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ASSESSMENT OF VULNERABILITY AND RISKS CAUSED BY CLIMATE CHANGE IMPACTS ON RESOURCES, THE ENVIRONMENT, AND SOCIO-ECONOMIC CONDITIONS: A CASE STUDY OF ETHNIC MINORITY AND MOUNTAINOUS COMMUNES IN THUA THIEN HUE PROVINCE (VIETNAM)

Abstract: The study was conducted in ethnic minority and mountainous communes of Thua Thien Hue (A Luoi and Nam Dong), where fragmented terrain is prone to flash floods, landslides, and droughts. The population depends on agriculture and forestry but is highly affected by climate change. Using a research-based approach, the study assesses hazard, exposure, sensitivity, and adaptive capacity to determine vulnerability and risk levels. Very high vulnerability covers 6.82% of the area, mainly in A Luoi (74.03%), 2.85 times higher than Nam Dong. High vulnerability accounts for 21.43%, with A Luoi (82.48%) exceeding Nam Dong (17.52%) by 4.71 times. Very high-risk areas make up 4.69%, with Nam Dong (56.35%) surpassing A Luoi (43.65%) by 1.29 times. High-risk areas (13%) are concentrated in A Luoi, 2.58 times higher than Nam Dong. To reduce impacts, key measures include forest conservation, infrastructure upgrades, disaster warnings, and sustainable livelihoods.

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Key words: climate change, vulnerability level, risk level, ethnic minorities, A Luoi district, Nam Dong district

INTRODUCTION

Climate change has become one of the greatest challenges to global sustainable development. According to the Intergovernmental Panel on Climate Change (IPCC), climate change increases the frequency and intensity of extreme events such as storms, floods, droughts, soil erosion, and sea level rise, severely impacting natural resources, the environment, and human livelihoods. To comprehensively evaluate the impacts of climate change, the IPCC formulated a structured framework based on four key factors: hazard, exposure, sensitivity, and adaptive capacity (IPCC 2014, 2022; Pedersen et al. 2022). G. Yohe and R.S.J. Tol (2002) also emphasized that the vulnerability of a region depends on its adaptive capacity and level of exposure to natural hazards. According to W.N. Adger (2006), climate change vulnerability is not only linked to environmental conditions but is also influenced by socioeconomic factors and risk management capacity. Several international organizations, including the United Nations Development Programme (2022), the World Bank (2021), and the National Oceanic and Atmospheric Administration (2023), have conducted studies to determine vulnerability and risks, thereby proposing appropriate adaptation strategies.

In recent decades, climate change impacts have intensified globally, posing increasingly urgent challenges. According to the World Economic Forum (2023), climate change is considered one of the top threats to food security, water resources, and socio-economic development. Research by A. Haque et al. (2021) indicates that developing countries are more vulnerable to climate change due to a lack of infrastructure and adaptive resources. K. O'Brien et al. (2004) emphasized that the increasing frequency and intensity of extreme weather events can exacerbate issues related to poverty and inequality. Southeast Asia, including Vietnam, is projected to experience significant impacts such as extreme rainfall, landslides, flash floods, and prolonged droughts (Raitzer et al. 2021). Developed nations such as Japan (Hasegawa et al. 2012; Chen, Fujita 2013), the United States (Ahn et al. 2021; Sorensen 2000), and Australia (Anderson-Berry et al. 2018) have established early warning systems and resilient infrastructure. In contrast, many developing countries in South and Southeast Asia still lack comprehensive assessments of vulnerability and risks. Recent studies in Southeast Asia have provided valuable insights into regional disaster risk assessment and management. For instance, research conducted in Lao PDR (Phrakonkham 2020), Thailand (Inpin, Dania 2023), Cambodia (Phy et al. 2022), and Myanmar (Tun, Lassa 2023) highlights diverse approaches to integrating climate change considerations, governance structures, and spatial planning in disaster risk reduction. Incorporating such regional studies would enhance the comparative perspective of this paper and improve its relevance to the socio-environmental conditions of Central Vietnam. This lack of comprehensive assessments presents a critical barrier to developing effective adaptation and mitigation strategies (Kreft et al. 2017).

In Vietnam, climate change is severely affecting mountainous and coastal areas. According to the Ministry of Natural Resources and Environment (2021), the frequency of natural disasters has significantly increased, including flash floods, droughts, saltwater intrusion, and landslides. Notably, the central region, including Thua Thien Hue province, has been identified as one of the most vulnerable areas due to its steep terrain, dense river network, and frequent exposure to storms and floods. A study indicated that Central Vietnam has the highest level of vulnerability compared to other regions in the country, with disaster risks associated with sea level rise, typhoons, floods, and droughts (Son, Quan 2021). N.H. Son et al. (2019) also emphasized that the western mountainous areas of Central Vietnam, including Thua Thien Hue, are severely impacted due to complex terrain, challenging transportation conditions, and the degradation of forest ecosystems. The Ministry of Natural Resources and Environment[1] has introduced a vulnerability assessment framework based

[1] *Circular No. 01/2022/TT-BTNMT dated January 7, 2022, of the Minister of Natural Resources and Environment on detailed regulations for the implementation of the Environmental Protection Law and response to climate change* (2022).

on three key components: exposure, sensitivity, and adaptive capacity, similar to the IPCC model but adjusted to fit the Vietnamese context.

