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REGULAR RESEARCH ARTICLE

Livelihood Vulnerability to Climate Change of Casava Smallholders in Central Highlands of Vietnam

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ABSTRACT

This study utilized the Livelihood Vulnerability Index (LVI) within the IPCC framework (LVI-IPCC) for cassava farming households in the central highlands of Vietnam. Data were gathered from a household survey (364 households) in Krong Bong and Ea Kar districts, Dak Lak province, in-depth interviews (22 key informants) and two focus group discussions. By analyzing variations in LVI components and conducting a Poisson regression analysis, the results revealed that cassava farming households in the studied areas exhibited moderate vulnerability to climate change and variability. Variations in vulnerability levels were observed between the two districts, with disparities found across sensitivity, exposure, and adaptive capacity. Differences in LVI were also evident between the Kinh and ethnic minority groups and between the poor and non-poor farming households, primarily attributable to variations in adaptive capacity. Key determinants of household livelihood vulnerability included the intensity of climate risks, the frequency of extreme climate events, market risks, environmental shocks, land slope, land area at risk of flooding, climate change knowledge, transportation means, market linkages, access to credit, and income diversification. The study further proposed strategies for local authorities and relevant agencies to enhance climate change resilience among cassava farming households.

KEYWORDS

Climate risks; Central highlands; Livelihood vulnerability; Cassava; Smallholders; Dak Lak.

1. INTRODUCTION

Cassava (Manihot esculenta) is a vital tropical crop (Ayode, 2012), chosen by many vulnerable communities for its cost-effective cultivation (Kim, 2005). In 2022, Vietnam ranked fourth in cassava production (Kim et al., 2015), with the central highlands leading in cassava cultivation, accounting for 32.7% of the country's total cassava area (MARD, 2022). Cassava plays a crucial role in the income and livelihoods of upland households, especially in the central highlands (Nguyen et al., 2015). However, climate change poses a significant threat to cassava production and farmers' income (Kim et al., 2015). Despite cassava's drought tolerance and its role as an adaptive strategy for upland communities (Mupakati & Tanyanyiwa, 2017; Nui et al., 2021), changing climate conditions have been shown to negatively impact cassava growth, reducing yields and productivity (Emenyonu et al., 2020), ultimately affecting the livelihoods of cassava farmers (Anyaegbu et al., 2023; Emenyonu et al., 2020; Emmanuel et al., 2023).

Previous studies have examined climate change's impact on agriculture in Vietnam's central highlands (Dinh et al., 2022; Khoi & Thom, 2015), often focusing on extreme events like drought, hydrology, and rainfall patterns (Khoi & Hang, 2015; Tran Van Thuong et al., 2023). Some have investigated climate change effects on agriculture systems (Do et al., 2021), for specific crops like coffee and fruits, and farmers' responses (Tan et al., 2013). Little is known about climate change's impact on cassava production and cassava farmers' livelihoods as cassava production areas continue to expand. This study explores climate change's effects on cassava production, the vulnerability of cassava farmers' livelihoods, and the key factors shaping this vulnerability. It aims to provide policymakers with reliable information for crafting effective policies to enhance resilience and sustain livelihoods for different groups of cassava farmers in the central highlands.

2. LITERATURE REVIEW

2.1 Livelihood vulnerability of agricultural communities

Climate change has significantly impacted global agriculture due to its reliance on natural and climatic conditions (Gullino et al., 2022). Agricultural communities are vulnerable to these effects (Bandara and Cai 2014). Climate change, along with natural disasters like droughts, intense rainfall, landslides, flash floods, and abnormal weather, has caused numerous problems, including land degradation, increased pests and diseases, and reduced crop yields (Bai et al., 2022; Emmanuel et al., 2023; Urothody and Larsen 2010). In the southeastern part of Nigeria, increased rainfall frequency and flooding are considered the most significant risks for cassava farmers, resulting in significant crop losses and reduced household income (Emenyonu et al., 2020). Studies by Bai et al., (2022) and Bandara & Cai (2014) also show that climate change has significantly and negatively impacted agriculture productivity in China, Bangladesh, India, Nepal, Pakistan, and Sri Lanka, affecting food production, prices, and food security. This has made people more sensitive to food and water shortages for daily life and livelihood activities (Bai et al., 2022; Huong et al., 2019). Literature reviews reveal that climate change has increased production costs and reduced agricultural land in various parts of the world (Gullino et al., 2022; Sen et al., 2020). Increased production risks and reduced income significantly affect the ability of farming households to reinvest in agriculture to adapt to climate change and variability (Huynh et al., 2021a; Sen et al., 2020).

Livelihood vulnerability varies based on physical and social factors, impacting different communities, regions, countries, and sectors (Tran T. P. et al., 2023). Those living in upland areas with challenging topography, inadequate infrastructure, and limited alternative production means face high exposure to climate changes (Kurukulasuriya & Rosenthal 2003; Sen et al., 2023). In Vietnam, upland communities, typically comprising ethnic minorities with low education levels, high poverty rates, and agriculture-based livelihoods, are particularly susceptible to climatic variations (Tran Van Thanh et al., 2021). Therefore, it is crucial to investigate livelihood vulnerability in specific communities, such as cassava farmers in Vietnam's central highlands, to identify effective adaptive strategies that enhance resilience to increased climate variability.

2.2 Approaches to researching livelihood vulnerability to climate change

To study the impact of climate change on specific communities and the barriers to effective responses, researchers and policymakers utilize household livelihood vulnerability assessments (Shen et al., 2022). Three common indices for livelihood vulnerability assessment are LVI (Hahn et al., 2009), LVI-IPCC (IPCC, 2001), and the livelihood effect index (LEI) (Tran Van Thanh et al., 2021). While LEI provides a household-based composite index, both LVI and LVI-IPCC are composite indexes applicable at various levels, from the household to regional (Urothody & Larsen 2010). LVI combines all major indicators, while LVI-IPCC categorizes them into three contributing factors: exposure, sensitivity, and adaptive capacity (Hahn et al., 2009; IPCC, 2001). The LVI and LVI-IPCC approaches enable stakeholders to comprehend variations in vulnerability over time and space, identify key factors contributing to vulnerability, and develop strategies to reduce it (Tran Van Thanh et al., 2021). These two indices have been potent tools for assessing farmers' vulnerability to climate and disasters globally over the past decade (Huong et al., 2019; Rahman et al., 2023). Recently, these indices have been combined to assess livelihood vulnerability (Shen et al., 2022; Tran T. P. et al., 2023). Given the above information, the combination of LVI and the LVI-IPCC approach is suitable for evaluating the livelihood vulnerability of different groups of cassava farmers in this study.

2.3 Livelihood vulnerability assessment indicators

This study adapts the hierarchical approach used by Hahn et al. (2009), Shen et al. (2022), Nguyen et al. (2021), and Tran T. P. et al. (2023) to construct the LVI and LVI-IPCC, focusing on key indicators and contributing factors (see Figure 1). Indicators and sub-indicators were derived from existing literature and consultations with local officers, including agricultural staff at provincial, district, and commune levels. The composite indexes used in this study are presented in table 2. Consequently, the LVI-IPCC in this study comprises three contributing factors (sensitivity, exposure, and adaptive capacity), eight main indicators (sociodemographics (SD), psychology (Ps), environmental risks (Er), vulnerability context (VC), human resources (H), physical and natural resources (PN), financial resources (F), and social resources (S)), along with 26 sub-indicators.

