each major component.

The final LVIh is the weighted composite of the various measures of vulnerability and reflects the general vulnerability of the particular region or group *hh*. The larger the LVIh value, the greater the vulnerability; the smaller, the lesser the vulnerability. The exact values of LVI and hence its interpretation will depend upon the choice of weights, data on each variable used in composing the index, and the context within which the analysis is made. Multidimensional vulnerability assessments frequently employ this kind of index to guide policy and decision-making around risk mitigation and adaptation tactics (Hahn et al., 2009).

In every major component of WMi, weights determined by many subcomponents of every major component assure an equal contribution of the various subcomponents. The level from 0-0.6 will reflect the vulnerability and below, or low, can therefore be the Low Vulnerability Index (LVI) criteria. For any LVI-A L, weights for all of the above have to be carefully determined (Adu et al., 2018; I. Tessema & Simane, 2019; Etwire et al., 2013).

## IPCC Framework for Calculating LVI

These nine basic elements were grouped under three exposures, adaptive capability, and sensitivity based on the criteria of vulnerability by IPCC (Table 3). Again, each core component was subdivided into smaller indicators or subcomponents. Equations (2) to (6) were computed as per the method in LVI-IPCC. In contrast to a single weighted average in LVI, weighted averages for the subcomponents were computed separately in this approach. Equation (7) explains the contribution of the three elements.

$$CFh = \frac{\sum_{i=1}^{n} WM1Mhi}{\sum_{i=1}^{n} Wmi} \quad (7)$$

Where Mhi is the main element for the household, indicated by I; CFh is a contributing factor identified by the IPCC (exposure, sensitivity, or adaptation capacity); Each major component's weight is denoted by WMi, and the number of major components in each contributing factor is denoted by n. Exposure, adaptive capacity, and sensitivity are the three contributing components that are integrated using equation (8):

$$LVI - IPCCh = (eh - ah)\,sh \quad (8)$$

The LVI-IPCC represents the Livelihood Vulnerability Index for a given household (hh), structured according to the IPCC vulnerability framework. In this framework, *ah* denotes the household's adaptive capacity, *sh* represents its sensitivity, and *eh* corresponds to the calculated exposure score for household *h* (Simane et al., 2016; Hahn et al., 2009; Etwire et al., 2013). As outlined by Hahn et al. (2009), the LVI-IPCC Index ranges from -1, indicating the least susceptibility, to 1, signifying the highest level of vulnerability.

The principal component analysis (PCA) was used to aggregate the vulnerability components data, or vulnerability index (adaptation, exposure, and sensitivity).

## RESULTS AND DISCUSSIONS

### Results

Figure 2 shows the livelihood vulnerability indicators of the lowland, midland, and highland agroecological settings (AESs). These are calculated according to the Livelihood Vulnerability Index (LVI) approach for three components: exposure, sensitivity, and adaptive capacity. Greater numbers indicate greater climate risk as exposure radiates outward. With the highest exposure score, the midland AES (indicated by the red line) is more exposed to climate hazards than the highland and lowland AESs.

The vulnerability triangle diagram indicates the Climate Vulnerability Index (CVI) dimensions of three types of land—High Land (blue), Mid Land (red), and Low Land (green)—along with the Exposure, Sensitivity, and Adaptive Capacity dimensions. High Land, the most blue triangle, is the one that extends furthest in the direction of the Exposure and Sensitivity vertices, casting the highest degree of exposure and sensitivity to risks attributable to climate but revealing the lowest degree of expansion towards the adaptive capacity vertex, suggesting the lowest capacity to adapt. This places Highland at the greatest risk for climate change among the three clusterings. Mid-Land, indicated by the red triangle, is narrower in extent relative to High Land, with relatively moderate extensions along the directions of exposure and sensitivity, but more and yet still limited extent along adaptive capacity, indicating a moderate level of vulnerability. Contrarily, low land, the smallest green triangle, moves shortest to exposure and sensitivity, marking the lowest exposure and sensitivity, and longest towards adaptive capacity, marking the highest capacity to adapt. Lowland is thus the least vulnerable to climate change. The concentric triangles, ranging from 0.0 to 0.8, identify that larger triangles (with greater extensions in the direction of exposure and sensitivity and lesser extensions in the direction of adaptive capacity) reflect greater climate vulnerability, which confirms that high land is most exposed, followed by midland, and least exposed is low land.