A Luoi and Nam Dong districts, home to numerous ethnic minority communities such as Pa Co, Co Tu, Ta Oi, and Bru-Van Kieu, rely primarily on agriculture and forestry for their livelihoods. However, they are increasingly facing livelihood loss due to climate change (Le et al. 2019). The region's infrastructure remains underdeveloped, significantly increasing vulnerability and risk levels. During the heavy rainfall in early October 2020, prolonged heavy rainfall triggered 37 severe landslides across Thua Thien Hue province, mainly in mountainous districts such as A Luoi and Nam Dong. Specifically, seven landslides were recorded along the Ho Chi Minh Highway in A Luoi, while four occurred in Nam Dong, particularly around the Ka Tu Pass and inter-village roads in Huong Phu commune, disrupting transportation and threatening residential safety (Hanoi Institute for Socio-Economic Development Studies 2020). These events highlight the increasing susceptibility of upland communities to climate-related disasters. Given the lack of comprehensive studies on vulnerability and risk in ethnic minority and mountainous communes of Thua Thien Hue province, this research is of critical importance. It not only helps identify high-risk areas but also serves as a foundation for proposing adaptation measures such as strengthening forest protection, upgrading transportation and irrigation infrastructure, improving early warning systems, and promoting sustainable livelihood support. A thorough assessment of vulnerability and risk is essential for safeguarding local livelihoods while contributing to effective planning and sustainable development in the face of increasingly complex climate change impacts.

Therefore, it is essential to conduct research that assesses vulnerability and risk associated with climate change impacts on natural resources, the environment, and socio-economic conditions, using ethnic minority and mountainous communes in Thua Thien Hue province as representative case studies. The findings will serve as a scientific and practical basis for enhancing management capacity and developing effective climate change adaptation policies.

RESEARCH METHODOLOGY

The component-based methodology serves as a fundamental approach for assessing vulnerability to climate change and developing adaptation strategies. The IPCC employs this approach to analyze three key factors: Exposure, Sensitivity, and Adaptive Capacity, forming an assessment framework that helps nations identify the factors influencing vulnerability (IPCC 2014; 2022). The United Nations Development Programme (2017) has applied this method in multiple projects across developing countries, focusing on impoverished communities affected by droughts and sea level rise. The World Bank (2018) has adopted this approach to evaluate urban resilience, particularly in coastal cities of Southeast Asia. The German Agency for International Cooperation (2020) integrates both quantitative and qualitative data to assess the impacts of climate change on agriculture, water resources, and livelihoods in Vietnam, Bangladesh, and the Philippines. The widespread application of this approach highlights its effectiveness in supporting nations and communities in developing climate change adaptation solutions.

In this study, the assessment of climate change vulnerability follows the guidelines of the IPCC (2014), combined with the regulations of the Vietnamese Ministry of Natural Resources and Environment (2022) to align with the study area's context. The original IPCC framework was adapted because certain indicators and data requirements are not fully compatible with the available socio-economic and environmental datasets in Vietnam. This adjustment allows the framework to better capture local characteristics, integrate national climate data, and enhance the practical applicability of results for regional planning and policy implementation.

Development and standardization of indicators

In the initial phase, vulnerability indices are standardized and aggregated. This process brings different measurements onto a common scale (0–1). The hazard, exposure, sensitivity, and adaptive capacity indices are separately standardized, with their relationships to vulnerability identified as either positive (direct) or negative (inverse). Specifically, hazard, exposure, and sensitivity indices have a positive correlation with vulnerability, meaning that as their values increase, vulnerability also increases. In contrast, adaptive capacity has a negative correlation, where an increase in its value reduces vulnerability. Researchers determine these relationships through literature reviews, expert opinions, and empirical observations. For positively correlated indices, standardization follows the min-max normalization method within the study area's range. Conversely, for negatively correlated indices, the normalization formula is inverted to reflect the mitigating impact of increased adaptive capacity on vulnerability (Table 1).

Table 1. Normalization of indicators

No.	Main indicator	Sub-indicator	Normalization formula applied
1.	Hazard index	Temperature change by 2100	(1)
		Precipitation change by 2100	(1)
		Flash floods	(1)
		Droughts	(1)
2.	Exposure index	Accessibility to transportation	(1)
		Exposure level of cultivated areas	(1)
		Impact on residential areas	(1)
		Impact on industrial zones	(1)
3.	Sensitivity index	Community dependence level	(1)
		Soil conditions	(1)
		Water demand	(1)
		Access to information index	(2)
4.	Adaptive capacity	Financial capacity	(2)
		Technological capacity	(2)
		Organizational capacity	(2)

Source: own elaboration.

The second phase of the climate change vulnerability assessment process involves determining the weights of component indicators to reflect the importance and influence of each indicator in the vulnerability calculation. Various methods can be used for weighting, but the most common approach is the Analytic Hierarchy Process (AHP), developed by Saaty in 1980. AHP utilizes a pairwise comparison matrix, where indicators are evaluated based on their relative importance using a scale from 1 to 9. The values in the matrix are then normalized to compute the average weight of each factor (Saaty 1980).

After constructing the pairwise comparison matrix, the weights are calculated by normalizing the matrix values and averaging them by row. The consistency of the matrix is verified through the Consistency Ratio (CR), which is computed based on the Consistency Index (CI) and the Random Index (RI) (Voogd 1983). If $CR < 0.1$, the weight set is considered reliable; otherwise, the evaluation process needs to be adjusted to ensure consistency. This method ensures that the assigned weights are determined objectively, thereby enhancing the accuracy of climate change vulnerability assessments.

Formulas for calculating vulnerability and risk levels, and field survey methodology

The third phase of the climate change vulnerability assessment process involves calculating the vulnerability and risk indices. Once the component indicators have been normalized and weighted, the vulnerability index is computed using a composite formula, in which the normalized values of each component are multiplied by their respective weights.

The vulnerability index (V) is determined based on sensitivity (S) and adaptive capacity (AC), using the following formula: $V = (S+(1-AC))/2$. This equation reflects the principle that vulnerability increases when sensitivity is high and adaptive capacity is low.

Meanwhile, the risk index (R) is calculated as the mean value of three key factors: hazard (H), exposure (E), and vulnerability (V), expressed as: $R = (H + E + V)/3$. This calculation provides a spatially explicit assessment of risk levels, facilitating the development of targeted adaptation strategies for regions affected by climate change.