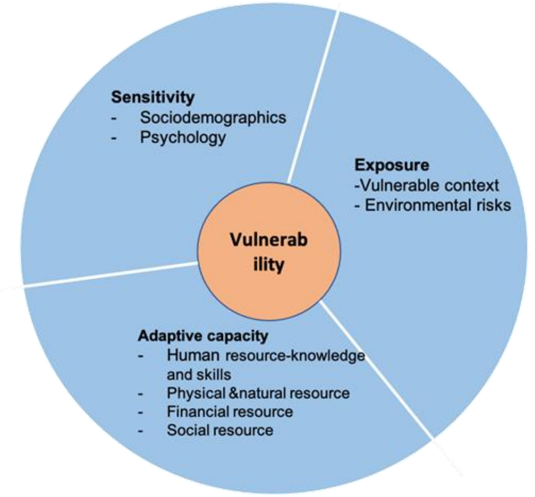

Figure 1. Major components and subcomponents of farmers' livelihood vulnerability [Source: Modified from Shen et al. (2022)]

3. METHODOLOGY

3.1 Study sites

The central highlands rank top three in the nation for cassava production. Dak Lak, a province in the region, leads in cassava production (GSO, 2023) with diverse ethnic groups, where the ethnic minorities, including Ede, Thai, Tay, H'Mong, and Nung occupied 35% of the region. The province, covering 1,308,400 hectares, dedicated 422,735.31 hectares (32.3%) to agriculture in 2022. Agriculture contributed 37.22% to the total GDP in 2022 according to the provincial people's committee of Dak Lak. The cassava cultivation area stood at approximately 44,041 hectares, with a growing trend.

The province's population in 2022 reached 1.9 million, of which 75.18% resided in rural areas and relied on agriculture for their livelihoods. Unfortunately, the poverty rate in the province is notably high at 18.72%, in contrast to the national average of 7.52% (GSO, 2023). This study focuses on the Krong Bong and Ea Kar districts, the primary cassava production areas in the province. In each district, we purposefully selected three communes for investigation: Ea So, Ea Tyl, and Ea Kar in Ea Kar district, as well as Dang Kang, Hoa Le, and Hoa Phong in Krong Bong district. The locations of the two districts and studied communes are shown in figure 2.

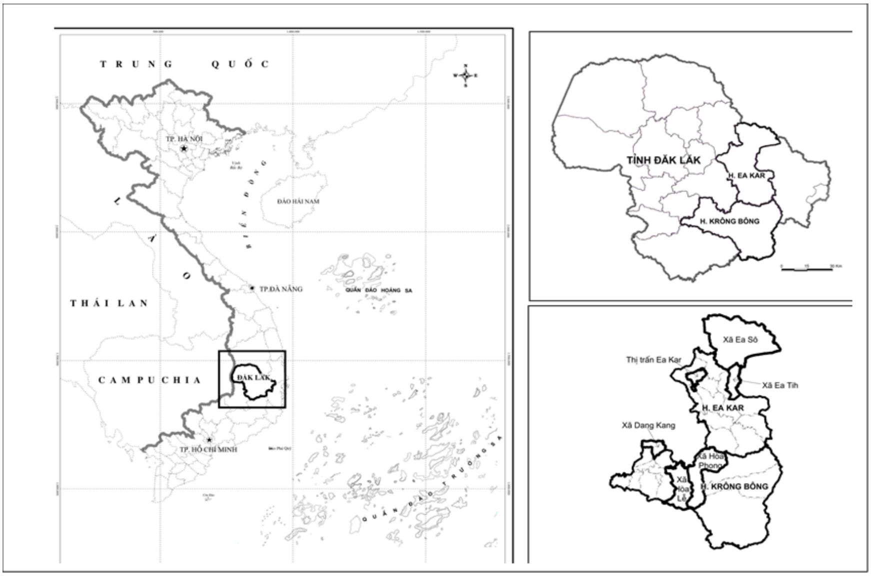

Figure 2. Maps of study sites, (a) the two districts, (b) the surveyed communes.

According to statistical records (Dak Lak PPC, 2023), both Krong Bong and Ea Kar were identified as poor districts with a poverty rate of 32,6 % and 10,2 % respectively, in 2022. The average income was 28,8 million VND (approximately 1,168.8 USD) per person per year in Krong Bong and 35,0 million VND (approximately 1,420.5 USD) per person per year in Ea Kar. These two districts are characterized by a significant proportion of ethnic minority residents, accounting for over 42% and 31% of the population of Krong Bong and Ea Kar, respectively. Krong Bong is more isolated and has a more complicated topography with higher slope hills compared to Ea Kar. It is located approximately 55 km away from the provincial center to the Northwest, while Ea Kar is 52 km away to the East, with better road infrastructure.

3.2 Data collection

Data for this study were collected from February to August 2023. Secondary data on cassava production and socio-economic characteristics of Dak Lak province were obtained from relevant departments, publications, and books. Primary data were gathered through in-depth interviews with local government officials, key farmers, group discussions, and household surveys. In-depth interviews involved 22 participants, including staff from provincial and district agricultural and rural development departments, commune chairmen, village heads, and extension workers. The interviews focused on factors influencing cassava production and the livelihoods of cassava farmers in the context of climate change. Two focus group discussions were held, each with 10-12 participants in the studied districts, addressing climate change, its impacts and livelihood vulnerability components. Households, totaling 364 (181 in 3 communes of Ea Kar district and 183 in 3 communes of Krong Bong district), were randomly selected. Among these households, 117 were classified and certified by the local government as poor households and 247 were non-poor households; 150 were Kinh households and the rest (214) belonged to ethnic minorities. A semi-structured questionnaire was designed to gather data on cassava production, sociodemographic information, climate vulnerability, environmental risks, and livelihood resources. A pretest of the questionnaire was conducted with ten households in the study site, resulting in revisions and finalization before the main survey. Data from household surveys were coded and managed in Excel 2016 and analyzed using SPSS 22. Qualitative data obtained from in-depth interviews and group discussions were documented, transcribed and grouped into different information categories such as stories, ideas and thoughts. These qualitative findings were then combined with quantitative data to address common research issues or findings.

The study methods and protocol were approved by the Research Ethics Committee for Social Sciences and Humanities of Hue University (No.2000/QĐ-ĐHH dated December 16, 2021). All methods were carried out in accordance with relevant guidelines and regulations.

3.3 Data analysis

This study assessed cassava farming households' livelihood vulnerability and identified influencing factors to propose effective interventions for different household groups. Based on socio-economic and geographical backgrounds, the study aimed to compare livelihood vulnerability and its determinants among household groups in the two districts. Additionally, the study sought to capture differences in livelihood vulnerability between ethnic groups (Kinh and ethnic minority households), and economic classification groups (poor and non-poor households) as they are considered social vulnerability groups in rural uplands. The analysis involved three steps, as follows:

- Calculating main indicators of LVI (Hahn et al., 2009)

The calculation of LVI indicators, as per Hahn et al.'s (2009) framework, involves three steps. The first step is to convert collected data into suitable measurement units and standardize each sub-indicator using the following formulas:

$$\text{Index Y} = \frac{\text{Observed} - \text{minimum}}{\text{Maximum} - \text{minimum}} \qquad (1)$$

After each sub-indicator was standardized, scores of each main indicator were calculated by averaging the sub-indicators using the following formulas:

$$N = \frac{\sum_{i=1}^{n} \text{indexY}_i}{n} \qquad (2)$$

N is one of 26 sub-indicators, where 'n' denotes the sample size, and Yi signifies the sub-indicators indexed as i within each sub-indicator. The third step involves computing the main indicator value, which is determined using the following equation."

$$M = \frac{\sum_{t=1}^{m} N_i}{m} \qquad (3)$$

M is one among 8 main indicators of LVI and m is number of sub-indicators in each main indicator.

- Calculating three contributing factors and LVI-IPCC

The three factors contributing to LVI-IPCC is calculated based on the following equation:

$$CF_j = \frac{\sum_{i=1}^{n} \omega_{Mi} M_{ji}}{\sum_{i=1}^{n} \omega_{Mi}} \quad (4)$$

where CFj represents an IPCC-defined factor (exposure, sensitivity, or adaptive capacity) for community j. Mji denotes the key indicators for community j, indexed by i, with ω_{Mi} as their weight. n stands for the number of indicators within each factor.

To calculate the LVI-IPCC, we utilize the following equation after determining the three contributing factors:

$$LVI - IPCC_j = (e_j - \partial_j) * S_j \quad (5)$$

where LVI–IPCCj is the LVI for community j expressed using the IPCC vulnerability framework; e, ∂_j and S were the calculated exposure score, adaptive capacity score sensitivity score for community j, respectively.

