Evaluation of Coastal Tourism Vulnerability to Climate Change Using AHP and Vulnerability Index – A Case Study of Sam Son City, Vietnam

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Abstract
This study assesses the vulnerability of coastal tourism to climate change in Sam Son using the Analytic Hierarchy Process (AHP) and vulnerability index. The framework incorporates three components: exposure, sensitivity, and adaptive capacity, with each component being quantified through weighted indicators derived from expert evaluations and standardized data. The results indicate that key tourism zones, particularly the Truong Le mountain area and Quang Cu ward, face high vulnerability due to their geographical location and low adaptive capacity, while inland areas exhibit greater resilience. These findings highlight significant spatial disparities in climate risk and underscore the importance of tailored adaptation strategies, including investment in infrastructure, disaster preparedness training, and climate-resilient tourism planning. This integrated approach not only provides a replicable model for assessing the climate sensitivity of tourism systems but also contributes to the development of sustainable policies for other coastal cities facing climate-related risks.

Keywords: AHP, Coastal Tourism, Climate Change, Vulnerability and Vulnerability Index

1. Introduction

Coastal tourism is a vital component of many economies worldwide, providing significant opportunities for growth and leisure, particularly in regions with rich natural resources and attractive landscapes. However, the sector faces critical challenges due to climate change, which affects both the environment and the socio-economic conditions of coastal areas [1]. Climate plays a crucial role in shaping tourism destinations, influencing factors such as demand, travel timing, and seasonal variations [2]. Additionally, it also affects the image and appeal of destinations, as well as the operational aspects of tourism businesses [3]. Climate change impacts coastal tourism in several ways, including increases in temperatures, coastal erosion, and shifting precipitation patterns, which reduce the appeal and availability of natural resources crucial to the tourism sector [4] and [5]. It also significantly affects the spatial and temporal distribution of tourism demand, the quality of the coastal environment, and operational strategies within tourism businesses [6] and [7]. Therefore, the challenge for localities in shaping the development direction of the tourism sector is to identify their climate-related risks [8] and develop adaptive solutions to mitigate the impacts of increasingly severe climate change [9].

Although considerable research has been conducted globally to assess the climate vulnerability of coastal tourism to climate change, studies have largely focused on well-established tourism destinations in developed countries. Few studies have specifically addressed the climate exposure and adaptive capacity of coastal tourism in developing countries like Vietnam, where socio-economic factors, local governance, and adaptive capacity are crucial in shaping resilience to climate change impacts. This gap highlights the need for localized studies that consider the unique socio-environmental context of such regions like Sam Son. Sam Son City is a coastal area in northern Vietnam, where the tourism sector is highly vulnerable to climate change.

Various methods exist for assessing climate risk in coastal tourism, such as GIS-based decision support systems and composite resilience indices. While GIS-based models provide valuable spatial analysis, they often lack the ability to incorporate expert judgment or handle subjective criteria, such as socio-economic factors and natural elements [10] and [11]. The weighted analysis approach offers an effective solution for incorporating expert assessments into the evaluation of tourism susceptibility. One of the most commonly employed techniques for determining criteria weights is the Analytic Hierarchy Process (AHP). The AHP method utilizes a pairwise comparison matrix, which generates a reciprocal matrix in the process of converting qualitative ratio data. The Eigenvalue is employed to determine the final weights of the criteria and assess the level of consistency through the consistency index [12][13] and [14]. One commonly used method to assess the level of physical vulnerability to climate change is the Coastal Vulnerability Index (CVI) method [10]. This method is robust in capturing the empirical characteristics of the coast and providing a map of vulnerable areas to help prevent natural disasters resulting from climate change [15]. On the other hand, the vulnerability index approach is limited in its consideration of non-climate stressors and are limited in terms of spatial aspects. Moreover, climate risk is specific to a particular location [16]. Therefore, It is crucial to develop integrated methodologies that combine socio-ecological systems and include non-climate stressors. This study aims to fill the research gap by integrating AHP with the Vulnerability Index, providing a more comprehensive vulnerability assessment of the tourism sector in Sam Son.

2. Data and Methods

2.1 Study Area

Sam Son City, located in Thanh Hoa Province, Vietnam, is a coastal city along the East Sea, situated at approximately 19.3°N latitude and 105.8°E longitude (Figure 1). With a coastline stretching 9 km and low-lying topography, Sam Son is highly vulnerable to climate change impacts such as rising levels, storms, and coastal erosion. The region experiences a tropical monsoon climate, with hot, humid summers that favor tourism but also exacerbate the risks associated with extreme weather events. In recent years, rising sea levels, coastal erosion, and saltwater intrusion have increasingly threatened coastal infrastructure and tourism activities. The tourism industry, which serves as the city's economic backbone, is particularly susceptible to these changes. Storm surges and intensified typhoons not only cause direct damage to beachfront infrastructure but also lead to long-term land degradation, reducing the city's capacity to attract visitors. Additionally, prolonged heatwaves may impact tourist comfort, shifting seasonal travel patterns and affecting local businesses. Without effective mitigation and adaptation strategies, these vulnerabilities could undermine Sam Son's long-term viability as a leading coastal destination. Addressing these challenges requires an integrated approach, including coastal defense systems, sustainable land-use planning, and climate-resilient tourism policies to enhance the city's adaptive capacity and safeguard its economic and environmental future.