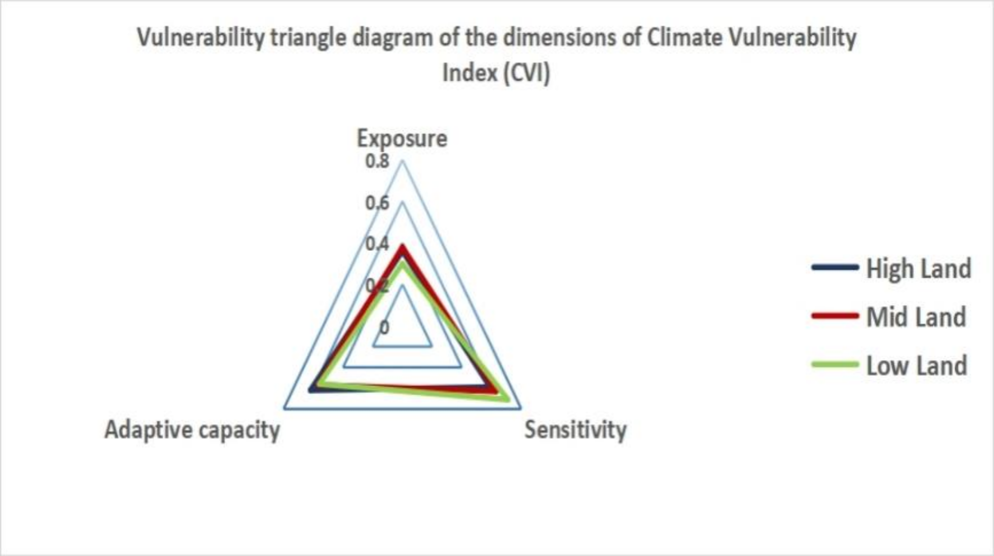

**Figure 2.** *Vulnerability Diagram of EWZ*

Climate vulnerability assessment by agroecological zones shows varied exposure, sensitivity, and adaptive capacity (Table 2). Midland had the largest range of maximum temperature variation (0.65), followed by highland (0.6) and lowland (0.57). Precipitation change was largest in the lowland (0.47), followed by the highland (0.45) and midland (0.31). Change in cessation of rain varied the most in the lowland (0.51), and change in onset reached the highest in the midland (0.25). Climate variability was indexed most in highland (0.46), followed by midland (0.44) and lowland (0.41).

Exposure to conflict and related issues was highest in Ohio midland, with displacement (0.38), looting (0.36), property destruction (0.33), and price increases (0.45). Insecurity (0.23) and supply chain issues were also highest in midland (0.43), with a profile index of 0.31, compared to 0.25 (highland) and 0.19 (lowland). Highland had the lowest conflict disruption.

Ecosystem analysis showed that lowland and midland had the most favourable land suitability (1.00, 0.99), while the highland lower was (0.82).

Lowland supported the most sustainable land use (index 0.83), followed by midland (0.72) and highland (0.62). Agricultural productivity was highest in the lowland (0.69), and lowest in the midland (0.57), with the highland showing the most livelihood diversification (0.5) as compared to the lowland (0.32).

**Table 2**

*Indexed indicators, profiles, and overall LVI for highland, midland, and lowland AESs*

| Component/ Sub-component | Indicators | Units | Indexed value for each indicator | | |
|---|---|---|---|---|---|
| | | | HL | ML | LL |
| Climate | •The standard deviation of the average daily maximum temperature by month between 1990 and 2022 | Changes over time, °c | 0.6 | 0.65 | 0.57 |
| | •The standard deviation of the average daily minimum temperature by month between 1990 and 2022 | Changes over time, oc | 0.6 | 0.6 | 0.61 |
| | •The standard deviation of the average monthly precipitation between 1990 and 2022 | Change in mm | 0.45 | 0.31 | 0.47 |
| | • Change of onset of RF (1990-2022) | Change of date | 0.222 | 0.25 | 0.24 |
| | • Change of cessation of RF(1990-2022) | Change of date | 0.48 | 0.44 | 0.51 |
| | Number of rainy days | Change of date | 0.45 | 0.44 | 0.23 |
| | Number of dry days | Change of date | 0.44 | 0.44 | 0.24 |
| | Profile Indexed Value | Date | 0.46 | 0.44 | 0.41 |
| Conflict | • Displacement | Percent | 0.19 | 0.38 | 0.17 |
| | • Looting of livestock and crops | Percent | 0.28 | 0.36 | 0.17 |
| | • Destruction of properties | Percent | 0.28 | 0.33 | 0.16 |
| | • Human death | Percent | 0.28 | 0.25 | 0.18 |
| | • Rising prices of goods | Percent | 0.26 | 0.45 | 0.18 |
| | • supply chain disturbances | Percent | 0.28 | 0.43 | 0.17 |
| | • Agricultural inputs supply disturbance | Percent | 0.18 | 0.23 | 0.18 |
| | • Road blockages | Percent | 0.28 | 0.18 | 0.15 |
| | • Insecurity of households | Percent | 0.13 | 0.23 | 0.18 |