The LVI–IPCC was scaled from −1 (least vulnerable) to +1 (most vulnerable).

- Identifying vulnerability determinants using a Poisson regression analysis. Determinant factors were identified by the following equation:

$$Y = a + {}_1X_1 + {}_1X_2 + \cdots + {}_nX_n + {}_mX_m + \quad (6)$$

where, Y is the LVI-IPCC; α is the regression coefficient of continuous variables and β is the regression coefficient of the dummy variable, Xn is the continuous variable and Xm is the dummy variable.

The independent variables were derived from the LVI index and from review of literature. The LVI-IPCC was identified as the dependent variable for regression analysis in this study.

4. RESULTS

4.1 Perceived climate change and variability

In the surveyed regions, respondents were questioned about their perceptions of climate change and its associated extreme events. The findings indicated comparable occurrences of extreme events in both districts (Table 1), with drought, heat stress, and abnormal weather ranking as the most severe. Respondents reflected that the weather is much dryer, hotter and lasts longer than it did about ten years ago. Additionally, there were some very hot days during the winter season that hadn't been experienced in the past. Increased frequency and intensity of heavy rains and floods posed significant challenges to farming, especially in foothill and valley locations. Due to the complex, hilly terrain, Krong Bong farmers experienced more severe flooding than those in Ea Kar. Additionally, respondents noted a recent rise in the intensity and prolonged heavy rains and storms in the study area. The rainy season has been prolonged from May to October, and sometimes even into November instead of the usual past period of May to September. This change occurs during the later development stages of cassava, seriously affecting starch quality.

Table 1. Farmers' perception of climate change at the studied sites

Climate extreme events	Krong Bong district	Ea Kar district
Heat stress	*****	*****
Drought (dry soil)	*****	*****
Prolong heavy rains & landslide	***	***
Floods	****	**
Strong winds/ storms	**	*
Abnormal weather	*****	*****

Notes: The more star denotes the more serious of changes: *- the least serious and *****- the most serious event [Source: Field survey 2022-2023]

4.2 Livelihood vulnerability index

The Livelihood Vulnerability Index assesses eight key indicators: sociodemographic, psychology, environmental risks, vulnerability context, human capacity (knowledge and skills), physical capital, social capital, and financial capital, along with their sub-indicators. Vulnerability is then evaluated across three contributing factors for different farming communities: two districts (Krong Bong and Ea Kar), the poor versus non-poor, and the Kinh versus ethnic minority groups. Each factor, main indicator, and sub-indicator exhibit varying levels of vulnerability and community comparisons. Additionally, we calculated standard deviations alongside the average scores. Low standard deviations suggest data clustering around the mean, while high standard deviations indicate a wider data distribution.

4.2.1 Sociodemographic

The sociodemographic vulnerability score consists of three sub-indicators: households with chronic illness, dependency ratio, and poverty rate. Table 2 results reveal that while poverty rates and dependency ratios differed significantly between Krong Bong and Ea Kar, there was no significant difference in the overall sociodemographic score. Both districts had similar average sociodemographic scores, with means of 0.41±0.17 and 0.40±0.16, respectively. Ea Kar had a lower poverty rate but a higher dependency ratio compared to Krong Bong (P<0.001).

4.2.2 Psychology

The household heads' psychology regarding climate change and variability was gauged through four key indicators: the proportion of income derived from cassava, days of food shortages, concern about climate risks, and months of water scarcity. Table 2 data revealed a significant difference in respondents' psychology between the two districts (P<0.001). In Ea Kar district, farmers exhibited lower climate risk-related stress, as evidenced by all four sub-indicators having lower vulnerability scores. Survey data indicated that Krong Bong district had a larger cassava production area (2.46 ha) compared to Ea Kar (1.17 ha), and their livelihoods were more reliant on cassava production (50.4% vs. 25.28%, respectively). Group discussions further highlighted that the challenging topography and hilly terrain of Krong Bong heightened the population's concerns about climate risks, especially floods and droughts. Prolonged drought posed an escalating water scarcity issue, impacting both agriculture and daily life.

4.2.3 Environmental risks & shocks (Ecology-economic risks)

Over the years, climate risks, livelihood damages, unstable agricultural markets, and environmental shocks like pests, diseases, soil erosion, and water pollution have become key factors contributing to environmental risk (Er). The survey results revealed an increase in the intensity and frequency of pests and diseases, such as Cassava mosaic virus, mealybugs, and red mites due to prolonged drought and abnormal rainfalls, affecting crop production in both districts. Abnormal floods at the end of the cassava cropping season damaged cassava roots, leading to nearly no harvest for many farmers. The average vulnerability score for Er in both districts was 0.55±0.20, indicating that farm households in these areas face moderate environmental risks. Notably, Krong Bong had a significantly higher Er score than Ea Kar due to higher scores in all three sub-indicators (P<0.001). Krong Bong's isolated location has posed challenges for farm households in selling their agricultural products, particularly cassava because of the low-quality starch and unusual harvesting period due to prolonged drought at the planting stage and prolonged rains at the harvesting stage. Additionally, with input and output prices being uncertain and reliant on middlemen farming households were more sensitive to climate change impacts.

4.2.4 Vulnerability context

The vulnerability context (VC) of the studied communities was reflected by factors such as land slope, household agricultural land affected by drought and floods, and the status of land degradation. The average VC score for both districts was 0.54±0.15, indicating moderate vulnerability to climate change among farmers in both communities. The proportion of household land affected by drought and floods was similar in both districts. However, the land slope in Krong Bong was slightly steeper than in Ea Kar ($P<0.05$), and land degradation was more pronounced in Ea Kar than in Krong Bong ($P<0.0001$). The higher level of land degradation in Ea Kar resulted in a significantly higher VC compared to Krong Bong ($P<0.05$).

4.2.5 Human capital-knowledge and skills

Three sub-indicators, encompassing the education of household heads, climate change awareness, and farming experience, determined the human capacity of respondents. The overall score for both districts was 0.39±0.15, indicating relatively low human capital in terms of climate change-related knowledge and skills. This low score was primarily attributed to a lack of climate change knowledge among farmers in both districts. Notably, Krong Bong exhibited a significantly higher overall score than Ea Kar, indicating that Ea Kar possesses heightened human capital inidcators, particularly in terms of household heads' education levels ($p<0.001$). Survey findings revealed that 3.8% of interviewed household heads in Krong Bong were illiterate, and 33.1% had only completed primary school, compared to 0% and 13.1% in Ea Kar. However, both communities had a high proportion of farmers with higher education, including high school and above (30.9% in Krong Bong and 36.1% in Ea Kar). Cassava farming experience was substantial in both districts, with approximately 9 years in Krong Bong and 11 years in Ea Kar.

4.2.6 Physical and natural capitals (PN)

The physical capital comprises four vital factors: agricultural area, housing conditions, information device status, and transportation means. These physical capitals are related to households' capacity for storing agricultural products, protecting people from extreme events or disasters, and enhancing households' access to climate information and related technologies. The average physical capital score for both districts was moderately high at 0.51±0.18. Ea Kar's farming households had significantly higher physical capital scores compared to Krong Bong, attributed to superior scores in all four sub-indicators ($p < 0.0001$). Fewer Krong Bong households possessed transportation means (Cong Nong vehicles) compared to Ea Kar (21.86% and 60.2%, respectively). Most Krong Bong farm households had to sell cassava roots to local collectors at their farms or local collector's stores, fetching prices of approximately 1200-1400 VND per kilogram. In contrast, more Ea Kar farmers sold their cassava to starch companies, receiving significantly better prices of 2000-2900 VND per kilogram. Farmers in both districts commonly owned and used digital devices, such as digital TVs, mobile phones, and smartphones. A high proportion of farmers at the study location owned mobile phones (87.80% in Krong Bong and 95.03% in Ea Kar). Ea Kar's farming households were better equipped with digital devices compared to Krong Bong.