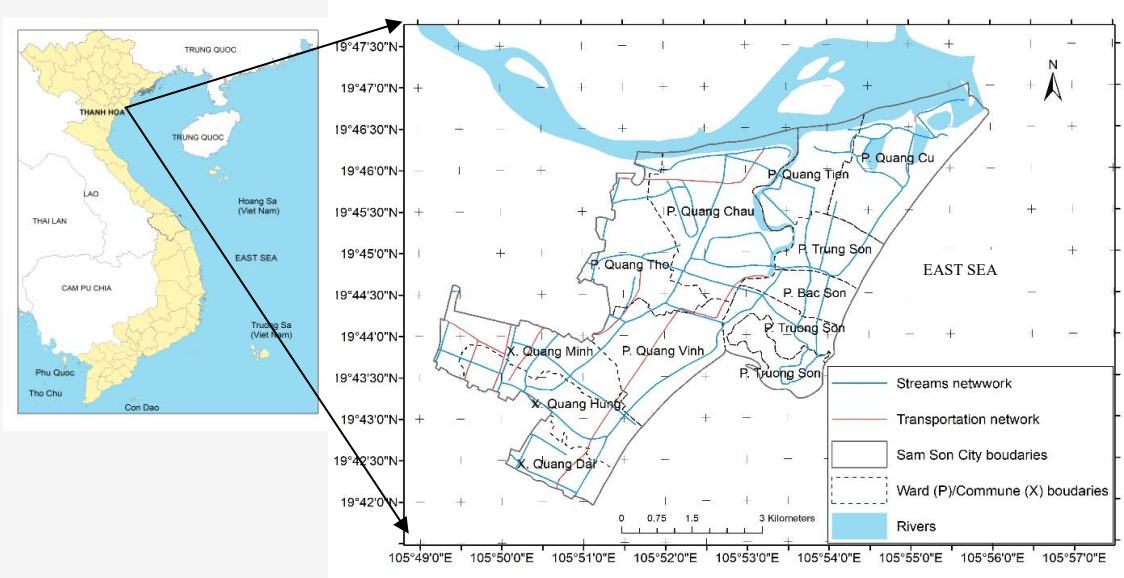

Figure 1: Sam Son city, Vietnam

2.2 Data

The criteria are designed to evaluate the vulnerability of the tourism sector (Table 1), which was developed based on field surveys conducted in the study area. It is organized into three main criteria: Exposure (E), which includes factors such as the coastal erosion rate, temperature variations (annual average, minimum, and maximum), and changes in precipitation (Table 2), as these directly influence the physical environment affecting tourism [5] and [17]; Sensitivity (S), which examines tourism-related aspects such as the number of cultural heritage sites, hotels meeting specific rating standards, and the type and number of tourism sites (Table 3). These indicators reflect the sector's dependence on environmental and cultural resources vulnerable to climate change [6]; and Adaptive capacity (AC), which evaluates the region's ability to adapt through infrastructure factors (e.g., proportion of households with permanent housing, access to electricity, and safe drinking water), healthcare facilities, and economic indicators like employment rates and income sources (Table 4).

Table 1: Used criteria to assess the vulnerability of the tourism sector in Sam Son

Criteria	Factors	Characteristics	Units
Exposure	Natural disaster	Coastal erosion rate from 1989-2023 (E1)	m/ year
	Temperature	Annual average air temperature variation (E2)	^oC
		Annual average maximum temperature variation (E3)	^oC
		Annual average minimum temperature variation (E4)	^oC
	Precipitation	Annual average precipitation variation (E5)	mm
Sensitivity	Potential Tourism	Number of tourists (S1)	Number
		Number of hotels (The number of hotels meeting the rating standards of at least one star or higher) (S2)	Number
		Type of tourism *(1. swimming; 2. resort; 3. culture; 4. Other activities)* (S3)	Character
		Number of cultural heritage sites (S4)	Number
Adaptive capacity	Infrastructure adaptation	Proportion of households with permanent housing (AC1)	%
		Proportion of households with access to electricity (AC2)	%
		Proportion of households with access to safe drinking water (AC3)	%
		Number of healthcare facilities (AC4)	Number
	Economic and Social	Employment rate (AC5)	%
		Proportion of households with non-agricultural income sources (AC6)	%
		Urban population ratio (AC7)	%
	Policy	Budget allocation for climate change adaptation (AC8)	Million VND
		Proportion of the population trained in disaster prevention (AC9)	%

Table 2: The criteria of exposure in Sam Son [18]

Wards and communes	E1	E2	E3	E4	E5
Bac Son	<0	0.029	0.028	0.184	0.269
Truong Son	<0	0.030	0.028	0.189	0.273
Other area	0.07 – 2.57	0.029	0.028	0.184	0.269
Trung Son	<0	0.029	0.028	0.184	0.269
Quang Tien	0.07 – 2.57	0.029	0.028	0.184	0.269
Quang Cu	>2.58	0.029	0.028	0.184	0.269
Quang Tho	0.07 – 2.57	0.029	0.028	0.184	0.269
Quang Chau	0.07 – 2.57	0.029	0.028	0.184	0.269
Quang Minh	<0	0.029	0.028	0.184	0.269
Quang Vinh	<0	0.029	0.028	0.184	0.269
Quang Hung	<0	0.029	0.028	0.184	0.269
Quang Dai	<0	0.029	0.028	0.184	0.269

Table 3: The criteria of sensitivity of Sam Son City in 2023 [18]

Wards and communes	S1	S2	S3	S4
Bac Son	1,496,100	41	4	2
Truong Son	1,225,000	26	4	3
Trung Son	1,182,500	25	4	2
Quang Tien	1,087,380	-	2	5
Quang Cu	2,024,900	6	4	6
Quang Tho	-	-	1	4
Quang Chau	-	-	1	7
Quang Minh	-	-	-	-
Quang Vinh	25,400	-	4	2
Quang Hung	3,540	-	2	1
Quang Dai	5,180	-	2	3

Table 4: The criteria of adaptive capacity of Sam Son City in 2023 [18]

Wards and communes	AC1 (%)	AC2 (%)	AC3 (%)	AC4 (number)	AC5 (%)	AC6 (%)	AC7 (%)	AC8 (%)	AC9 (%)
Bac Son	100.00	100	100	8	97.3	99.1	100	2.9	2.8
Truong Son	100.00	100	100	3	97.6	86.5	100	3.1	2.6
Trung Son	99.97	100	100	1	97.8	82.7	100	3.1	2.6
Quang Tien	99.97	100	100	1	98.2	60.6	100	2.3	2.8
Quang Cu	99.97	100	100	1	98.4	57.1	100	2.8	3.5
Quang Tho	100.00	100	100	3	97.8	95.8	100	0.7	3.1
Quang Chau	100.00	100	100	1	97.6	69.8	100	1.9	3.3
Quang Minh	99.91	100	100	1	95.3	92.8	-	0.3	3.8
Quang Vinh	100.00	100	100	1	98.5	64.7	100	2.8	3.6
Quang Hung	99.72	100	100	1	94.2	94.1	-	1.9	3.7
Quang Dai	99.87	100	100	1	94.0	96.6	-	1.4	3.1