***Table 2* continues.**

| | | | | | |
|---|---|---|---|---|---|
| | • Trauma | Percent | 0.08 | 0.09 | 0.16 |
| | • Profile indexed value | | 0.25 | 0.31 | 0.19 |
| Ecosystem | • Land suitability for agriculture | % | 0.82 | 0.99 | 1.00 |
| | • Sustainability of land use system | % | 0.65 | 0.73 | 0.87 |
| | • Land with improved soil water conservation techniques | % | 0.72 | 0.76 | 0.89 |
| | • Irrigation potential | % | 0.27 | 0.43 | 0.54 |
| | • Profile indexed value | | 0.62 | 0.72 | 0.83 |
| Agriculture | • Average annual total production | Quintal/ha | 0.66 | 0.63 | 0.69 |
| | • Average changes in productivity per hectare | Qui/hectare | 0.58 | 0.57 | 0.69 |
| | • The diversity of crop species (Inverse) | Number | 0.54 | 0.58 | 0.62 |
| | •Livelihood diversification | Number | 0.5 | 0.4 | 0.32 |
| | • Profile indexed value | | 0.57 | 0.54 | 0.58 |
| 5. Wealth | • Average farm size of HH | Hectare per HH | 0.45 | 0.44 | 0.57 |
| | • Average number of livestock per HH | TLU per HH | 0.43 | 0.47 | 0.59 |
| | • Profile indexed value | | 0.44 | 0.45 | 0.58 |
| Technology | • Households (HHs) who used Insecticide and pesticide | % | 0.58 | 0.45 | 0.43 |
| | • HHs who used fertilizer | % | 0.78 | 0.68 | 0.67 |
| | • HHs who used improved seed | % | 0.77 | 0.78 | 0.79 |
| | • HHs who have irrigation potential | % | 0.68 | 0.55 | 0.78 |
| | • Profile indexed value | % | 0.70 | 0.62 | 0.66 |
| 7. Infrastructure | • Average time to access all-weather roads | % | 0.45 | 0.55 | 0.07 |
| | • Average time to access schools | % | 0.78 | 0.79 | 0.64 |
| | • Average time to access veterinary services | % | 0.54 | 0.64 | 0.53 |
| | • Average time to access markets | % | 0.64 | 0.63 | 0.70 |
| | • HHs who have access to savings and credit | % | 0.45 | 0.49 | 0.45 |

***Table 2 continues.***

| | | | | | |
|---|---|---|---|---|---|
| | • HHs who have access to electricity | % | 0.55 | 0.09 | 0.13 |
| | • HHs who have access to telephone | % | 0.48 | 0.47 | 0.37 |
| | • HHs who have access to clean drinking water | % | 0.25 | 0.24 | 0.25 |
| | • Profile indexed value | % | 0.52 | 0.48 | 0.39 |
| Community | • Male-headed households | % | 0.86 | 0.96 | 0.93 |
| | • Dependency ratio | Number | 1.00 | 1.00 | 0.78 |
| | • Household heads attended some level of school | % | 1.00 | 0.71 | 1.00 |
| | • Extension service received | % | 0.91 | 0.88 | 0.78 |
| | • Average number of trainings attended | % | 0.91 | 1.0 | 0.75 |
| | • Average time to access health services | % | 0.50 | 0.52 | 0.43 |
| | • Radio Ownership | % | 0.6 | 0.5 | 0.2 |
| | • Profile indexed value | % | 0.82 | 0.79 | 0.68 |
| Governance | • (% of HHs participated in the watershed management | % | 0.44 | 0.48 | 0.35 |
| | • Membership in CBOs | % | 0.52 | 0.43 | 0.46 |
| | • Availability of local aid | % | 0.63 | 0.56 | 0.39 |
| | • Average number of non-working days per month | % | 0.36 | 0.33 | 0.30 |
| | • HHs who have the tradition of working together | % | 1.00 | 0.8 | 1.00 |
| | • Profile indexed value | | 0.59 | 0.52 | 0.50 |