4.2.7 Social capital

In this study, social capital comprises three sub-indicators: membership in community organizations, primary contacts with market actors for agricultural product sales, and the frequency of interactions with extension workers. Table 2 reveals that the overall social capital score for the two districts was significantly different (P<0.0001) and quite low, with values of 0.30±0.15. Ea Kar had a higher social capital score. Although Krong Bong had more community organization involvement and market contacts, ANOVA analysis didn't show a significant difference. Krong Bong's lower social capital score was primarily attributed to significantly fewer interactions with extension workers and agricultural staff. This indicates that farmers in Ea Kar not only participated in community organizations and consulted market actors but also had more frequent interactions with extension workers and agricultural staff compared to farmers in Krong Bong.

4.2.8 Financial capital

Household average annual income, the number of income sources, and access to credit are three sub-indicators that constitute the financial capacity of the studied communities. The average financial capital score for both districts was 0.24±0.13, indicating very low financial capital among farmers in these areas. Notably, Krong Bong farmers scored significantly lower than those in Ea Kar (P<0.0001). Although the survey revealed that the average annual income of farm households in Krong Bong was not lower than that of Ea Kar, the lower financial score in Krong Bong primarily resulted from limited income source diversity and restricted access to credit. This correlation is understandable as Krong Bong's livelihoods are more reliant on cassava, and they possess fewer physical assets, which are essential for accessing formal credit.

4.2.9 Sensitivity of farm households to climate variability

The studied communities had an overall sensitivity score to climate extremes and variability of 0.35±0.12 (Table 2). ANOVA revealed a significant difference in this score between Krong Bong and Ea Kar farm households (P<0.0001), with Krong Bong being more sensitive than Ea Kar due to a higher poverty rate (P<0.001), greater dependence on cassava production for income, and increased psychological tension related to water scarcity and other climate change risks (P<0.0001). The survey results indicated a poverty rate of 40.44% in Krong Bong and 23.76% in Ea Kar.

4.2.10 Exposure of farm households to climate change and variability

The farm households in both districts had a moderately high overall livelihood exposure score of 0.54±0.11, indicating moderate exposure to climate change and variability. An analysis of variation revealed a significant difference in exposure scores between the two districts (P<0.001). The lower exposure of farmers in Ea Kar district was primarily due to differences in environmental risk intensity, particularly in sub-indicators of environmental risks and vulnerability context.

4.2.11 Adaptive capacity of farm households to climate change and variability

The adaptive capacity analysis comprises four key indicators: human, physical, financial, and social capital. Farm households in the two districts showed a low adaptive capacity with an average score of 0.37±0.11. All four indicators scored below 0.5, except for physical resources, indicating inadequate livelihood resources (as per Hahn et al., 2009). The primary reason for the low adaptive capacity was the deficient livelihood resources in the studied communities, particularly in the financial and social aspects. Consequently, farm households in Krong Bong had lower adaptive capacity scores compared to those in Ea Kar (P<0.0001) due to their more limited resources.

Table 2. Livelihood index of cassava households in Dak Lak province

Indicators	Unit	Krong Bong (n=181)	Ea Kar (n=183)	Sig.	Overall
SENSITIVITY		**0.41±0.11**	**0.30±0.08**	**0.0001**	**0.35±0.12**
● Sociodemographic (SD)		0.41±0.17	0.40±0.16	0.439	0.41±0.17
- Household with members	Person	0.10±0.30	0.06±0.24	0.186	0.08±0.27
with chronic illness		0.42±0.12	0.51±0.13	0.001	0.46±0.25
- Dependency ratio	%	0.76±0.43	0.60±0.49	0.001	0.68±0.47
- Poor household	Dummy				
● Psychology (Ps)		0.40±0.11	0.25±0.12	0. 000	0.33±0.13
- Share of income from	%	0.53±0.20	0.43±0.26	0.000	0.48±0.24
cassava in household	days	0.08±0.19	0.05±0.16	0.179	0.07±0.18
income	1-5	0.50±0.26	0.21±0.21	0.000	0.36±0.26
- Days shortage of food	Months	0.51±0.28	0.31±0.22		0.46±0.30
- Worry about climate risks					
- Months lacking of water					
for daily use					
EXPOSURE		**0.56±0.10**	**0.53±0.10**	**0.001**	**0.54±0.11**
Environmental Risks/ Shocks (Er)		**0.61±0.21**	**0.49±0.16**	**0.000**	**0.55±0.20**
- Climate extreme events	1-5	0.81±0.20	0.65±0.21	0.000	0.73±0.22
and damages over years	1-5	0.50±0.36	0.37±0.36	0.001	0.43±0.36
- Market variation and	1-5	0.52±0.23	0.46±0.17	0.001	0.49±0.20
shocks					
- Environmental shocks					
including pests, diseases.					
● **Vulnerability context- VC**		**0.51±0.13**	**0.56±0.16**	**0.004**	**0.54±0.15**
- Land slope status	1-5	0.46±0.27	0.40±0.26	0.038	0.43±0.26
- Proportion of land area	%	0.53±0.18	0.52±0.17	0.363	0.53±0.18
under drought & floods					
- Land degradation	1-5	0.55±0.18	0.76±0.34	0.0001	0.66±0.29
ADAPTIVE CAPACITY		**0.36±0.12**	**0.41±0.07**	**0.0001**	**0.37±0.11**
● Human capital- knowledge		0.35±0.15	0.43±0.13	0.0001	0.39±0.15
and skills (H)					
- Education of household	Grade	0.57±0.31	0.71±0.21	0.0001	0.61±0.27
head		0.19±0.24	0.33±0.25	0.0001	0.26±0.26
- Knowledge about climate	1-5	0.29±0.23	0.24±0.18	0.007	0.27±0.21
change	Year				
- Cassava farming					
experience					
Physical and natural capitals (PN)		**0.49±0.21**	**0.59±0.10**	**0.000**	**0.54±0.18**
- Agricultural land	ha	0.32±0.17	0.12±0.10	0.0001	0.23±0.21
- House conditions	1-5	0.43±0.36	0.57±0.22	0.0001	0.55±0.32
- Status of owned	1-5	0.69 ±0.16	0.89±0.09	0.0001	0.79±0.16
information/digital					
devices	1-5	0.45±0.43	0.65±0.21	0.0001	0.55±0.35
- Agricultural					
transportation means					
● **Financial capital (F)**		**0.19±0.10**	**0.28±0.14**	**0.0001**	**0.24±0.13**
- Average annual income	Million	0.11±0.14	0.12±0.07	0.834	0.12±0.11
- Number of income	#	0.23±0.18	0.39±0.21	0.0001	0.31±0.21
sources	1-5	0.24±0.29	0.35±0.30	0.0001	0.29±0.30
- Ability to access to credit					

Indicators	Unit	Krong Bong (n=181)	Ea Kar (n=183)	Sig.	Overall
• **Social Capital (S)**		**0.27±0.17**	**0.33±0.12**	**0.0001**	**0.30±0.15**
- Number of networks/ community organization being members	#	0.39±0.26	0.37±0.24	0.486	0.38±0.25
- Number of networks/market contacts for selling cassava	#	0.21±0.30	0.19±0.23	0.525	0.20±0.27
- Frequency of contacting extension workers and agricultural experts	1-5	0.22±0.27	0.43±0.17	0.0001	0.33±0.25
Livelihood vulnerability (LVI-IPCC)		**0.086 ±0.046**	**0.036 ±0.057**	**0.0001**	**0.060 ±0.052**

4.2.12 The livelihood vulnerability index (LVI- IPCC) of cassava farm households

Results revealed that the average Vulnerability Index under the IPCC framework (LVI-IPCC) for the two districts was 0.060±0.052 (Table 2), signifying moderate vulnerability to climate change and variability among farmers in both areas on the -1 to +1 scale of the IPCC framework. Ea Kar had an LVI-IPCC score of 0.036, whereas Krong Bong scored 0.086. Krong Bong's farming households were significantly more vulnerable to climate change and variability than those in Ea Kar (P<0.0001). This heightened vulnerability in Krong Bong was attributed to greater sensitivity, increased exposure, and lower adaptive capacity compared to farm households in Ea Kar. Notably, financial capital, social capital, psychology, and environmental risks, among the eight main indicators, exhibited substantial discrepancies between the two districts, contributing significantly to the variation in vulnerability levels in the two studied communities.