Additionally, it considers policy factors, including budget allocation for climate change adaptation and the proportion of the population trained in disaster prevention, which are essential for enhancing the region's ability to respond to climate impacts [6]. These indicators were selected based on established literature and frameworks for climate change adaptation, ensuring their scientific validity and relevance to the specific context of Sam Son City. The exposure indicators are categorized into two climatic subregions: the Truong Le mountain area and the Sam Son coastal plain area; the indicators for the other variables are based on data at the wards and communes level. The Table 2 presents the criteria of exposure in Sam Son, detailing various environmental factors across different wards and communes. The data highlight regional differences, with specific communes such as Truong Son and Quang Cu experiencing varying rates of coastal erosion, which may influence their vulnerability to climate change, particularly with respect to tourism. The sensitivity criteria for Sam Son are presented in Table 3, which details the key variables across the different wards and communes. Bac Son emerges as the most visited commune, with nearly 1.5 million tourists and the highest number of hotels (41), offering a diverse array of tourism activities. In contrast, communes such as Quang Minh and Quang Chau report no hotels, suggesting less development in terms of tourism infrastructure. The distribution of historical sites is also uneven, with Quang Cu hosting the highest number at 5 sites. Furthermore, the types of tourism vary across communes, ranging from beach-oriented activities (swimming) and resort tourism to cultural and other recreational pursuits.

Table 4 shows the criteria of adaptive capacity in Sam Son, focusing on key indicators related to infrastructure, economic, social, and policy adaptation across different wards and communes. The data shows variations in adaptive capacity, with Bac Son having the highest levels in terms of employment rate, healthcare facilities, and disaster prevention training. While most communes show strong infrastructure adaptation, such as access to electricity and safe drinking water, some areas exhibit lower scores in non-agricultural income sources and climate change adaptation budgeting. The table highlights disparities in adaptive capacity, with some wards demonstrating greater resilience than others.

2.3 Methodology

The methodology for evaluating the vulnerability of coastal tourism in Sam Son City begins with data collection, focusing on three key factors: exposure, sensitivity, and adaptive capacity. Exposure is evaluated based on tourism-related criteria that reflect the extent to which climate change impacts the tourism sector. Sensitivity assesses the degree to which tourism is affected by climatic factors, while Adaptive Capacity examines the ability of the tourism sector to prevent and mitigate the negative effects of climate change (Figure 2). The Analytic Hierarchy Process (AHP) is employed to assign weights to each factor of these factors and their respective indicators. The experts involved in this study were selected based on their expertise in climate change, coastal tourism, and vulnerability assessments. A total of 6 experts were chosen, including professionals from environmental science, tourism management, and local governance. These experts were selected for their in-depth knowledge of the region's socio-economic and environmental context and their experience in climate adaptation strategies. This diverse group ensured a comprehensive and balanced evaluation of the factors influencing the vulnerability of tourism to climate change. Additionally, AHP was chosen for this study due to its ability to handle complex decision-making problems that involve multiple criteria. AHP allows for both qualitative and quantitative data to be integrated into the decision-making process. This is particularly important in climate vulnerability assessments, where expert judgment plays a crucial role in evaluating the relative importance of various factors. The Analytic Hierarchy Process facilitates group decision-making, enabling experts to assign relative weights to indicators based on their expertise. The pairwise comparison matrices and consistency ratios were calculated, with the consistency ratio being below 0.1, indicating the reliability of the expert assessments. This method is widely used in environmental and risk management studies, as it provides a clear structure for prioritizing factors and making informed decisions.