*HL highland, ML midland, and LL lowland exposure and sensitivity components and higher vulnerability factor for the adaptive capacity component. The highland and wetland AESs scored intermediate results and the details of the major profiles and their associated indicators are discussed below*

Agriculture indices were 0.58 (lowland), 0.57 (highland), and 0.54 (midland). Wealth indicators valued lowland, with larger farms (0.57) and animals (0.59) than highland's lowest (0.45, 0.43). The wealth index was 0.58 (lowland) and 0.44 (highland). Technology adoption was highest in highland (0.70), with fertilizer (0.78) and insecticide application (0.58), followed by lowland (0.66) and midland (0.62).

Infrastructure disparity exposed highland and midland to better market, school, and credit opportunities. Electricity was strongest in the highland (0.55), and weakest in the midland (0.09). Infrastructure indicators were 0.52 (highland), 0.48 (midland), and 0.39 (lowland). Community indicators like dependency and education were strongest in the highlands (index 0.82), then in the midlands (0.79) and lowlands (0.68). Governance was more favourable towards the highland (0.59) compared to the lowland (0.50).

Lowlands are most vulnerable with low capacity to adapt and high climate hazards, despite the enhanced land quality. Midlands have extreme disruption of conflict, whereas highlands exhibit the best capacity to adapt, facilitated by infrastructure, technology, and local resilience. The Livelihood Vulnerability Index (LVI) spider diagram visually analyzes vulnerability in eight aspects—Climate, Conflict, Governance, Infrastructure, Ecosystem, Technology, Agriculture, and Wealth—for High Land, Midland, and Low Land. The values range from 0 (low vulnerability/high resilience) to 1 (high vulnerability/low resilience) indicating regional strengths and weaknesses in livelihood security (Figure. 3). High Land (blue line) is the highest in vulnerability, especially in environmental and conflict aspects. Climate vulnerability is almost 1, indicating severe weather risks like rising temperatures or extreme weather, possibly due to its exposed terrain. Conflict is close to 0.8, indicating significant unrest or instability disrupting life and government, which also scores 0.6–0.8, suggesting weak institutions.

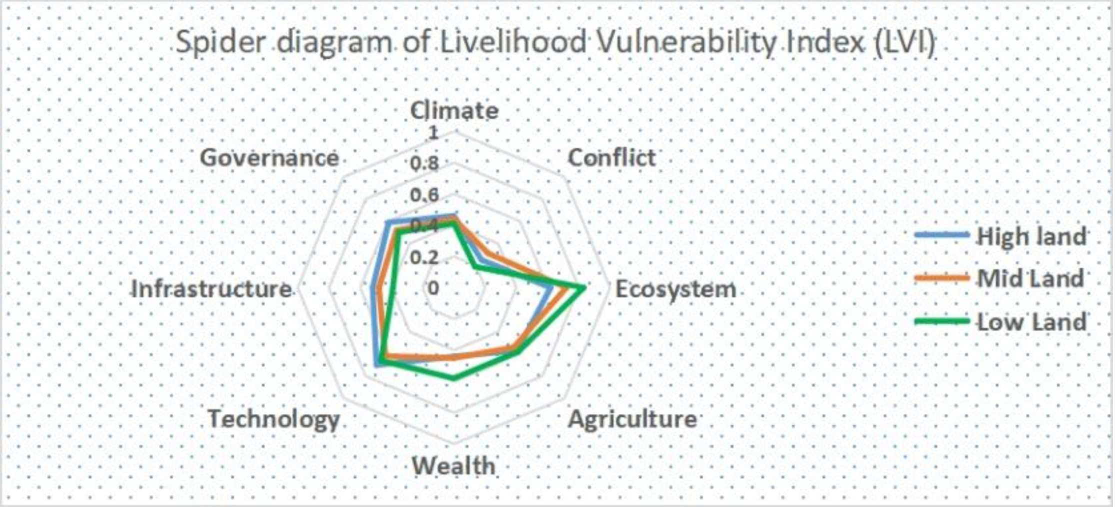

**Figure 3.** *Spider diagram of major profiles of Livelihood Vulnerability Index (LVI)*

Highland performs well in infrastructure, technology, and wealth (scores close to 0), with good roads, access to technology, and economic assets mitigating some risks. Agriculture and ecosystem rate 0.4–0.6, reflecting moderate resource degradation.