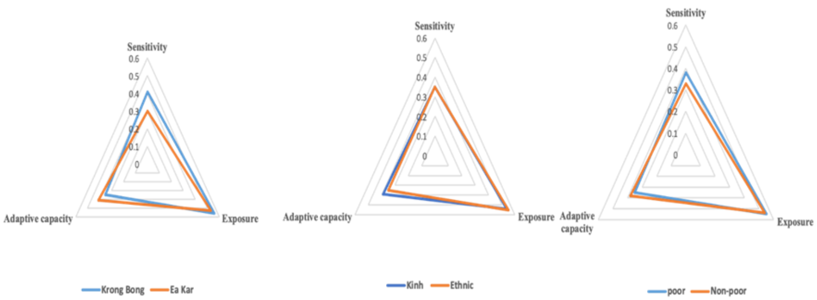

Figure 3a, b, c. Vulnerability triangle diagram of LVI-IPCC for different farming communities in the studied area.

The LVI-IPCC assessed vulnerability for different farmer communities in Krong Bong and Ea Kar districts, considering ethnicity (Kinh and ethnic minority) and household economic classification (poor and non-poor) (Figure 3a, 3b, and 3c, respectively), using a scale from 0 (low) to 0.6 (high). The results revealed that cassava farming households in Krong Bong were more sensitive and exposed to climate change, with lower adaptive capacity compared to those in Ea Kar. Variations in vulnerability levels were also observed among ethnic and economic groups (P<0.05 and P<0.1, respectively). Figures 3b and 4b indicated that ethnic minority farming households were slightly more sensitive and exposed to climate change, with lower adaptive capacity compared to

Kinh, making them more vulnerable. This could stem from several factors, including demographics (higher poverty rate, greater livelihood dependence on cassava), heightened psychology or tension regarding climate risks and lower human capital scores among ethnic minorities compared to the Kinh. Slight differences were also observed in vulnerability triangles for poor and non-poor farming households (Figure 3c). Figures 3c and 4c showed that the poor exhibited higher sensitivity and lower adaptive capacity regarding sociodemographic factors and natural resource use compared to the non-poor, contributing significantly to the difference in vulnerability levels between these two groups.

Figure 4a, b, c. Vulnerability spider diagram of the eight main indicators of the livelihood vulnerability index for different communities in the studied areas

The spider diagrams indicate that physical capital is the primary contributor to the adaptive capacity of farming households in all groups, followed by human capital. Financial and social capital are notably low, signifying financial and social vulnerability across all groups. Additionally, the diagrams reveal that the two main indicators of exposure, vulnerability context, and environmental risks, are consistently high at around 6 for all groups of farming households. This suggests that these households are highly exposed to climate change and variability.

4.3 Determining factors of vulnerability

Poisson regression was conducted for each district and the entire research sample, with LVI-IPCC values as the dependent variable and LVI indicators as the independent variables. Initially, all 26 indicators were included, but 5 were eliminated after a correlation test. The remaining 21 independent variables are presented in Table 3. The VIF for all independent variables ranged from 1.126 to 2.228, with most being less than 2, indicating no multicollinearity or autocorrelation. The adjusted R^2 values were 0.719 for Krong Bong, 0.686 for Ea Kar, and 0.701 for the overall dataset, explaining up to 71.9%, 68.6%, and 70.1% of the variation in the dependent variables by the respective models. Table 3 results revealed that twelve variables, including climate risk perception, frequency of extreme climate events, market risks, environmental shocks, land slope, land area at risk of flooding, climate change knowledge, transportation means, community organizations, market linkage, access to credit, and income diversification, were significant determinants of household livelihood vulnerability in all three cases. Among these, climate risk perception and land slope were the most influential variables, significantly affecting household vulnerability to climate change ($p < 0.001$) with coefficients ranging from 0.11 to 0.46 for the two districts and the overall index. Household income, housing types, and farming experience were important determinants of vulnerability for farming households in Krong Bong and the overall dataset but not for Ea Kar. In contrast, information devices and contact with extension workers were significant determinants of vulnerability for farming households in Ea Kar but not in Krong Bong.

Table 3. Regression results of determinants of LVI-IPCC

Variables	Measurement	Krong Bong		Ea Kar		Overall	
		B	S.E	B	S.E	B	S.E
Constant		-0.043	0.032	-0.04	0.034	-0.025	0.021
Household types	Dummy (0- non-poor household)	0.006	0.011	0.005	0.011	.012*	0.007
Education of household head	Grade	-0.002	0.003	-0.004	0.003	-0.002	0.002
Ethnicity	Dummy (0- Ethnic minority people)	-0.002	0.004	-0.004	0.01	-0.004	0.003
Farming experience	Years of cultivating cassava	-.006**	0.003	-0.001	0.005	-.005**	0.002
Climate change knowledge	Understanding climate change impacts and adaptation (1-5)	-.006*	0.004	-.009**	0.003	-.008***	0.002
Household income	Average household's annual income (Million VND)	-.102**	0.039	-0.016	0.021	-.030**	0.015
Income diversification	Number of income sources	-.030**	0.011	-.037*	0.019	-.034***	0.009
Access to credit	Credit accessibility (1-5)	-.024***	0.007	-.026**	0.009	-.027***	0.005
Tension of climate risks	Worry about climate risks (1-5)	.114***	0.022	.087***	0.026	.075***	0.015
Climate extreme events	Number of extreme events/year	.008**	0.004	.011***	0.003	.010***	0.002
Market risks	Market uncertainty and shock (1-5)	.031***	0.003	.029***	0.004	.029***	0.002
Environmental shocks	Frequency and tensitive of environmental shocks (1-5)	.014***	0.003	.016***	0.004	.013***	0.002
Land slope	Slope household's agricultural land (1-5)	.061***	0.007	.046***	0.01	.055***	0.006
Land area at risks of drought	%	0.008	0.011	-0.01	0.017	-0.006	0.01
Land area at risks of flooding	%	.060***	0.011	.032**	0.013	.044***	0.008
Transportation means	Well-equipped transportation means:(1-5)	-.018***	0.003	-.008**	0.003	-.011***	0.002
House types	Dummy (0- temporary house, 1- concrete house)	-.009***	0.003	-0.004	0.003	-.007***	0.002

Variables	Measurement	Krong Bong		Ea Kar		Overall	
		B	S.E	B	S.E	B	S.E
Information devices and facilities	Well-equipped information devices and facilities (1-5)	-0.001	0.008	-.014**	0.006	-.009**	0.004
Community organizations	Number of community organizations involved	-.008***	0.002	-.005**	0.002	-.008***	0.001
Agricultural extension	Frequency contact extension worker (1-5)	-.011***	0.003	-.007**	0.003	-.009**	0.002
Market linkage	Number of market contacts	-0.002	0.002	-.006**	0.003	- .003***	0.001
Adjusted R2		0.719		0.686		0.701	
F		23.17		19.7		41.59	
S.E		0.023		0.028		0.026	
Sig.		0		0		0	