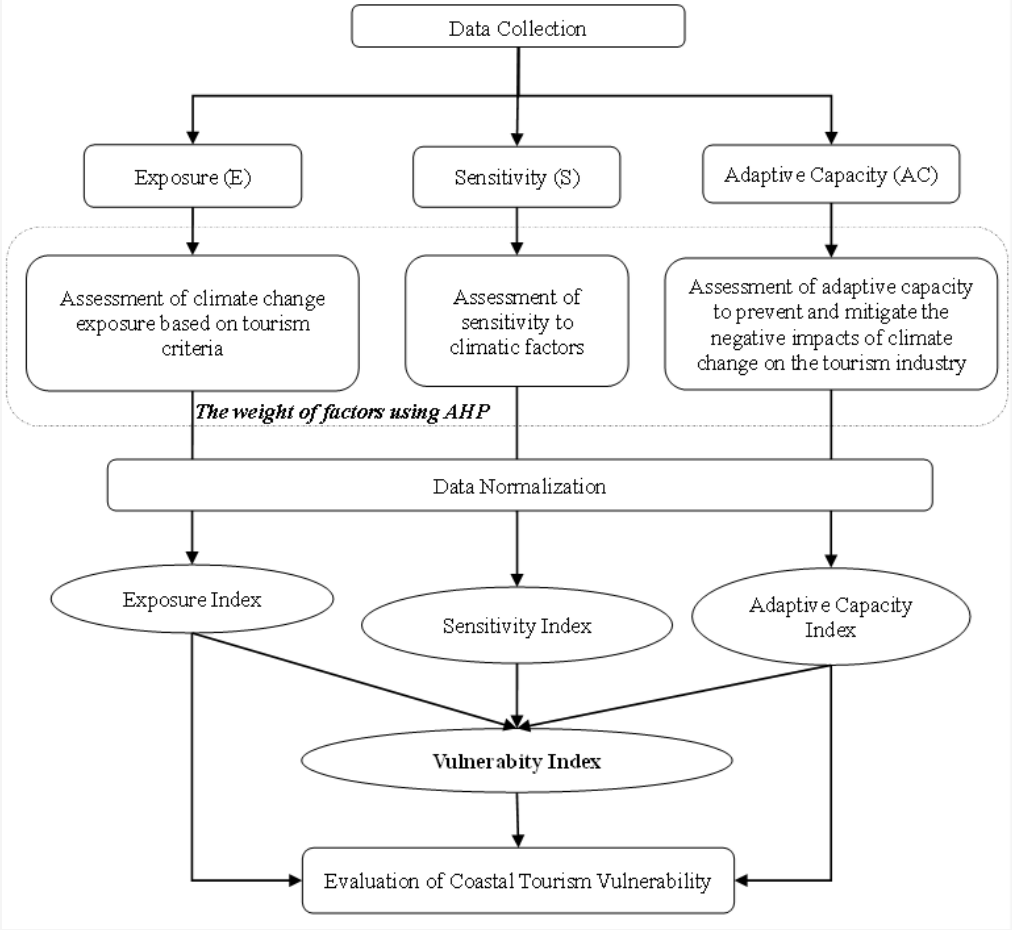

Figure 2: Coastal tourism vulnerability evaluation methodology

The data is then normalized to generate the Exposure Index, Sensitivity Index, and Adaptive Capacity Index. Ultimately, these normalized indices are combined to calculate the Vulnerability Index, which provides a measure of the overall susceptibility of coastal tourism to climate change. This approach allows for the identification of regions at higher risk and informs the development of appropriate adaptation strategies to enhance the resilience of the tourism sector to climate change impacts.

2.3.1 The weight of factors using AHP

The Analytic Hierarchy Process, developed by Saaty in the 1990s, is a widely utilized decision-making methodology applied across diverse fields [19] and [20]. It provides an effective framework for addressing complex, multi-criteria problems by establishing priorities and facilitating optimal decisions [21] using pairwise comparisons [22]. It integrates expert knowledge and both objective and subjective data within a hierarchical structure of goals, criteria, and alternatives, enabling decision-makers to establish priorities and rank solutions effectively [23][24] and [25]. The Analytic Hierarchy Process (AHP) can be effectively employed to assess the vulnerability of the tourism sector to the impacts of climate change, focusing on three key factors: exposure, sensitivity, and adaptive capacity. Within the AHP framework, the overarching goal is to evaluate the overall vulnerability, which is determined by these three sub-criteria. These sub-criteria are assessment of climate change exposure based on tourism criteria, assessment of sensitivity to climatic factors, and assessment of adaptive capacity to prevent and mitigate the negative impacts of climate change on the tourism.

2.3.2 Vulnerability index

The vulnerability index method, developed by the OECD in 2003, has been widely applied to assess coastal vulnerability and is adopted in this study to evaluate the vulnerability levels of Sam Son City. The vulnerability index calculation is carried out in three steps: 1) Standardizing the selected indicators for each variable. The data for each indicator was normalized using the min-max method, where the values of each indicator were scaled between 0 and 1. Additionally, for factors in categorical form such as Type of tourism, they were converted into a scale reflecting their impact on the tourism industry based on expert opinions before being standardized. This method was chosen to ensure comparability across different types of data; 2) Calculating the index for exposure (EI), sensitivity (SI), and adaptive capacity factors (ACI) by Equation 1; 3) The vulnerability index (VI) was calculated by combining the EI, SI, and ACI, using the Equation 2 [26]. The indices EI, SI, and ACI are calculated using Equation 1:

$$A = \frac{\sum_{j=1}^{k} X_{ij} \cdot wX_{ij}}{\sum_{j=1}^{k} wX_{ij}}$$

Equation 1

Where:

A: The value of the component index, EI, SI, or ACI;

X_{ij}: The normalized value of indicator j at wards and communes i;

wX_{ij}: The weight of the j^{th} indicator at wards and communes i.

The integration of the values of the three components/variables results in the overall vulnerability index (VI). The VI is calculated using Equation 2:

$$Vi = \frac{1}{3}\left(EI + SI + 1 - ACI\right)$$

Equation 2

The vulnerability assessment scale is defined within a range from 0 to 1, categorizing the vulnerability into three levels: low, medium, and high, or four levels: low, medium, high, and very high. However, for different regions, the assessment scale may be adjusted based on the specific vulnerability index of that area, dividing it into different levels.

3. Results

3.1 The Weight and Index of Factors

3.1.1 Exposure factors

Assessment of climate change vulnerability based on tourism development criteria. The exposure factors refer to climatic elements that affect tourism in Sam Son. These factors are identified and compared using a pairwise comparison matrix in the AHP method. Each climatic factor is valuated relation to others to determine its weight. The pairwise comparison matrix helps calculate the priority of each factor and ensures consistency in the evaluation, with a consistency ratio (CR of 0.09). The following Table 5 presents the weight of each exposure factor.

Table 5 reveals that annual precipitation variation and coastal erosion are the most significant climatic threats, with weights of 0.26 and 0.25, respectively. These factors indicate that fluctuations in precipitation and coastal degradation are the most significant challenges in Sam Son. The high weight assigned to coastal erosion emphasizes the urgent

need for targeted coastal protection projects in areas like Truong Son ward and Quang Cu ward, which are particularly vulnerable to sea-level rise and coastal storms. Increased variability in precipitation may lead to extreme weather events, which can disrupt tourism activities and negatively impact visitor experiences. Additionally, temperature-related factors also contribute significantly, with annual average maximum temperature variation (0.22) being the most influential among them. Temperature data is divided into average, average minimum, and average maximum values to capture the full range of climatic conditions affecting tourism. Using only a single temperature parameter would not provide a comprehensive view of the climate's impact on the region's tourism sector. The average minimum temperature is considered more important than the average temperature because lower temperatures during off-peak seasons can directly influence tourism patterns, particularly in coastal areas. The temperature variation in the study area shows notable fluctuations, with extreme variations in both minimum and maximum temperatures affecting tourism activities. This suggests that extreme temperature fluctuations may affect tourist comfort and outdoor recreational activities, potentially leading to shifts in visitor preferences and seasonal tourism patterns. Annual average minimum temperature variation (0.17) follows, highlighting the impact of lower temperature fluctuations, particularly on off-peak tourism seasons. However, annual average air temperature variation (0.10) has the lowest weight, indicating a comparatively lower impact on tourism development relative to other climatic variables. The Figure 3 was created by calculating the EI for each communes and wards using Equation 1, which combines the normalized values of exposure indicators (e.g., coastal erosion, temperature, and precipitation variations) with their respective weights. The Exposure Index for each region was then visualized spatially.