Midland (orange line) is relatively well-balanced but concerning. Climate and conflict are both at the same level, close to 0.8, driven by climatic risks (e.g., lack of water) and societal tensions. Both Governance (0.6) and Ecosystem (0.6) capture weak policy and resource quality dimensions in the mid-rank position. Infrastructure, Technology, Agriculture, and Wealth all between 0.2–0.4, depicting average resilience and somewhat lower levels of development compared to High Land. Mid Land exposed to huge threats requiring tailored climate and conflict intervention. Low Land (green line) is the strongest. Climate, Conflict, and Governance score 0.4–0.6, suggesting lighter weather and social problems, perhaps due to conditions being stable. Ecosystem (0.4) suggests light environmental issues. Infrastructure, Technology, Agriculture, and Wealth score near 0, highlighting strong systems—transport, tech, agriculture, and wealth—that promote resilience and livelihoods. By contrast, Climate and Conflict are priority concerns in the High Land and Mid-Land and are exacerbated by weak governance. Low Land's infrastructure, technology, agriculture, and wealth bases suggest these regions develop resilience, and there is a lesson to be learned by High Land and Mid-Land. The interlinking factors—climate leading to conflict, and infrastructure as a shock buffer—demand context-specific interventions like climate adaptation, conflict management, and investment in governance and technology to reduce vulnerability and guarantee sustainable development in areas.

The Analysis of Variance (ANOVA) in Table 3 examines the statistical significance of varying independent variables with regard to the effect on a dependent variable, most likely related to livelihood vulnerability or some similar result within this study. The F-test statistics are placed in a table along with relevant significance levels (p-values) and the use of asterisks for indicating the level of statistical significance, typically * when p<0.05, ** for p<0.01, and *** when p<0.001. This analysis gives a robust statistical model to describe how significant variables influence the dependent variable and tells us about their significance and effect size.

**Table 3**

*Continuous variables considered in the ANOVA analysis for the three AESs*

| Variables | F-test | Significance |
|---|---|---|
| Age | 7.26*** | 0.00 |
| Education | 8.05*** | 0.00 |
| Land size | 5.04*** | 0.00 |
| TLU | 3.65*** | 0.00 |
| Dependency Ratio | 1.95 | 0.0524 |

***Significant at 1%

The results show several variables with strongly significant effects. Age is very important with an F-test statistic of 7.26 and p-value of 0.00, significant at the 0.1% level. Differences between ages, e.g., between youth and old, are a primary driver of the outcome. This can be due to differences in experience, physical capability, or availability of resources influencing vulnerability or resilience. Similarly, education also shows a very strong impact, with an F-test value of 8.05 and a p-value of 0.00. This is highly significant and emphasizes education's pivotal role, likely increasing adaptive capacity, improved decision-making skills, or increased income opportunities, all of which can reduce vulnerability.

Land Size is the other important variable, with an extremely strong effect in its F-test of 5.04 and p-value of 0.00. It implies that the extent of land holdings has a strong impact on the dependent variable due to possibly being influential on farm production, financial stability, or vulnerability to weather risks. Tropical Livestock Units (TLU), the measure of livestock ownership, also reveals a considerable impact (F=3.65, p=0.00), showing that livestock makes a considerable contribution to the result. This could be because livestock serves as a source of income, food security, or a coping mechanism against economic or climatic shocks.

By contrast, the dependency ratio has less unequivocal findings, with an F-test statistic equal to 1.95 and a p-value of 0.0524. This is just beyond the conventional 0.05 significance level and implies a marginally significant effect. The ratio of dependents (children or elderly) per working age, which can impact the dependent variable less systematically, may require more samples or more analysis to conclude its contribution. Table 4 presents the Exposure, Sensitivity, and Adaptive Capacity components of the Livelihood Vulnerability Index (LVI) and LVI-IPCC scores for High Land, Mid-Land, and Low Land, assessing livelihood vulnerability in these agro-ecological zones to climate-related stresses.