To verify, supplement, and refine the analytical results and map development, the research team conducted four field surveys from 2020 to 2023 in A Luoi and Nam Dong districts, focusing on areas highly vulnerable to climate change. The collected data provided additional insights into the vulnerability levels and the actual impacts of climate change on ethnic minority and mountainous communities in Thua Thien Hue province. In addition, the research team interviewed ethnic minority households in the area based on three criteria: being an ethnic minority, having agricultural land affected by climate change, and being able to communicate normally with farming experience. The sample was randomly selected using Slovin's formula: $n = N/(1 + Ne^2)$ (where n is the required number of households for interviews, N is the total number of households meeting the three criteria, and e is the margin of error, with $e = 0.05$). With a total of 3,004 ethnic minority households, the calculated sample size was 353 households. The households were randomly selected from the list of ethnic minority farmers provided by the commune-level People's Committees. During the sampling process, the research team also ensured that the ethnic composition of the interviewed households roughly reflected the actual population distribution of the two districts: Ta Oi accounted for about 35%, Pa Co 25%, Co Tu 20%, and Bru–Van Kieu 20%. This approach ensured the representativeness of the sample, allowing the analytical results to accurately reflect the livelihood characteristics and vulnerability levels of each ethnic group in the study area. The interviews were conducted in Vietnamese using a semi-structured questionnaire covering four main aspects: household information (name, age, gender, education, economic status), perceptions of climate change and natural disasters (measured using a Likert scale), impacts of disasters on socio-economic conditions and the environment, and expectations and recommendations for production support and disaster response strategies.

STUDY AREA

The ethnic minority and mountainous communes of Thua Thien Hue province are located in the western part of the province, specifically within Nam Dong and A Luoi districts. This region lies along the Truong Son mountain range and shares a border with the Lao People's Democratic Republic. It is situated in the central region of Vietnam (Fig. 1). According to *Decision No. 861/QD-TTg Approving the list of communes in Region III, Region II, Region I in ethnic minority and mountainous areas for the period 2021–2025* (2021), Thua Thien Hue province has 24 communes classified as ethnic minority and mountainous areas for the 2021–2025 period, including 14 communes in Category III and 71 extremely difficult villages[2]. The Pa Co, Ta Oi, Co Tu, and Bru Van Kieu ethnic groups live in this region. Their presence contributes to socio-cultural diversity (Son et al. 2022). The area holds

[2] From January 1, 2025, Thua Thien Hue province was officially renamed Hue City (*Resolution No. 175/2024/QH15 on the establishment of Hue City as a centrally governed city* 2024). However, since this study utilizes historical data collected prior to 2025, the term Thua Thien Hue province is retained throughout the research instead of Hue City to ensure consistency with the dataset.

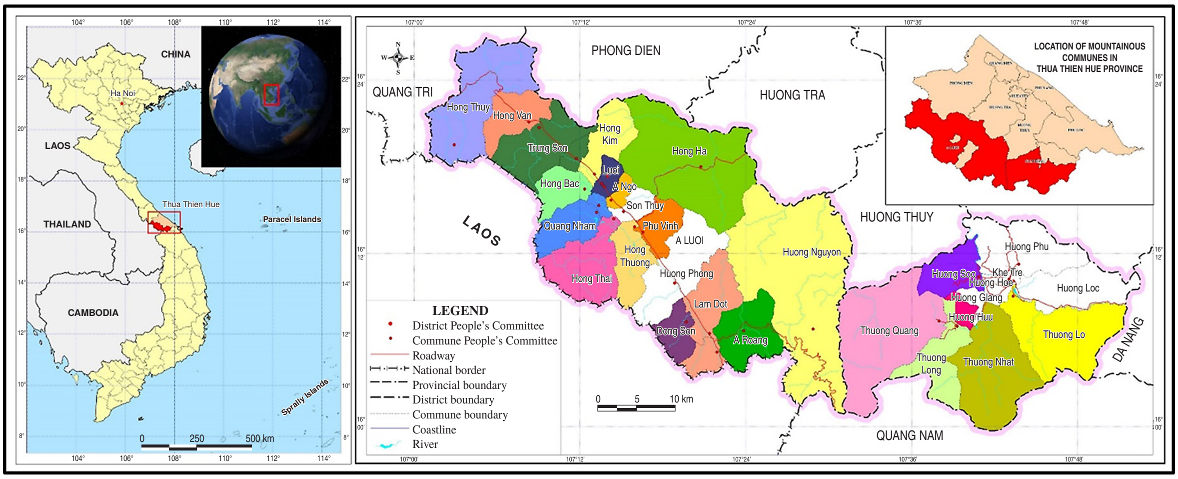


Fig. 1. Study area location
Source: own elaboration.

significant economic development potential while also playing a strategic role in national defense, security, and environmental protection.

The study area is characterized by a heterogeneous topography, including medium mountains (500–700 m), low mountains (100–200 m), hills, and valleys, and is influenced by a humid tropical monsoon climate. During the dry season, temperatures can reach up to 40°C, with humidity levels ranging from 81% to 88%. The rainy season, lasting from August to January, brings an average annual precipitation of 2,300–6,300 mm in Nam Dong and 2,900–5,800 mm in A Luoi, leading to flooding and landslides (Kowalczyk, Quan 2023). The combination of steep slopes and high rainfall increases the risk of soil erosion, yet the fertile soil supports agriculture, livestock farming, and forestry. The region has a dense river and stream network, with critical water sources supplied by the Ta Trach and Huu Trach rivers, as well as reservoirs such as Ta Trach, Thuong Nhat hdropower, and Thuong Lo, which provide water for domestic use and production (Son et al. 2016).

In 2023, the ethnic minority population in Thua Thien Hue was 53,933 people, primarily concentrated in A Luoi, Nam Dong, and several mountainous communes in Phu Loc, Phong Dien, and Huong Tra. Among them, the Pa Co accounted for 39% (21,299 people), the Co Tu made up 31% (17,068 people), the Ta Oi comprised 24% (12,962 people), and the Pa Hy population was 2,243 people (Thua Thien Hue Statistical Office 2024). The majority of residents depend on natural resource extraction, thereby exerting considerable pressure on local ecosystems. While population growth provides a large labor force, it also poses challenges for resource management, as economic growth has not kept pace with the increasing demands.