Table 5: Weights for exposure factors (E)

Number	ID	Exposure factor (E)	Weight
1	E1	Coastal erosion rate	0.25
2	E2	Annual average air temperature variation	0.10
3	E3	Annual average minimum temperature variation	0.17
4	E4	Annual average maximum temperature variation	0.22
5	E5	Annual average precipitation variation	0.26

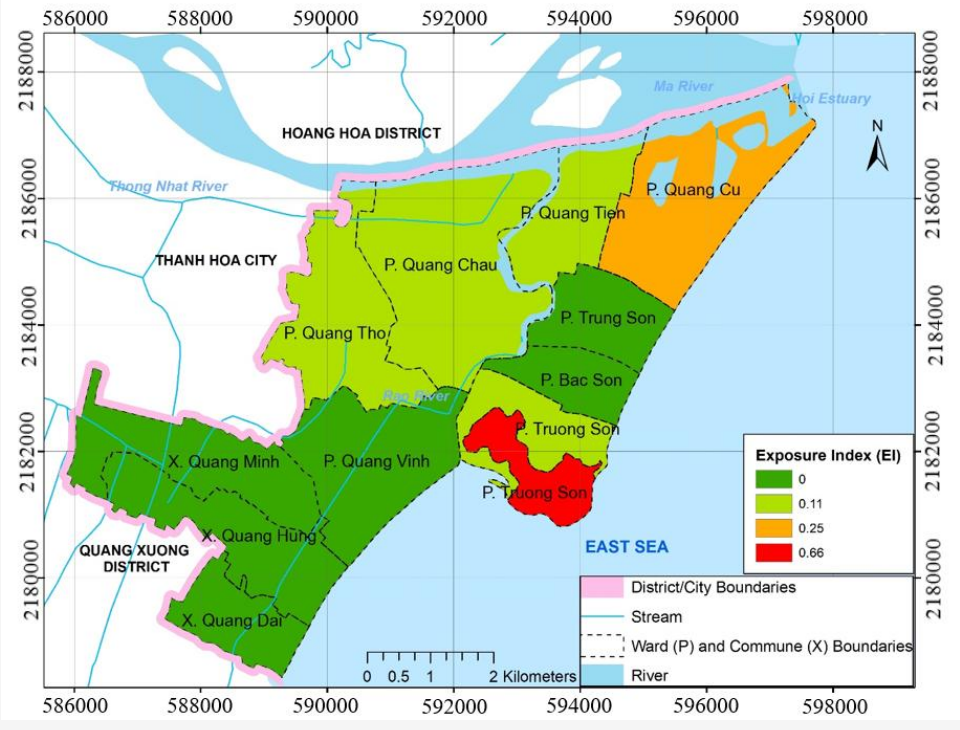

Figure 3: Exposure index

3.1.2 Sensitivity index

To calculate the weights of sensitivity factors, the AHP model considers the priority level of tourism factors affected by climate change. These factors are compared using a pairwise comparison matrix to determine their relative importance. The pairwise comparison process ensures consistency in the evaluation, with a consistency ratio (CR) of 0.01).

Table 6 shows that the weights assigned to the sensitivity factors in Sam Son's tourism industry, derived from the AHP model, show varying degrees of vulnerability to climate change. Tourist Volume (0.33) is the most sensitive factor, indicating that areas with high tourist traffic, such as Truong Le mountain area and Quang Cu ward, are more vulnerable to climate impacts. Given the significant tourist volume in these areas, we recommend that local authorities prioritize sustainable tourism practices and infrastructure development to mitigate the impacts of extreme weather events.

Following closely is Tourism Infrastructure (0.24), which highlights the importance of maintaining resilient facilities and services, as damage to infrastructure from climate events could have a devastating effect on tourism operations. Type of tourism (0.25) also plays a substantial role, as certain forms of tourism may be more susceptible to specific climate risks such as beach tourism facing sea-level rise, or cultural tourism threatened by the destruction of heritage sites. Lastly, the number of cultural heritage sites (0.18) is the least sensitive factor, though still significant, pointing to the fact that the loss or degradation of cultural sites, while impactful, is less critical in comparison to the other factors. This analysis suggests that climate change adaptation efforts should prioritize high-impact areas such as tourist volume and infrastructure to safeguard the future of tourism industry in Sam Son. Figure 4 represents the SI.

Table 6: Weights for sensitivity factors (S)

Number	ID	Sensitivity factors (S)	Weight
1	S1	Number of tourists	0.33
2	S2	Number of hotels	0.24
3	S3	Type of tourism	0.25
4	S4	Number of cultural heritage sites	0.18