**Table 4**

*Calculated indices for contributing factors and the Livelihood Vulnerability Index under the LVI-IPCC framework.*

| Agro-ecology | Exposure | Sensitivity | Adaptive Capacity | LVI-IPCC |
|---|---|---|---|---|
| High Land | 0.36 | 0.59 | 0.62 | -0.124 |
| Mid-Land | 0.38 | 0.63 | 0.57 | -0.142 |
| Low Land | 0.3 | 0.71 | 0.56 | -0.229 |

Highland has moderate exposure (0.36), implying lower climate risk than others but greater sensitivity (0.59), i.e., livelihoods are more likely to be impacted. Its adaptive capacity (0.62) is the highest, i.e., high coping ability, perhaps due to better infrastructure or assets. The LVI-IPCC score (-0.124) implies low vulnerability, as high adaptive capacity makes up for moderate exposure and sensitivity.

Land exposure (0.38) is slightly greater, indicating greater climate risk, with sensitivity (0.63) greater than high land, suggesting greater susceptibility. Its adaptive capacity (0.57) is lower, indicating lesser resilience than Highland. The LVI-IPCC score (-0.142) indicates slightly greater vulnerability, driven by high exposure and sensitivity, moderated by adaptive capacity.

Low Land has the lowest exposure (0.30), suggesting low climate risk, possibly due to favourable conditions. However, its sensitivity (0.71) is the highest, indicating high susceptibility, possibly due to reliance on vulnerable resources. Adaptive capacity (0.56) is the lowest, denoting poor adaptation, possibly due to minimal infrastructure or economic resources. Despite low exposure, its LVI-IPCC score (-0.229) shows the highest vulnerability, since high sensitivity and poor adaptive capacity have priority.

The table highlights distinct vulnerability profiles: Highland is blessed with high adaptive capacity; midland has moderate threats with higher exposure and sensitivity, while lowland, though with low exposure, is the most vulnerable due to high sensitivity and low adaptive capacity. These findings underscore the need for region-specific responses, particularly to build resilience in Low Land.

The Analysis of Variance (ANOVA), Table 5, tests the statistical significance of factors affecting a dependent variable, which is most likely associated with livelihood vulnerability or resilience. It gives F-test statistics and p-values, and asterisks (* p<0.05, ** p<0.01, *** p<0.001) are used to show levels of significance.

Having farmland shows a significant effect (F=4.04, p=0.0076**), which means land holding affects the outcome at the 1% level, perhaps through enhanced productivity, food security, or stability. Access to irrigation is highly significant (F=8.53, p=0.0037**), which indicates it enhances resilience or reduces vulnerability, perhaps through increased yields and avoidance of climate risks. Mobile phone possession has the strongest effect (F=17.75, p=0.000***), at the 0.1% level, highlighting its role in communication, information access, or economic opportunities. Having all-weather roads is important (F=6.34, p=0.0123**), indicating that good transport is important for outcomes, perhaps via better access to markets or mobility. Having the right land is extremely important (F=9.58, p=0.0021**), highlighting its role in agricultural security.

Access to help matters (F=4.20, p=0.0412*), influencing at the 5% level, possibly by reducing exposure or helping to cope. Access to health cover is highly significant (F=16.61, p=0.000***), showing it enhances resilience by mitigating medical expense risk. Access to extension services, and offering farm support, is highly significant (F=11.93, p=0.0006**), enhancing productivity and adaptive capacity. Access to electric facilities is significant (F=5.92, p=0.0155**), whereby electricity maintains livelihoods through economic enterprise or technology utilization. Access to clean water is of marginal significance (F=2.93, p=0.088*), at a 10% level of influence, most likely associated with health and agriculture. Income diversity is also of marginal significance (F=2.33, p=0.0745*), meaning various sources of income are decreasing vulnerability, albeit less strongly.

In general, the ANOVA shows that access to mobile phones, access to health insurance, irrigation, suitable land, and extension services have very strong impacts, which show their critical roles in determining livelihood outcomes. Marginal effects of access to clean water and income diversification show less strong influences, which are worth examining further.