The economy has undergone positive structural shifts, with an annual production value growth rate exceeding 16%. The agriculture, forestry, and fisheries sector remains the key economic pillar, with 18,000 ha of rice cultivation, a total grain production of 18,580 tons, 44,000 livestock, and 334,810 poultry (Thua Thien Hue Statistical Office 2024). Rubber is the dominant crop, with 2,900 ha under cultivation, generating an income of 30 million VND per hectare per year. The industrial and handicraft sector has grown by 13.3% per year, primarily driven by hydropower and traditional crafts such as Dèng weaving, broom making, and wood carving. The service and tourism sectors are also expanding, with numerous ecotourism and historical sites. Infrastructure investment has been comprehensive, with 100% of communes connected to the national power grid, equipped with solidly built schools and healthcare stations, and supported by key transportation networks such as La Son

– Nam Dong, Cam Lo – Tuy Loan, and the upgraded Route 14, laying the foundation for sustainable development.

RESULTS AND DISCUSSION

Development of hazard, exposure, sensitivity, and adaptive capacity indices

The construction of hazard, exposure, sensitivity, and adaptive capacity indices serves as a critical foundation for assessing climate change vulnerability (Table 1). The hazard index (H) is determined based on the impacts of flash floods, droughts, temperature variations, and precipitation changes. According to RCP4.5 and RCP8.5 (Representative Concentration Pathways) scenarios, the average temperature in Thua Thien Hue is projected to increase by 1.4°C to 3.4°C by the end of the century, while precipitation levels are expected to rise, ranging from 11.4% to 15.1%, depending on the scenario (Ministry of Natural Resources and Environment 2021). The impact level of flash floods is assessed based on factors such as topography, maximum precipitation, and vegetation cover. Droughts, characterized by gradual accumulation and prolonged duration, are evaluated using the aridity index (K), which is calculated based on the water balance between precipitation and evaporation. These indices are normalized and integrated to develop a hazard assessment map, facilitating the identification of vulnerability levels across different areas in response to climate change impacts.

The exposure index is determined based on four sub-indices: accessibility to transportation, exposure level of cultivated areas, impact of residential areas, and impact of industrial zones. The transportation accessibility index reflects the vulnerability of production areas located near roads, with a maximum distance of 1 km. The impact of residential areas is assessed within a maximum distance of 7.5 km, while the impact of industrial zones extends up to 10 km, indicating that production areas closer to these zones are more susceptible to external influences. The exposure level of agricultural areas is quantified as the proportion of cultivated land relative to the total natural land area, representing the vulnerability of regions with a high proportion of cultivated land.

The sensitivity index is determined based on four sub-indices: community dependence level, soil conditions, water demand, and access to information. The community dependence level reflects reliance on agricultural production, where a higher labor-to-population ratio indicates greater sensitivity. Soil conditions represent water retention capacity, with areas having poor water retention being more vulnerable. Water demand is assessed based on crop distribution, as different crops exhibit varying levels of sensitivity to climate conditions. The access to information index evaluates village-level access to broadcasting systems, where regions with lower access to information dissemination are considered more sensitive.

The adaptive capacity index reflects the ability to respond to climate change through financial capacity, technological capacity, and organizational capacity. Financial capacity measures the ability to mobilize and allocate resources for implementing sustainable adaptation measures. Technological capacity assesses the extent to which existing or new technologies are applied to mitigate climate change risks. Organizational capacity represents the ability of institutions and organizations to integrate adaptation strategies into decision-making processes, implement appropriate measures, and continuously update them over time. These three factors collectively determine overall adaptive capacity, helping to reduce vulnerability to climate change impacts.

Vulnerability assessment

The vulnerability index is determined based on two key indicators: sensitivity index and adaptive capacity index. The vulnerability level is calculated using the formula: $V = (S + (1 - AC))/2$. This formula quantifies the degree of vulnerability to climate change impacts. By overlaying the sensitivity and adaptive capacity maps, the spatial distribution of vulnerability levels is identified. The results of the vulnerability assessment are as follows (Fig. 2).

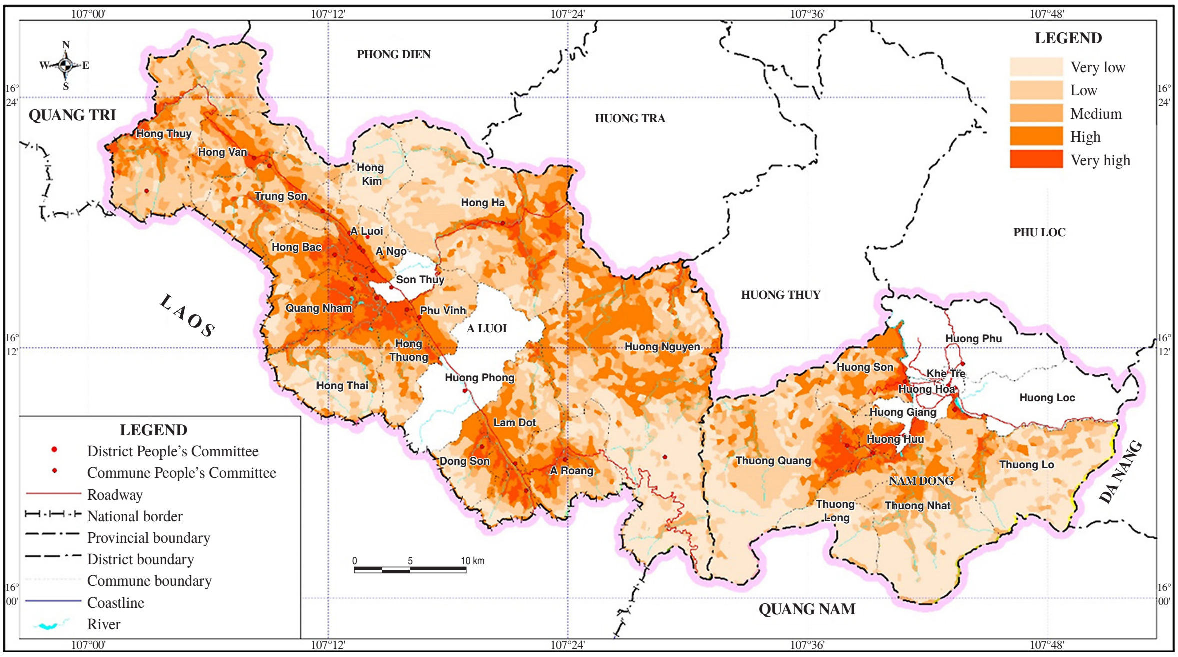
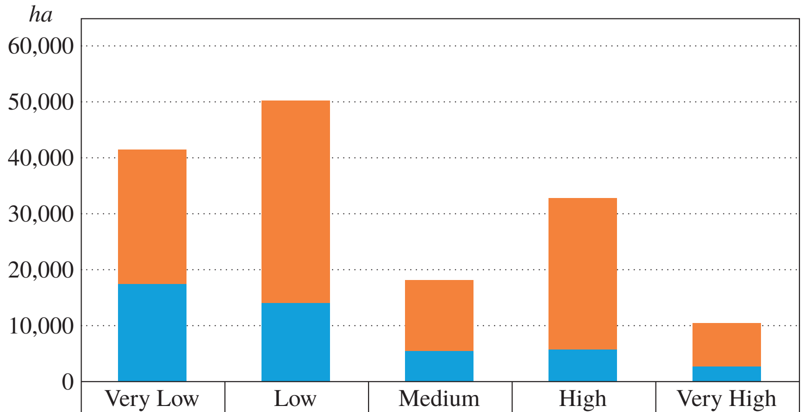