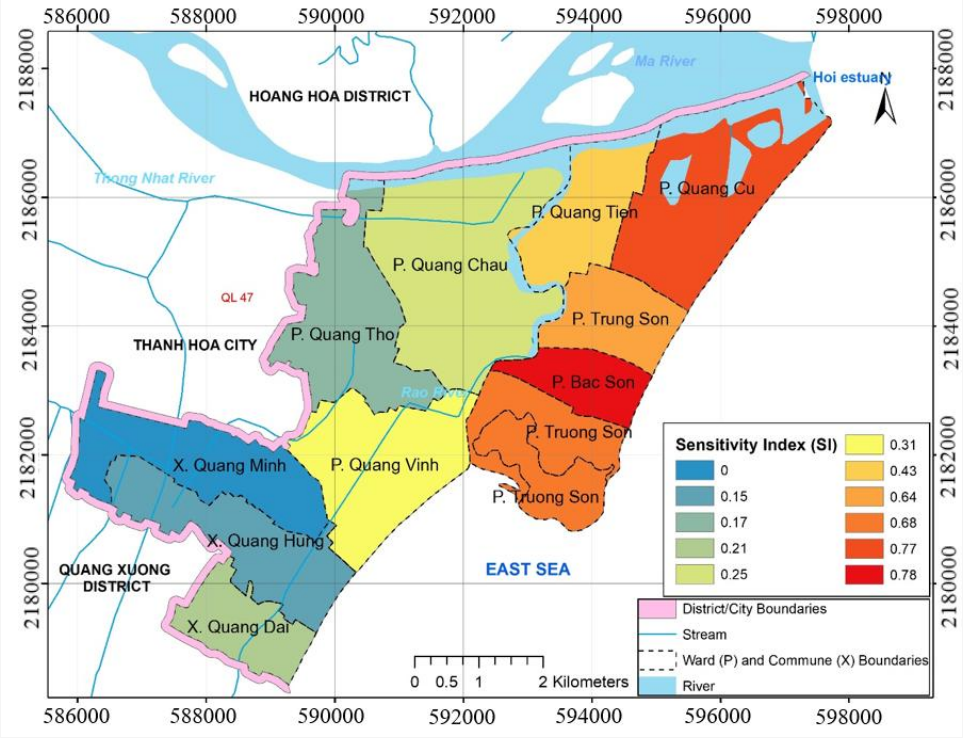

Figure 4: Sensitivity index

3.1.3 Adaptive capacity index

To achieve the objective of preventing and mitigating the adverse impacts of natural disasters and extreme climatic events on the tourism industry, the AHP method is used to determine the weightings of adaptive capacity of tourism industry in Sam Son City. This is done by evaluating the relevant factors through a pairwise comparison matrix to establish their relative importance. The consistency ratio (CR) of 0.02 confirms the reliability of the evaluation. The following Table 7 indicates the weightings of adaptive capacity factors for the tourism industry in Sam Son City.

Table 7 reveals that disaster preparedness training has the highest weight (0.29), which underscores the importance of local training programs to enhance community resilience in Sam Son, areas like Truong Le mountain and Quang Cu ward, which face higher exposure and sensitivity to climate change, would greatly benefit from increased investments in disaster prevention and training programs. Strengthening local education initiatives on climate resilience, particularly for those in high-risk areas, is a crucial step toward improving adaptive capacity. Additionally, the budget allocation for climate change adaptation with a weight of 0.28, highlights the need for adequate financial resources to implement mitigation and resilience strategies. Other important factors include the proportion of households with permanent housing and the employment rate with weights of 0.13 and 0.10, respectively, which contribute to the overall stability and resilience of the community. On the other hand, factors like access to electricity and healthcare facilities are of lower importance, with weights of 0.03 and 0.04, respectively, indicating that while these factors remain relevant, they have a lesser direct impact on the adaptive capacity of the tourism sector in comparison to others. Overall, the findings suggest that climate adaptation strategies for Sam Son's tourism industry should prioritize disaster preparedness, adequate financial investment, and stable housing to effectively address the challenges posed by climate change.

Figure 5 present the ACI for different wards and communes in Sam Son City. Figure 5 provide valuable insights into the regions' relative resilience and preparedness in responding to the challenges posed by climate change. This information is critical for identifying areas that require targeted adaptation measures to strengthen the local tourism sector and community resilience.

3.2 Coastal Tourism Vulnerability to Climate Change

3.2.1 Evaluation of the impact of exposure factors on tourism

Exposure factors refer to climatic and natural disaster elements that impact the vulnerability of the tourism sector. The higher the Exposure Index, the stronger the impact of climate change on tourism. The Exposure Index value is categorized into three levels: 1) EI value ranging from 0.0 to 0.24: low; 2) EI value ranging from 0.25 to 0.70: medium; 3) EI value ranging from 0.71 to 1.0: high. Figure 6 illustrates the EI across various wards and communes, distinguishing between low and medium exposure levels. The majority of the areas, including Bac Son ward, Trung Son ward, Quang Minh commune, Quang Vinh ward, Quang Hung commune, and Quang Dai commune, exhibit an Exposure Index of 0, indicating minimal environmental exposure. Geographical factors significantly contribute to exposure disparities in Sam Son. Coastal areas such as Truong Son ward and Quang Cu ward are more exposed due to their proximity to the coastline, facing risks like coastal erosion and storm surges. The topography also plays a role, with inland areas at higher elevations being less vulnerable. Additionally, geological features, such as the stability of coastal structures, and proximity to river mouths, like in Quang Cu ward, amplify exposure to flooding and erosion. These geographical variations highlight the need for location-specific adaptation strategies.

Table 7: Weights for adaptive capacity factors (AC)

Number	ID	Adaptive capacity factors (AC)	Weight
1	AC1	Proportion of households with permanent housing	0.13
2	AC2	Proportion of households with access to electricity	0.03
3	AC3	Proportion of households with access to safe drinking water	0.02
4	AC4	Number of healthcare facilities	0.04
5	AC5	Employment rate	0.10
6	AC6	Proportion of households with non-agricultural income sources	0.06
7	AC7	Urban population ratio	0.09
8	AC8	Budget allocation for climate change adaptation	0.28
9	AC9	Proportion of the population trained in disaster prevention	0.29