5. DISCUSSION

The survey of farming households in Krong Bong and Ea Kar - the primary cassava production areas in Dak Lak province, reveals significant climate change impacts on the livelihoods of these communities. Extreme events such as heat stress, drought, floods, and abnormal weather have severely affected cassava farmers, particularly damaging crop production. Rotten cassava roots due to abnormal flooding and increased pests and diseases from drought and abnormal weather are the most serious consequences. This finding supports previous studies by Chaya et al. (2021), Devi et al. (2022), and Graziosi et al. (2016), emphasizing how climate change has led to increased pest and disease pressures, significantly affecting cassava farmers in Africa and Southeast Asia. Using the LVI-IPCC approach, our results highlight differing livelihood vulnerabilities to climate change and variability between the two districts. Despite both districts sharing challenges such as complex topography, high poverty rates, low income, and limited education, Ea Kar, due to its proximity to the town and administrative center, is less vulnerable than Krong Bong. This finding aligns with previous research indicating that livelihood vulnerability varies among farmer communities and districts at different elevations and spatial distributions (Arifah et al., 2022; Huong et al., 2019; Tran V. T. et al., 2021). Krong Bong, characterized by fragmented topography, remoteness, and poor transportation infrastructure, exposes farming households to higher climate risks, including floods, landslides, and drought. The district also faces a higher poverty rate, increased climate risk tension, a greater dependency ratio, and challenges accessing markets and information centers, resulting in greater sensitivity compared to Ea Kar. Additionally, Krong Bong exhibits lower adaptive capacity, influenced by factors such as human, physical, natural, financial, and social resources. The LVI analysis also showed a difference in levels of vulnerability between the Kinh and Ethinic minority groups and between the poor and non-poor groups. Although they have the same spatial distribution with the same vulnerable context and environmental problems, the difference in vulnerability among groups was, thus, derived from the endogenous factors such as psychology, sociodemographic and adaptive capacity. This aligns with the work of Arifah et al. (2022), Tran T. P. et al. (2023), and Tran Van Thanh. et al., (2021).

The economically disadvantaged are more psychologically vulnerable to climate change risks due to limited physical, natural, and social resources compared to the more affluent. In-depth interviews revealed that impoverished individuals in these areas have unstable, low incomes and limited access to credit, resulting in insufficient financial resources for essential adaptation strategies such as certified cassava seeds, mulching, organic fertilizers, and land preparation techniques. Most farming households, particularly those with lower incomes, rely on low-quality cassava seeds from previous crops or neighboring sources, which lack guarantees in terms of productivity and resistance to pests and diseases. Consequently, the economically disadvantaged face higher climate change risks and stress levels compared to their more prosperous counterparts, corroborating findings from Sen et al., (2020) and Wilts et al., (2021). Ethnic minorities are more susceptible to climate change and variability than the Kinh ethnic group. Survey results demonstrated that ethnic minority households possess lower human capital and fewer physical and natural resources compared to the Kinh people. This finding supports results from Rahman et al., (2023) in West China and a study by Tran T. P. et al., (2023) in Vietnam's central region.

Regression analysis results revealed that climate risk tension significantly determined livelihood vulnerability in Krong Bong (B=0.11), Ea Kar (B=0.87), and overall (B=0.75) (Luu et al., 2021; Duan et al., 2022; Wubalem, 2021). The districts' fragmented topography and sloping agricultural lands, particularly in Krong Bong, increased susceptibility to drought, floods, soil erosion, and land degradation. A high proportion of farmers in both areas lacked knowledge about climate change impacts and adaptation strategies, with 87% and 68% in Krong Bong and Ea Kar, respectively, having not participated in climate change-related trainings. Although all respondents recognized weather changes and extreme events, most were unaware of potential impacts and available adaptation strategies. Their cassava farming decisions were primarily based on personal experience, advice from previous generations, or neighborly guidance. This lack of understanding, compounded by socioeconomic factors, rendered the poor and ethnic minority communities more sensitive and vulnerable to climate change (Arifah et al., 2022; Nguyen et al., 2019; Tran T. P. et al., 2023). To address this vulnerability, local government, extension agents, and the department of agricultural and rural development should integrate climate change information, adaptation best-practices, and demonstrations relevant to local farmers into their annual work plans to facilitate learning and adoption.

The regression results revealed that membership in community organizations and frequent contact with extension workers significantly affect farming household vulnerability. Greater involvement in these organizations and more frequent contact with extension staff lead to reduced vulnerability. Village leaders during group discussions explained that participation in community organizations allows farmers to share problems and receive advice, suggestions, and support from fellow members. They also highlighted that contact with extension staff not only provides production technology advice but also facilitates better market linkages for cassava root pricing. This finding reinforces the role of extension agents in building climate change resilience for farming households, as noted by Antwi-Agyei & Stringer (2021) and Kamruzzaman et al. (2021). However, a limited percentage of farmers in both districts (57% in Ea Kar and 78% in Krong Bong) had contact with extension staff or engagement with stakeholders in agricultural production and consumption. Farmers primarily rely on personal experience and parental wisdom, eschewing advice from technical advisors. Similar results were found in the upland areas of Thua Thien Hue province, Vietnam, by Le et al., (2021).

Market linkages, transportation, and market uncertainty significantly affect farming households' vulnerability. More links to cassava markets and better transportation (e.g., Cong Nong vehicles) reduce vulnerability. However, due to high poverty (>50%) and low income (136.5-148.6 million VND per year), few farmers, especially those in Krong Bong, own a Cong Nong vehicle. This forces them to sell cassava products at lower prices. Krong Bong's farmers also struggle with market uncertainty due to isolation, difficult terrain, and poor roads. These factors significantly contribute to the vulnerability of farming households (Tran Van Thanh et al., 2021). Farmers recommend that the government prioritize infrastructure improvements for isolated communities, enhancing market access. Additionally, they suggest implementing credit programs and providing cassava seedlings to mitigate climate-related risks. Improved roads would facilitate visits by extension workers and foster collaboration between farmers and external partners.

Income diversification significantly reduced the vulnerability of farming households (Table 3). For each additional source of income, livelihood vulnerability decreased by 0.034 on the IPCC vulnerability scale. Unlike Ea Kar, Krong Bong farming households had larger agricultural land holdings and relied more heavily on agriculture for their livelihoods. Consequently, they exhibited less income diversity and greater vulnerability. This finding aligns with numerous prior studies, which consistently report that households with greater income source diversification experience reduced livelihood vulnerability (Huynh et al., 2021a; Huynh et al., 2021b; Tran T. P. et al., 2023).

6. CONCLUSIONS AND IMPLICATIONS

This paper explores climate change vulnerability among cassava farming households in two upland districts in Dak Lak province, Vietnam. We utilize Hahn's LVI framework (2009) based on the IPCC definition to calculate the vulnerability index (LVI-IPCC) for Krong Bong and Ea Kar districts. The LVI-IPCC in this study comprises 8 main indicators, 25 sub-indicators, and 3 contributing factors. ANOVA analysis compared vulnerability levels between the districts, as well as among different socioeconomic groups. Additionally, a Poisson regression model assessed determinants of vulnerability in farming households.

The analysis revealed that cassava farmers in Krong Bong and Ea Kar districts are moderately susceptible to climate change and variability. Prominent extreme events such as prolonged droughts, floods, and abnormal weather have resulted in increased pest infestations, diseases, spoiled cassava crops, and soil erosion. The LVI-IPCC results indicate that communities with a higher proportion of poor and ethnic minority populations were more susceptible to climate change and variability. The poor and ethnic minority farming households are particularly vulnerable across all three contributing factors (sensitivity, exposure, and adaptive capacity). Out of the eight primary indicators, farming households in both districts exhibit moderate vulnerability in terms of environmental risks (Er), vulnerable context (Vc), sociodemographic (Sd), financial resources (F), and social resources (S). However, they are less vulnerable in terms of human resources (H), physical and natural resources (PN), and psychology. The most vulnerable aspects are related to annual income, market connections, access to credit, income diversity, and awareness of climate change. Krong Bong is more vulnerable than Ea Kar in all eight aspects. Furthermore, ethnic minorities are more vulnerable than the Kinh people concerning human capital, physical and natural capital, sociodemographics, and psychology. The limited interaction of farming households with extension agents and local government has resulted in a high percentage of farmers lacking information about potential climate change impacts and available adaptation strategies.

Livelihood vulnerability levels varied significantly among farming groups (by district, ethnicity, and economic classification) with p-values of <0.001, 0.05, and 0.1, respectively. The primary driver of this variation was the geographical location of these communities. Those residing closer to urban and administrative centers displayed lower vulnerability to climate change due to improved access to climate information, services, technology, and market resources related to cassava products, bolstering their adaptive capacity.