Fig. 2. Vulnerability index map
Source: own elaboration.



	Very Low	Low	Medium	High	Very High
A Luoi	23,984.42	36,186.38	12,625.87	27,046.52	7,730.71
Nam Dong	17,456.35	14,034.05	5,485.66	5,743.60	2,711.31

Fig. 3. Vulnerability index area distribution
Source: own elaboration.

In the study area, the very high vulnerability level covers 10,442.02 ha (6.82% of the total natural area), primarily concentrated in Quang Nham, Hong Ha, and Thuong Quang communes, while the high vulnerability level accounts for 32,790.12 ha (21.43%), with the most affected communes being Huong Nguyen, Hong Ha, and Lam Dot. The moderate vulnerability level covers 18,111.53 ha (11.84%), whereas the low vulnerability level occupies 50,220.43 ha (32.82%). The very low vulnerability level represents 27.08% of the total natural area of ethnic minority and mountainous communes in Thua Thien Hue province (Fig. 3). The findings reveal pronounced spatial disparities in vulnerability levels, with some communes being more severely affected due to topography, soil conditions, and limited adaptive capacity. Identifying high-vulnerability areas is crucial for proposing effective adaptation measures, and the following section presents strategies to mitigate climate change impacts in these highly vulnerable areas.

Table 2. Vulnerability index area (ha) by commune

District	Commune	Very low	Low	Medium	High	Very high	Total
A Luoi	A Ngo	101.77	302.43	67.19	189.99	170.3	831.68
	A Roang	753.86	1,932.40	728.8	1,541.72	438.88	5,395.66
	Huong Nguyen	8,922.73	6,958.67	3,283.85	7,323.73	391.83	26,880.8
	Hong Bac	139.64	750.26	324.46	1,286.99	489.82	2,991.17
	Hong Ha	4,752.47	6,848.06	1,958.78	2,928.32	977.33	17,464.96
	Hong Kim	2,668.45	817.89	94.92	195.73	173.09	3,950.08
	Hong Thuong	393.8	1,080.92	273.59	1,336.39	733.3	3,818.0
	Hong Thuy	853.06	6,354.07	1,936.78	1,612.36	476.72	11,233.0
	Hong Thai	1,926.85	2,155.33	374.36	1,493.26	690.99	6,640.79
	Hong Van	147.09	1,442.07	1,016.61	1,038.83	296.48	3,941.08
	Lam Dot	851.61	1,530.35	813.59	2,635.52	641.88	6,472.96
	Dong Son	750.77	631.46	117.0	756.97	276.39	2,532.57
	Phu Vinh	181.02	1,480.6	119.86	859.41	90.78	2,731.67
	Quang Nham	181.90	543.9	350.81	1,891.05	1,165.31	4,132.98
	Trung Son	1,104.75	2,816.79	1,138.72	1,790.66	410.67	7,261.59
	TT A Luoi	254.65	541.17	26.55	165.59	306.94	1,294.90
Nam Dong	Huong Huu	0	261.04	55.84	240.01	385.39	942.28
	Huong Son	251.59	1,272.24	652.49	1,264.25	472.06	3,912.63
	Thuong Long	2,116.28	1,463.56	369.10	623.17	325.47	4,897.58
	Thuong Lo	4,721.66	2,845.51	1,332.37	677.88	300.98	9,878.39
	Thuong Nhat	5,118.26	2,178.24	1,877.89	1,204.28	362.67	10,741.34
	Thuong Quang	5,248.56	6,013.45	1,197.98	1,734.01	864.74	15,058.74
Total		41,440.77	50,220.43	18,111.53	32,790.12	10,442.02	153,004.87

Source: own elaboration.

The very low vulnerability level accounts for 27.08% of the total natural area of ethnic minority and mountainous communes in Thua Thien Hue province, covering 41,440.77 ha, with A Luoi district comprising 23,984.43 ha (57.88%), mainly in Hong Ha, Huong Nguyen, and Hong Kim communes, while Nam Dong district accounts for 17,456.34 ha (42.12%), with the largest areas in Thuong Nhat, Thuong Quang, and Thuong Lo communes. The low vulnerability level covers 32.82% of the total natural area, making it the largest category among all vulnerability levels, with a total of 50,220.43 ha, of which A Luoi district holds 36,186.38 ha (72.06%), mainly in Huong Nguyen, Hong Ha, Hong Thuy, and Hong Thai communes, while Nam Dong district accounts for 14,034.05 ha (27.94%), with the largest areas in Thuong Lo, Thuong Nhat, and Thuong Quang communes. These areas have low vulnerability levels due to high forest cover, effective flood drainage capacity, and well-developed infrastructure, but they still face climate change risks, particularly during extreme weather events such as flooding and prolonged droughts.