**Table 5**

*Explanatory variables considered for ANOVA for the four agro-ecological systems*

| Variables | F-test | Significance |
|---|---|---|
| Own farmland | 4.04** | 0.0076 |
| Access to irrigation | 8.53** | 0.0037 |
| Own mobile phone | 17.75*** | 0.000 |
| Access to all-weather road | 6.34** | 0.0123 |
| Access to suitable land | 9.58** | 0.0021 |
| Access to aid | 4.20** | 0.0412 |
| Access to health insurance | 16.61*** | 0.000 |
| Access to extension services | 11.93** | 0.0006 |
| Access to an electric facility | 5.92** | 0.0155 |
| Access to clean water | 2.93* | 0.088 |
| Diversity of income | 2.33* | 0.0745 |

**, ** and *** significant at 10%, 5% and 1%, respectively*

The very strong significance of infrastructure, technology, and resource access shows key policy areas for resilience building.

## Discussions

The study analyzed livelihood vulnerability in the midland, highland, and lowland agro-ecological settings (AESs) of East Wollega Zone, Ethiopia, founded on the Livelihood Vulnerability Index (LVI) model and Climate Vulnerability Index (CVI) triangle diagram. The findings provide a summary of exposure, sensitivity, and adaptive capacity, in line with previous research in Sub-Saharan Africa (Tessema & Simane, 2019 & Zeleke et al., 2023).

LVI results reveal the midland AES to have the highest exposure and sensitivity to climatic stresses, namely erratic rainfall and temperature rise. This aligns with evidence emerging from the Blue Nile Basin Finchaa catchment, in which intermediate geographical locations experience elevated climate vulnerabilities (Tessema & Simane, 2019). Conversely, highland AES is least vulnerable given that comparatively stable climatic conditions at higher elevations, a trend observed in past studies (Zeleke et al., 2023). Lowland AES is moderately vulnerable to droughts and temporary interruptions in rainfall but to a lesser extent than the midland AES, as also suggested by Tessema and Simane (2019).

Sensitivity to climate variability is highest in the lowland AES, primarily because it is dependent on climate-sensitive resources such as water and agriculture. This finding is supported by a study that indicates that agricultural dependence raises vulnerability in lowland regions (Asfaw et al., 2021). Moderate sensitivity characterizes the midland AES, influenced by both highland and lowland climatic conditions. Meanwhile, the highland AES, while it gets rain and temperature variation, exhibits the lowest sensitivity, which is consistent with studies by Zeleke et al. (2023) and Asfaw et al. (2021).

Adaptive capacity varies significantly among the AESs. The highland AES has the highest adaptive capacity due to its increased access to resources, infrastructure, and local resilience, as shown through research conducted by Esayas et al. (2019), Ademe et al. (2020), and Solomon et al. (2021). The lowland AES, however, has the lowest adaptive capacity, characterized by poor infrastructure, institutional lack of support, and limited livelihood opportunities, a pattern also identified by Asfaw et al. (2021). The midland AES has moderate adaptive capacity, balancing its high exposure with a certain level of resilience (Below et al., 2012).

The CVI triangle diagram also confirms these findings by highlighting differential climatic hazards across AESs. Interestingly, it indicates the highland AES to be most exposed and sensitive to climatic threats but with the lowest adaptive capacity. These results suggest higher risks due to extremities of climatic conditions and low adaptive capacities, consistent with research in Ethiopia and other developing nations (Deressa et al., 2011). Meanwhile, the midland AES also portrays a more balanced but still vulnerable profile whose exposure is heavily influenced by conflict-related factors such as displacement, looting, and property destruction, as implied by previous research (Zeleke et al., 2023). Lowland AES, while exhibiting lower climate sensitivity, remains vulnerable due to weak institutional protection and the absence of infrastructure, validating research by Tessema and Simane (2019).

The LVI-IPCC scores also confirm the vulnerability disparities among AESs. The lowland AES, with a composite LVI-IPCC score of -0.229, is the most vulnerable due to high sensitivity and low adaptive capacity, consistent with Asfaw et al. (2021). The highland AES, with a score of -0.124, is the least vulnerable due to its higher adaptive capacity, as noted by Zeleke et al. (2023). The midland AES (-0.142) is intermediate, with high exposure to both climatic and conflict-related stresses, in line with Tessema and Simane (2019). The findings call for region-specific resilience interventions.