The Poisson model analyzing household livelihood vulnerability determinants identified key factors: climate risk tension, extreme climate events frequency, market risks, environmental shocks, land slope, flood-prone land area, climate knowledge, transportation, market access, credit availability, and income diversification. Frequent contact with extension agents and community network participation are vital for accessing climate info and support. In Ea Kar, households had more contact with extension workers and implemented more adaptation measures (certified seeds, crop rotation, organic fertilization) than in Krong Bong.

The above findings are crucial for policymakers, agricultural practitioners, and scientists aiming to reduce vulnerability and enhance climate resilience among cassava farming households in the central highlands, particularly in remote communities. First, policies and activities must focus on increasing awareness of potential climate change impacts and adaptation strategies among remote upland farmers. This should involve existing information channels, such as national and local media, community networks, and integrating climate change into relevant department plans. This will provide timely and accessible climate information. Secondly, national and local adaptation plans should prioritize support for economically vulnerable upland communities, which are more susceptible to climate change and have limited coping capacity. Third, the government should enhance the capacity of extension staff to collaborate with ethnic communities, offering tailored climate response programs and effective communication tools. This will aid farming households in making adaptation decisions. Fourth, there should be a focus on improving transportation systems to connect remote communities with markets, information services, and administrative centers. Fifth, income-boosting policies should be designed to diversify income sources, encourage community participation, strengthen collaboration with cassava starch companies, and build household assets, with a priority on the poor and ethnic minority households. These households should receive training to enhance their skills and capacity for diversified livelihood activities and higher off-farm earnings. They should also demonstrate adaptation best practices suitable for their socio-economic conditions. Finally, it is important to note that this study used cross-sectional data from household surveys to compute the Livelihood Vulnerability Index (LVI), providing a snapshot of one year. Given the rapidly changing socio-economic conditions, especially policies affecting access to natural resources and land ownership, this may not reflect long-term livelihood development and adaptive capacity for cassava-dependent households. Additionally, this study employed the balanced weight method to compute the LVI instead of unbalanced weighted techniques like Analytic Hierarchy Process (AHP) or Principal Component Analysis (PCA). Future research should consider these factors for a more comprehensive exploration of livelihood vulnerability and opportunities to enhance climate adaptive capacity for all farmers.

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REFERENCES

Antwi-Agyei, P., & Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management, 32,* 100304. https://doi.org/10.1016/j.crm.2021.100304

Anyaegbu, C. N., Okpara, K. E., Taweepreda, W., Akeju, D., Techato, K., Onyeneke, R. U., ... & Pongpiachan, S. (2022). Impact of climate change on cassava yield in Nigeria: An autoregressive distributed lag bound approach. *Agriculture, 13*(1), 80. https://doi.org/10.3390/agriculture13010080

Ayoade, A. R. (2012). Determinants of climate change on cassava production in Oyo State, Nigeria. *Global Journal of Science Frontier Research, Agriculture & Biology, 12*(D3), 45–49.

Bai, D., Ye, L., Yang, Z., & Wang, G. (2022). Impact of climate change on agricultural productivity: a combination of spatial Durbin model and entropy approaches. *International Journal of Climate Change Strategies and Management.* https://doi.org/10.1108/IJCCSM-02-2022-0016

Bandara, J. S., & Cai, Y. (2014). The impact of climate change on food crop productivity, food prices and food security in South Asia. *Economic Analysis and Policy, 44*(4), 451-465. https://doi.org/10.1016/j.eap.2014.09.005

Chaya, M., Xiang, T., Green, A., & Gu, B. (2021). Impact of climate change on pests of rice and cassava. *CABI Reviews.* https://doi.org/10.1079/pavsnnr20 2116050

Dak Lak PPC. (2023). *Socio-economic developemt report of the year 2022*. The Provincial People Committee of Dak Lak. Retrieved from https://dbnd.daklak.gov.vn/

Devi, B., Kumar, M. N., Chutia, M., & Bhattacharyya, N. (2022). Abiotic and biotic stress challenges of Cassava in changing climate and strategies to overcome: A review. *Scientia Horticulturae, 305,* 111432. https://doi.org/10.1016/j.scienta.2022.111432

Dinh, Q., Balica, S., Popescu, I., & Jonoski, A. (2012). Climate change impact on flood hazard, vulnerability and risk of the Long Xuyen Quadrangle in the Mekong Delta. *International journal of river basin management, 10*(1), 103-120. https://doi.org/10.1080/15715124.2012.663383

Dinh, T. L. A., Aires, F., & Rahn, E. (2022). Statistical analysis of the weather impact on Robusta Coffee Yield in Vietnam. *Frontiers in Environmental Science, 10,* 820916. https://doi.org/10.3389/fenvs.2022.820916

Do, V. Q., Phung, M. L., Truong, D. T., Pham, T. T. T., Dang, V. T., & Nguyen, T. K. (2021). The impact of extreme events and climate change on agricultural and fishery enterprises in Central Vietnam. *Sustainability, 13*(13), 7121. https://doi.org/10.3390/su13137121

Duan, L., Liu, C., Xu, H., Pan, H., Liu, H., Yan, X., ... & Lu, H. (2022). Susceptibility assessment of flash floods: a bibliometrics analysis and review. *Remote Sensing,* *14*(21), 5432. https://doi.org/10.3390/rs14215432

Emenyonu, C. A., Eze, C. C., & Ejike, O. U. (2020). Factors influencing cassava farmers' climate change risk perception in anambra state, Nigeria. *American Journal of Climate Change, 9*(3), 217-227. https://doi.org/10.4236/ajcc. 2020.93014

Emmanuel, O. E., Ogonna, I. C., & Chukwuemeka, E. N. (2023). Climate Change Impacts and Adaptation Strategies of Cassava Farmers in Ebonyi State, Nigeria: Climate Change Impacts and Adaptation Strategies of Cassava Farmers. *Journal of Agricultural Extension, 27*(1), 35-48.

Graziosi, I., Minato, N., Alvarez, E., Ngo, D. T., Hoat, T. X., Aye, T. M., ... & Wyckhuys, K. A. (2016). Emerging pests and diseases of South-east Asian cassava: a comprehensive evaluation of geographic priorities, management options and research needs. *Pest Management Science, 72*(6), 1071-1089. https://doi.org/10.1002/ps.4250

GSO. (2023). *Socio- Economic situation of Vietnam in the fourth quarter 2020 and the whole year 2019*. General Statistics Office of Vietnam.

Gullino, M. L., Albajes, R., Al-Jboory, I., Angelotti, F., Chakraborty, S., Garrett, K. A., ... & Stephenson, T. (2022). Climate change and pathways used by pests as challenges to plant health in agriculture and forestry. *Sustainability, 14*(19), 12421. https://doi.org/10.3390/su141912421

Hahn, M. B., Riederer, A. M., & Foster, S. O. (2009). The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Global environmental change, 19*(1), 74-88. https://doi.org/10.1016/j.gloenvcha.2008.11.002

Huong, N. T. L., Yao, S., & Fahad, S. (2019). Assessing household livelihood vulnerability to climate change: The case of Northwest Vietnam. *Human and Ecological Risk Assessment: An International Journal, 25*(5), 1157-1175. https://doi.org/10.1080/10807039.2018.1460801

Huynh, P. T., Le, N. D., Le, S. T., & Nguyen, H. X. (2021). Vulnerability of fishery-based livelihoods to climate change in coastal communities in central Vietnam. *Coastal Management, 49*(3), 275-292. https://doi.org/10.1080/08920753.2021.1899927

Huynh, P. T., Le, N. D., Le, S. T., & Tran, T. N. (2021a). Adaptive livelihood strategies among small-scale fishing households to climate change-related stressors in Central Coast Vietnam. *International Journal of Climate Change Strategies and Management, 13*(4/5), 492-510. https://doi.org/10.1108/IJCCSM-04-2020-0034

IPCC. (2001). *Climate Change Synthesis Report.* Cambridge University Press.