The moderate vulnerability level accounts for 11.84% of the total natural area, covering 18,111.53 ha, with A Luoi district comprising 12,625.87 ha (69.71%), which is 2.3 times larger than that of Nam Dong district (5,485.66 ha – 30.29%). In A Luoi, the communes with the largest areas in this category include Huong Nguyen (3,283.85 ha), Hong Ha (1,958.78 ha), and Hong Thuy (1,612.36 ha), while in Nam Dong, the most affected communes are Thuong Nhat (1,877.89 ha), Thuong Lo (1,332.37 ha), and Thuong Quang (1,197.98 ha). These areas have more complex terrain, higher risks of soil erosion, and poorer flood drainage capacity compared to those with low vulnerability levels. Strengthening soil and water resource protection measures is essential to mitigate long-term risks.

According to the study results, 21.43% of the total area falls into the high vulnerability category, indicating that nearly a quarter of the study area is severely impacted by climate change, requiring special adaptation measures. A Luoi district accounts for 27,046.52 ha (82.48% of the high vulnerability area), which is 4.71 times larger than in Nam Dong district (5,743.60 ha – 17.52%). The most affected communes in A Luoi include Huong Nguyen (7,323.73 ha), Hong Ha (2,928.32 ha), and Lam Dot (2,635.52 ha), while in Nam Dong, the high vulnerability areas are concentrated in Thuong Quang (864.74 ha), Thuong Lo (300.98 ha), and Thuong Nhat (362.67 ha). These areas are characterized by steep mountainous terrain, deforestation, or sparse vegetation, which increase risks of landslides, droughts, and soil erosion. Additionally, transportation and irrigation infrastructure in some communes has not been fully upgraded, limiting their adaptive capacity to natural disasters. In the absence of timely intervention, these areas are at risk of transitioning into the very high vulnerability category.

The very high vulnerability level accounts for 6.82% of the study area's total land, covering 10,442.02 ha, primarily concentrated in A Luoi district (7,730.71 ha – 74.03%), which is 2.85 times larger than in Nam Dong district (2,711.31 ha – 25.97%). The most severely affected communes in A Luoi include Quang Nham (1,165.31 ha), Hong Ha (977.33 ha), Hong Thuong (733.30 ha), and Hong Thai (690.99 ha), while communes with smaller affected areas include Phu Vinh (90.78 ha) and A Ngo (170.3 ha). In Nam Dong, the very high vulnerability level is primarily observed in Thuong Quang (864.74 ha), Huong Son (472.06 ha), and Thuong Nhat (362.67 ha). These areas feature steep slopes, significant river and stream fragmentation, and high susceptibility to flash floods, droughts, and landslides. Additionally, forest degradation and low vegetation cover further reduce their natural protective capacity. Many of these communes also face economic difficulties and lack adequate infrastructure to mitigate the impacts of climate change. Implementing resource management projects, strengthening protective forests, and improving transportation and irrigation systems is crucial to reducing vulnerability in the future.

From the above analysis, it is evident that A Luoi district is more severely affected than Nam Dong district, with a significantly larger area classified as high and very high vulnerability. Communes with low and very low vulnerability levels are typically located in areas with stable terrain, balanced ecosystems, and higher adaptive capacity. In contrast, communes with high and very high vulnerability levels are often characterized by steep slopes, significant topographical fragmentation, deforestation, or frequent exposure to natural disasters, increasing the risks of landslides, droughts, and flash floods. Therefore, to reduce vulnerability, it is essential to implement disaster risk management strategies, strengthen forest resource protection, improve transportation and irrigation infrastructure, and enhance local community resilience, ensuring sustainable development amid increasingly complex climate change challenges.

Risk assesment

Based on the risk assessment formula $R = (H + E + V)/3$, the climate change risk level is calculated by integrating three key factors: hazard index, exposure index, and vulnerability index. Risk levels were determined through spatial overlay analysis of the relevant indices, illustrating the spatial distribution of risk levels as follows (Fig. 4 and 5).

The calculation shows that 7,178.19 ha (4.69%) fall into the very high-risk category. These areas are highly vulnerable to flash floods, landslides, and droughts, while 19,884.66 ha (13.0%) is classified as high risk, with significant disaster potential, though variations exist in topography, vegetation cover,