Infrastructure is central to vulnerability reduction by enhancing market access, education, and service delivery. The highland and midland AESs are endowed with better infrastructure, which reduces vulnerability by enhancing connectivity, in line with Tessema and Simane (2019) and Zeleke et al. (2023). In comparison, infrastructural deficits afflict the lowland AES, compounding its vulnerability and limiting its adaptive capacity, as found by Asfaw et al. (2021). Resilience is also influenced by social capital through the facilitation of community-based adaptation strategies, which are more resilient in the highland AES (Solomon et al., 2021). Concurrently, governance plays an important role in the development of resilience, with stronger institutions in the highland AES augmenting adaptive capacity, whereas weaker governance in the midland and lowland AESs necessitates targeted interventions (Asfaw et al., 2021; Simane et al., 2016).

Patterns of vulnerability are also impacted by agricultural productivity and land sustainability. Lowland AES families possess larger farms and livestock, a common trend in dryland economies where livestock serves as a coping mechanism (Zeleke et al., 2023). The highland AES, despite limited land resources, has higher livelihood diversification and technological adoption, which aligns with previous evidence on risk reduction through non-farm income and agricultural intensification (Ellis, 2000; Deressa et al., 2011). Additionally, the statistical analysis highlights the powerful roles played by socioeconomic determinants such as education, age, and asset ownership in conditioning vulnerability levels (Asfaw et al., 2021).

Overall, the findings of the study highlight the spatially differentiated vulnerabilities of AESs. Climate-related threats are most severe for the highland AES, the midland AES is affected most by conflict, and the lowland AES is faced with exposure and low adaptive capacity. These results highlight the need for targeted interventions, including climate adaptation in the highland AES, conflict resolution institutions in the midland AES, and governance and infrastructure development in the lowland AES. The intertwined issues of climate change, conflict, and governance call for an integrated vulnerability reduction approach, ensuring sustainable development pathways for rural Ethiopians and other societies.

## CONCLUSIONS

The findings of this study reveal high variation in climate vulnerability, conflict exposure, and adaptive capacity across agroecological zones in East Wollega, Ethiopia. The Climate Vulnerability Index (CVI) analysis reveals that highlands face the greatest climate risk due to high exposure and sensitivity to climate variability coupled with low adaptive capacity. Moderate vulnerability occurs in mid-altitude areas, while comparatively lower vulnerability is revealed in lowland areas due to higher adaptive capacity and lower climate risks.

Climatic variability and exposure to conflict also enhance livelihood vulnerability, particularly in the Midlands, where livelihoods are deranged by displacement, looting, and insecurity. Although the highlands have fewer conflicts, governance problems thwart efforts at constructing resilience. Ecosystem and land-use analyses show that lowland and midland areas have better land suitability and sustainable agriculture, while highland areas have higher constraints. Notwithstanding this, highland areas have higher livelihood diversification, which is an adaptation to climate and economic shocks.

Statistical analyses confirm that major determinants such as education, land size, livestock ownership, access to infrastructure, irrigation, and technology significantly influence livelihood vulnerability. Access to health services, extension services, and mobile phones also matters in order to construct resilience. These findings call for targeted interventions: highland areas must improve their infrastructure and livelihood diversification, midland areas need conflict mitigation and governance strengthening, and lowland areas must prioritize resource management and economic diversification to enhance resilience in climate and conflict-prone zones.

### Recommendations

To enhance rural households' resilience to climate variability and conflict, targeted adaptation strategies and institutional support are essential. Promoting drought-resistant crops, improving irrigation, and investing in soil and water conservation can mitigate climate impacts. Strengthening early warning systems and providing climate information will help households make informed decisions. Policies supporting sustainable agriculture and enhancing adaptive capacity are crucial.

Given the impact of conflict on livelihoods, particularly in mid-altitude areas, improving security and governance is vital. Strengthening community-led conflict resolution, ensuring equitable resource access, and investing in infrastructure like roads, markets, health, and education can reduce tensions and support diversification. A stable environment will enable rural households to pursue alternative income sources.

A holistic policy approach is needed to address both climate and conflict vulnerabilities. Governments and development agencies should strengthen institutional frameworks, expand credit access, ensure land tenure security, and enhance social protection. Integrating climate adaptation, conflict mitigation, and economic development will foster sustainable rural livelihoods.

## CRediT authorship contribution statement

**Dereje Chimdessa**: Conceptualization, methodology, Investigation and writing

**Admassu Tesso:** validation and supervision, review and editing

**Dereje Tolera:** Validation. Supervision, review, and editing

## Declaration of competing interest

The authors declare that there is no conflict of interest.

## Data availability

Data will be made available on request.

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