Kamruzzaman, M., Daniell, K. A., Chowdhury, A., & Crimp, S. (2021). The role of extension and advisory services in strengthening farmers' innovation networks to adapt to climate extremes. *Sustainability, 13*(4), 1941. https://doi.org/10.3390/su13041941

Khoi, D. N., & Hang, P. T. T. (2015). Uncertainty assessment of climate change impacts on hydrology: a case study for the central highlands of Vietnam. In Shrestha, S., Anal, A. K., Salam, P. A. & van der Valk, M. (Eds.), *Managing water resources under climate uncertainty: examples from Asia, Europe, Latin America, and Australia* (pp. 31-44). Springer.

Khoi, D. N., & Thom, V. T. (2015). Impacts of climate variability and land-use change on hydrology in the period 1981-2009 in the Central Highlands of Vietnam. *Global Nest Journal, 17*(4), 870-881.

Kim, H., Mai, N. T. T., Mai, N. B., & Howeler, R. (2015). Cassava conservation and sustainable development in Vietnam. *In Cassava production in Asia for multiple* *uses and for multiple markets. Proceedings of the Ninth Regional Cassava Workshop* (Vol. 27, pp. 35-56), Nanning, Guangxi, China PR.

Kim, H., Van Bien, P., Howeler, R. H., Wang, J. J., Ngoan, T. N., Kawano, K., & Ceballos, H. (2005). *The history and developments of the cassava sector in Vietnam.* CGIAR.

Kurukulasuriya, P., & Rosenthal, S. (2003). *Climate change and agriculture*. World Bank Environment Department Paper, 91. The World Bank.

Lindenberg, M. (2002). Measuring household livelihood security at the family and community level in the developing world. *World development, 30*(2), 301-318. https://doi.org/10.1016/S0305-750X(01)00105-X

Luu, C., Ha, H., Bui, Q. D., Luong, N. D., Khuc, D. T., Vu, H., & Nguyen, D. Q. (2023). Flash flood and landslide susceptibility analysis for a mountainous roadway in Vietnam using spatial modeling. *Quaternary Science Advances, 11,* 100083. https://doi.org/10.1016/j.qsa.2023.100083

MARD. (2022). Worthy strategies needed for casava sustainable development. MARD. Retrieved from https://vietnamagriculture.nongnghiep.vn/worthy-strategies-needed-for-cassava-sustainable-development-d320200.html

Mupakati, T., & Tanyanyiwa, V. I. (2017). Cassava production as a climate change adaptation strategy in Chilonga Ward, Chiredzi District, Zimbabwe. *Jàmbá: Journal of Disaster Risk Studies, 9*(1), 1-10.

Nguyen, H. V., Nguye, X. L., and Nguye, V. D. (2015). *Mối quan hệ bất hoà? phát triển cây sắn- sinh kế người dân và tài nguyên rừng.* Trung tâm Con người và Thiên nhiên (PanNature) và Tổ chức Forest Trends. Retrieved from https://nature.org.vn/vn/wp-content/uploads/2015/08/PAN_FT_Seminar_CassavavsForestProtection_Report_17072015_Final.pdf.

Nguyen, T. A., Nguyen, B. T., Van Ta, H., Nguyen, N. T. P., Hoang, H. T., Nguyen, Q. P., & Hens, L. (2021). Livelihood vulnerability to climate change in the mountains of Northern Vietnam: comparing the Hmong and the Dzao ethnic minority populations. *Environment, Development and Sustainability, 23,* 13469–13489. https://doi.org/10.1007/s10668-020-01221-y

Nguyen, T. T. T., Khoi, D. N., Xuan, T. T., & Tychon, B. (2019). Assessment of livelihood vulnerability to drought: A case study in Dak Nong Province, Vietnam. *International Journal of Disaster Risk Science, 10*, 604-615. https://doi.org/10.1007/s13753-019-00230-4

Nui, N. H., Bien, V. T., Trung, N. D., Lua, T. H., Cuong, N. T., Spillane, C., ... & Le Vinh, B. (2020). Cassava Farmers' Perception on Climate Change: A Case Study in Van Yen District, Yen Bai Province*. Vietnam Journal of Agricultural Sciences, 3*(3), 700-711. https://doi.org/10.31817/vjas.2020.3.3.04

Rahman, M. M., Arif, M. S. I., Hossain, M. T., Almohamad, H., Al Dughairi, A. A., Al-Mutiry, M., & Abdo, H. G. (2023). Households' vulnerability assessment: empirical evidence from cyclone-prone area of Bangladesh. *Geoscience letters, 10*(1), 26. https://doi.org/10.1186/s40562-023-00280-z

Salman, D., Yassi, A., & Demmallino, E. B. (2022). Livelihood vulnerability of smallholder farmers to climate change: A comparative analysis based on irrigation access in South Sulawesi, Indonesia. *Regional Sustainability, 3*(3), 244-253. https://doi.org/10.1016/j.regsus.2022.10.002

Sen, L. T. H., Bond, J., & Hoang, H. D. T. (2023). Exploring smallholder farmers' climate adaptation decision-making in mountainous areas of Central Vietnam: implications for extension services. *The Journal of Agricultural Education and Extension, 29*(2), 247-268. https://doi.org/10.1080/1389224X.2022.20 39248

Sen, L. T. H., Bond, J., Phuong, L. T. H., Winkel, A., Tran, U. C., & Le, N. V. (2021). The importance of climate change awareness for the adaptive capacity of ethnic minority farmers in the mountainous areas of Thua Thien Hue province. *Local Environment, 26*(2), 239-251. https://doi.org/10.1080/13549839.2021.1886064

Sen, L. T. H., Bond, J., Winkels, A., Linh, N. H. K., & Dung, N. T. (2020). Climate change resilience and adaption of ethnic minority communities in the upland area in Thừa Thiên-Huế province, Vietnam. *NJAS-Wageningen Journal of Life Sciences, 92,* 100324. https://doi.org/10.1016/j.njas.2020.100324

Shen, J., Duan, W., Wang, Y., & Zhang, Y. (2022). Household livelihood vulnerability to climate change in west China. *International Journal of Environmental Research and Public Health, 19*(1), 551. https://doi.org/10.3390/ijerph190 10551

Tan, P. V., Thanh, N. D., and Hiep, N. V. (2013). *A review of evidence recent climate change in the Central Highlands of Vietnam.* Coffee and Climate.

Tran, T. P., Tan, N. Q., Dinh, N. C., Van Chuong, H., Ha, H. D., & Hung, H. T. (2023). Livelihood vulnerability to climate change: Indexes and insights from two ethnic minority communities in Central Vietnam. *Environmental Challenges, 10,* 100666. https://doi.org/10.1016/j.envc.2022.100666

Tran, Van Thuong., Tran, D. X., & Nguyen, D. B. (2023). Agricultural drought in the Vietnamese Central Highlands at 1-km resolution: Monthly and annual datasets. *Data in Brief, 48,* 109194. https://doi.org/10.1016/j.dib.2023. 109194

Tran, Van Thanh., An-Vo, D. A., Cockfield, G., & Mushtaq, S. (2021). Assessing livelihood vulnerability of minority ethnic groups to climate change: A case study from the northwest mountainous regions of Vietnam. *Sustainability, 13*(13), 7106. https://doi.org/10.3390/su13137106

Urothody, A. A., & Larsen, H. O. (2010). Measuring climate change vulnerability: a comparison of two indexes. *Banko Janakari, 20*(1), 9-16.

Wilts, R., Latka, C., & Britz, W. (2021). Who is most vulnerable to climate change induced yield changes? A dynamic long run household analysis in lower income countries. *Climate Risk Management, 33*, 100330. https://doi.org/10.1016/j.crm.2021.100330

Wubalem, A. (2021). Landslide susceptibility mapping using statistical methods in Uatzau catchment area, northwestern Ethiopia. *Geoenvironmental Disasters, 8*(1), 1. https://doi.org/10.1186/s40677-020-00170-y