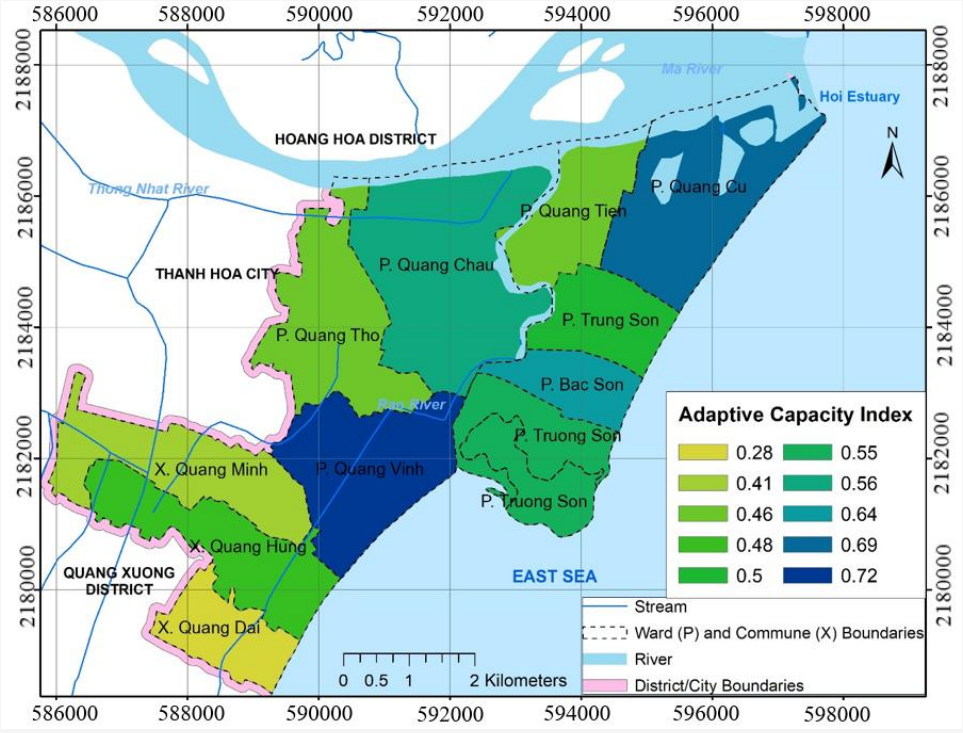

Figure 5: Adaptive capacity index

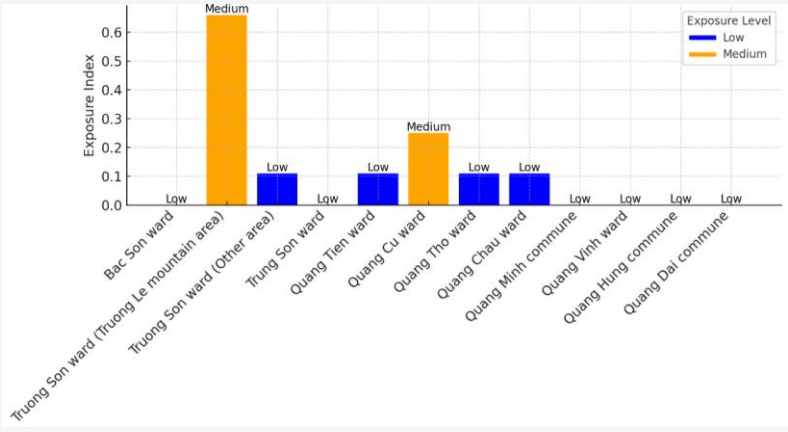

Figure 6: Spatial distribution of exposure index for tourism vulnerability in Sam Son city

Several other areas, such as Truong Son ward (Other area), Quang Tien ward, Quang Tho ward, and Quang Chau ward, have slightly higher values (0.11) but still remain within the Low Exposure category. However, Truong Son ward (Truong Le mountain area) has the highest exposure level (0.66), followed by Quang Cu ward (0.25), both categorized as Medium Exposure. The disparity in exposure levels suggests that certain environmental or geographical factors contribute to the higher exposure in specific areas. The significant exposure in Truong Son ward (Truong Le mountain area) may indicate increased environmental risks, necessitating further investigation and potential mitigation measures. Overall, the data highlights a predominance of low exposure levels across most areas, with only a few regions exhibiting medium risks.

3.2.2 Sensitivity assessment of tourism

Sensitivity factors represent the tourism industry's responsiveness to the impacts of exposure indicators. The higher the Sensitivity Index, the greater the vulnerability to climate change. In Sam Son City, the sensitivity of tourism ranges from 0 to 0.78, corresponding to three assessment levels: low (SI = 0.0-0.25), medium (SI = 0.31-0.43), and high (SI = 0.64-1.0) (Figure 7).

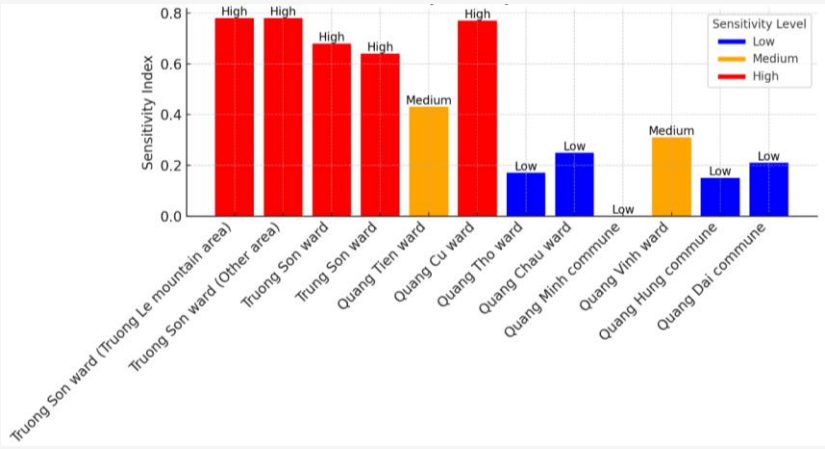

Figure 7: Spatial distribution of Sensitivity Index for tourism vulnerability in Sam Son City

Figure 7 illustrates the Sensitivity Index of various regions to climate change impacts, a crucial factor in assessing the vulnerability of tourism destinations. This index reflects the extent to which different areas are affected by climate change, considering factors such as natural conditions, infrastructure, livelihoods, and population density.

The analysis reveals that high-sensitivity areas, including Bac Son ward, Truong Son ward, Trung Son ward, and Quang Cu ward, exhibit Sensitivity Index values exceeding 0.6. These regions are likely to experience significant climate change effects, potentially due to their coastal locations, high population density, or economic dependence on climate-sensitive sectors such as tourism. Identifying these high-sensitivity areas underscores the urgent need for adaptation and mitigation measures to protect ecosystems and promote sustainable development. Meanwhile, medium-sensitivity areas, such as Quang Tien ward and Quang Vinh ward, have index values ranging between 0.4 and 0.5. These areas face medium vulnerability, which may be attributed to relatively better socio-economic conditions or infrastructure that enhances resilience against climate change impacts. In contrast, low-sensitivity areas, including Quang Tho ward, Quang Chau ward, Quang Minh commune, Quang Hung commune, and Quang Dai commune, register Sensitivity Index values below 0.3. These regions may demonstrate a higher adaptive capacity, possibly due to favorable environmental conditions or effective risk management policies.