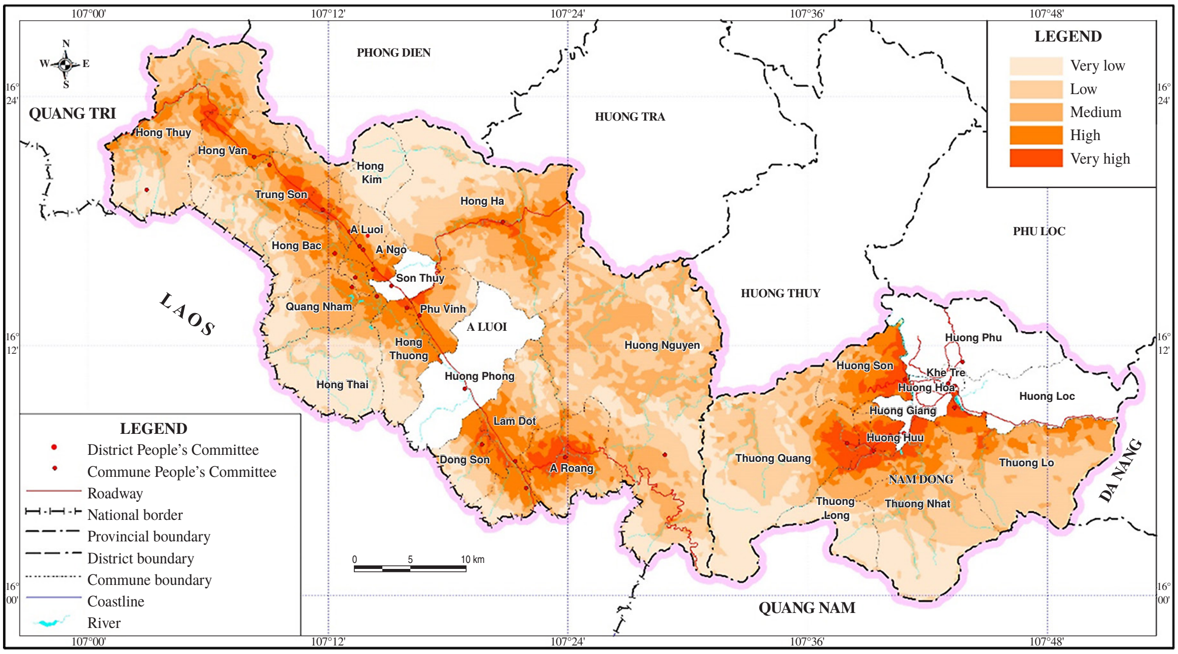
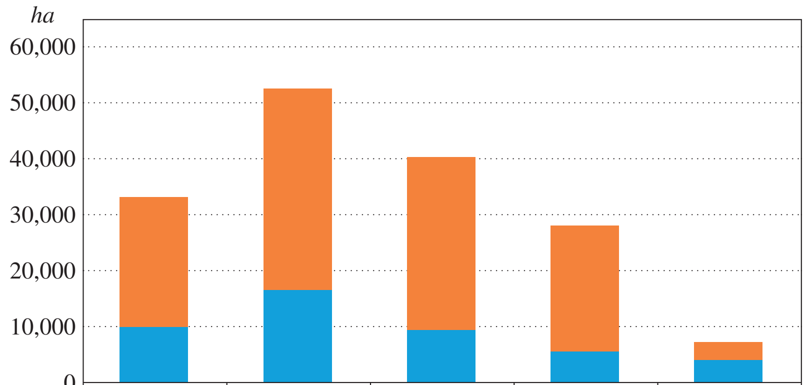


Fig. 4. Risk index map
Source: own elaboration.



	Very Low	Low	Medium	High	Very High
A Luoi	23,233.07	36,007.55	30,864.14	14,336.09	3,133.05
Nam Dong	9,895.99	16,548.95	9,392.32	5,548.57	4,045.14

Fig. 5. Risk index area distribution
Source: own elaboration.

and infrastructure conditions. The moderate-risk category covers 40,256.46 ha (26.31%), still posing potential threats, especially as extreme weather events increase in frequency. The low-risk category accounts for 852,556.5 ha (34.35%), where dense vegetation and high forest coverage help mitigate climate impacts, but sustainable management is required to maintain long-term resilience. Lastly, the very low-risk category encompasses 33,129.06 ha (21.65%), consisting of areas less affected by climate change due to stable terrain, protective forests, and well-developed disaster mitigation infrastructure. Overall, climate change risk is unevenly distributed, necessitating solutions such as

Table 3. Risk level area (ha)

District	Commune	Very low	Low	Medium	High	Very high	Total
A Luoi	A Ngo	34.4	152.25	212.29	301.33	131.41	831.68
	A Roang	69.14	818.47	2,009.7	1,405.95	1,092.41	5,395.66
	Huong Nguyen	4,270.73	12,974.15	9,507.99	127.45	0.48	26,880.8
	Hong Bac	501.79	739.4	1,113.39	636.59	0	2,991.17
	Hong Ha	4,395.89	6,112.66	4,660.58	2,118.36	177.46	17,464.96
	Hong Kim	2,750.98	419.82	323.78	363.96	91.54	3,950.08
	Hong Thuong	1,043.23	759.91	965.6	953.57	95.68	3,818.0
	Hong Thuy	1,479.78	4,998.01	3,236.84	1,367.85	150.52	11,233.0
	Hong Thai	4,377.36	1,211.53	658.34	393.55	0	6,640.79
	Hong Van	337.75	1,216.75	1,301.55	851.25	233.79	3,941.08
	Lam Dot	899.24	1,415.67	1,711.09	2,240.37	206.59	6,472.96
	Dong Son	795.43	719.6	293.81	580.43	143.3	2,532.57
	Phu Vinh	189.5	782.12	806.25	846.66	107.14	2,731.67
	Quang Nham	743.54	969.75	1,755.84	663.85	0.00	4,132.98
	Trung Son	1,255.64	2,067.4	2,218.96	1,016.86	702.73	7,261.59
	TT A Luoi	88.66	650.06	88.12	468.06	0	1,294.9
Nam Dong	Huong Huu	0	0	155.44	189.06	597.77	942.28
	Huong Son	0	423.49	919.16	1,600.59	969.39	3,912.63
	Thuong Long	1,900.41	843.46	1,023.57	425.09	705.04	4,897.58
	Thuong Lo	0	5,159.3	2,777.12	1,511.59	430.38	9,878.39
	Thuong Nhat	3,008.55	3,773.19	2,419.13	1,006.69	533.79	10,741.34
	Thuong Quang	4,987.03	6,349.51	2,097.9	815.54	808.76	15,058.74
Total		33,129.06	52,556.5	40,256.46	19,884.66	7,178.19	153,004.87

Source: own elaboration.

enhancing protective forests, improving flood drainage, upgrading infrastructure, and strengthening disaster response capacity to safeguard vulnerable regions.

The assessment of climate change risk levels in ethnic minority and mountainous communes of Thua Thien Hue province reveals significant regional disparities. The very low-risk category accounts for 21.65% of the total natural area, equivalent to 33,129.06 ha, with A Luoi district comprising 23,233.07 ha (70.13%), primarily in Huong Nguyen, Hong Ha, and Hong Thai communes, while Nam Dong district accounts for 9,895.99 ha (29.87%), mainly in Thuong Quang and Thuong Nhat communes. The low-risk category covers 34.35% of the total natural area, equivalent to 52,556.5 ha, with A Luoi district accounting for 36,007.55 ha (68.51%), concentrated in Huong Nguyen, Hong Ha, and Hong Thuy communes, while Nam Dong district covers 16,548.95 ha (31.49%), with the largest areas in Thuong Lo, Thuong Nhat, and Thuong Quang communes. These communes have more favorable natural conditions compared to those in the moderate-risk category and above, but they are still affected by extreme climate events, particularly prolonged heavy rainfall leading to localized flooding. The increasing pressure from climate change could elevate risk levels in these areas, necessitating plans to upgrade irrigation systems and develop climate-adaptive production models tailored to local environmental conditions.

The average risk level accounts for 26.31% of the total natural area, equivalent to 40,256.46 ha. A Luoi district has a significantly larger affected area, covering 30,864.14 ha (76.67%), which is 3.29 times larger than Nam Dong district (9,392.32 ha – 23.33%). The communes with the highest moderate-risk areas in A Luoi include Huong Nguyen (9,507.99 ha), Hong Ha (4,660.58 ha), and Hong Thuy (3,236.84 ha), while in Nam Dong, the most affected communes are Thuong Lo (2,777.12 ha) and Thuong Nhat (2,419.13 ha). These communes are characterized by fragmented terrain due to river and stream systems, making them highly susceptible to flash floods and soil erosion during the rainy season, while also facing drought risks during the dry season. Therefore, implementing sustainable farming models, protecting vegetation cover, and establishing early warning systems are essential solutions to mitigate risks and enhance resilience.

The high-risk area covers an area of 19,884.66 ha, accounting for 13.0% of the total natural area.A Luoi district has 14,336.09 ha (72.1% of the high-risk area), which is 2.58 times larger than Nam Dong district (5,548.57 ha – 27.9%). The communes with the largest high-risk areas in A Luoi include Lam Dot (2,240.37 ha), Hong Ha (2,118.36 ha), A Roang (1,405.95 ha), and Hong Thuy (1,367.85 ha), while in Nam Dong, the most affected communes are Thuong Lo (1,511.59 ha), Huong Son (1,600.59 ha), and Thuong Nhat (1,006.69 ha). These areas are characterized by steep mountainous terrain, sparse vegetation cover, and strong exposure to natural disasters, including landslides, prolonged droughts, and flash floods. The lack of well-developed infrastructure further complicates disaster response efforts. Therefore, in addition to strengthening disaster prevention infrastructure, it is essential to implement sustainable livelihood support policies, improve access to climate information, and enhance community awareness to minimize the impacts of climate change.

The most severe level of risk is the very high-risk category, covering 7,178.19 ha, which accounts for 4.69% of the total natural area. Nam Dong district has a larger affected area, totaling 4,045.14 ha (56.35%), which is 1.29 times higher than A Luoi district (3,133.05 ha – 43.65%). The most severely impacted communes in Nam Dong include Huong Son (969.39 ha), Thuong Quang (808.76 ha), Thuong Long (705.04 ha), and Thuong Nhat (533.79 ha), while in A Luoi, the communes with the highest very high-risk areas are A Roang (1,092.41 ha), Trung Son (702.73 ha), and Hong Van (233.79 ha). These zones exhibit rugged topography and fragmented hydrographic networks. Protective forest cover is declining, making them highly vulnerable to extreme weather events such as flash floods, landslides, and severe droughts. Additionally, some communes face economic difficulties and lack essential infrastructure for disaster prevention, further increasing their vulnerability levels. Implementing protective forest restoration projects, investing in early warning systems, and supporting the development of community protection structures are crucial measures to reduce risks and enhance resilience in these highly vulnerable areas.

Therefore, climate change risk levels are unevenly distributed across the study area, with A Luoi district experiencing greater impacts at low to moderate risk levels, while Nam Dong district has a higher proportion of areas classified as very high risk. This variation reflects the influence of topography, ecosystem characteristics, forest cover levels, and adaptive capacity in each region. As climate change intensifies, key adaptation measures should include strengthening protective forests, improving transportation and irrigation infrastructure, developing early warning systems, and enhancing community resilience to ensure sustainable development and reduce climate-related risks in the mountainous areas of Thua Thien Hue province.

CONCLUSION

The study area comprises the mountainous and ethnic minority communes of Thua Thien Hue province, mainly in A Luoi and Nam Dong districts. This region features complex terrain and a dense river network, making it highly susceptible to flash floods, landslides, and droughts. The population is primarily composed of Pa Co, Co Tu, Ta Oi, and Bru–Van Kieu ethnic groups whose livelihoods depend on agriculture and forestry, making them particularly vulnerable to climate change impacts.

The study developed a set of indices to assess climate change-related vulnerability and risk, consisting of four components: hazard, exposure, sensitivity, and adaptive capacity. The results show that climate change has significantly affected natural resources and community livelihoods, particularly in high-vulnerability areas. Households dependent on agriculture are the most affected, while those engaged in service sectors show higher adaptive capacity. Based on these findings, a sustainable livelihood framework grounded in indigenous knowledge was proposed to strengthen community resilience.

The spatial analysis indicates clear variations in vulnerability and risk between the two districts. Areas classified as very high and high vulnerability or risk account for about 5–7% of the total area, concentrated mainly in A Luoi (Quang Nham, Hong Ha, Hong Thuong) and Nam Dong (Thuong Quang, Huong Son, Thuong Nhat). In contrast, about 60% of the area falls within low to very low vulnerability levels, corresponding to regions with stable topography, high forest cover, and better infrastructure. These differences highlight the strong relationship between topographic conditions, vegetation cover, and infrastructure in shaping climate vulnerability.

To reduce risks, comprehensive solutions are required, including forest protection, irrigation improvement, development of early warning systems, access to preferential credit, training on sustainable farming practices, and promotion of market linkages. In the future, the research team plans to expand the study area, integrate climate projection models and economic analysis to enhance the accuracy and applicability of the findings.

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