3.2.3 Assessment of the adaptive capacity

Adaptive capacity factors represent the ability of socio-economic elements related to the tourism industry to withstand and adapt to the impacts of climate change and natural disasters. The higher the adaptive capacity, the better the ability to withstand the effects of climate change, resulting in lower levels of damage. Adaptive capacity depends on factors such as infrastructure, socio-economic conditions, and local policy mechanisms. In Sam Son, the value of the ACI is categorized into three levels: 1) ACI value ranging from 0.0 to 0.35: low adaptive capacity; 2) ACI value ranging from 0.36 to 0.63: medium adaptive capacity; 3) ACI value ranging from 0.63 to 1.0: high adaptive capacity. Figure 8 presents the calculation results for the ACI and the assessment of the adaptive capacity of the wards and communes regarding the tourism industry in Sam Son City. The adaptive capacity of Sam Son City's tourism sector to climate change is closely linked to the spatial variation in sensitivity levels across different wards and communes (Figure 8). The high-sensitivity areas, including Bac Son, Truong Son, Trung Son, and Quang Cu wards, exhibit significant vulnerability due to their elevated Sensitivity Index values (>0.6). These locations, likely key tourism hubs, are more exposed to coastal erosion, rising sea levels, extreme weather events, and flooding, necessitating urgent adaptation measures such as improved coastal defenses, resilient infrastructure, and disaster preparedness programs. The medium-sensitivity areas, such as Quang Tien and Quang Vinh wards, demonstrate medium vulnerability, suggesting a relatively better adaptive capacity, potentially due to economic diversification, improved infrastructure, or proactive governance. However, these areas still require targeted interventions to enhance resilience, particularly in sustainable urban planning and climate-smart tourism initiatives. In contrast, low-sensitivity areas like Quang Tho, Quang Chau, Quang Minh, Quang Hung, and Quang Dai communes exhibit greater adaptive capacity, possibly due to their lower exposure to climate risks, diversified economic base, or effective environmental management strategies.

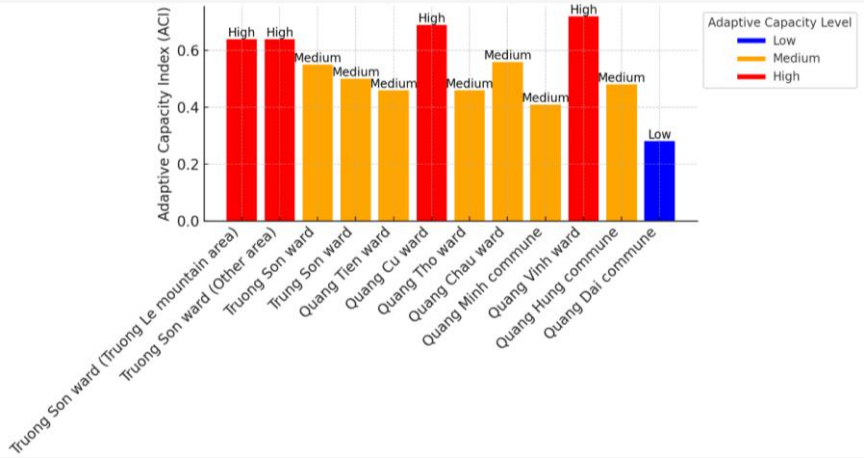

Figure 8: Spatial distribution of Adaptive Capacity Index for tourism vulnerability in Sam Son City

These regions could serve as climate-resilient tourism zones, offering alternative tourism models such as ecotourism and cultural tourism, reducing overall dependency on climate-sensitive coastal tourism. To strengthen adaptive capacity across all regions, an integrated approach combining climate-resilient infrastructure, sustainable tourism diversification, governance reforms, and ecosystem-based adaptation strategies is essential. Enhancing early warning systems, enforcing climate adaptation policies, and promoting sustainable tourism practices will be crucial in ensuring the long-term sustainability of Sam Son's tourism sector amid growing climate challenges. A low ACI suggests that the area has limited resources or infrastructure to cope with climate change impacts. For tourism stakeholders, this highlights the urgent need for capacity-building through training, disaster preparedness, and investment in climate-resilient infrastructure to better withstand extreme weather events and recover from climate-induced disruptions.

3.2.4 Assessment of coastal tourism vulnerability

The vulnerability index (VI) is an integrated measure composed of three variables: Exposure Index, Sensitivity Index, and Adaptive Capacity Index. The vulnerability level is directly proportional to the values of exposure and sensitivity, and inversely proportional to adaptive capacity. The severity levels of vulnerability were determined based on several previous studies conducted in similar areas, such as coastal regions where tourism development occurs [27] and [28]. Additionally, the decision to classify vulnerability into two categories (low and medium) was based on the distinct vulnerability patterns observed in Sam Son City.

The following Figure 9 illustrates that the vulnerability value of the tourism industry in Sam Son City ranges from 0.2 to 0.6, corresponding to a low to medium vulnerability level. Coastal areas, particularly in the Truong Le mountain area, exhibit high vulnerability due to their exposure to coastal erosion and storms, while inland regions with better infrastructure and adaptive capacity were classified as low vulnerability. This classification simplifies the analysis and helps prioritize immediate intervention in the most vulnerable areas. Figure 9 illustrates the VI for the tourism industry in Sam Son, showing the distribution of vulnerability across the area. A medium VI is observed in the northeastern part of the study area, a pattern that stands out compared to the low vulnerability areas. This pattern is attributed to a combination of factors, including medium exposure to coastal risks, topographical features, limited tourism infrastructure, and economic factors. A medium vulnerability indicates medium risk to tourism operations, such as intermittent disruptions due to coastal erosion, flooding, or extreme weather events. These regions are likely to experience seasonal or occasional disruptions in tourism activities, requiring stakeholders to focus on resilient infrastructure and preparedness plans to minimize the effects of such disruptions, particularly during peak tourism seasons.

4. Discussions

The findings suggest that areas with higher exposure, such as Truong Son ward and Quang Cu ward, require urgent investments in coastal defense and infrastructure improvements. Areas with high tourist volume, such as Truong Le mountain area, should focus on sustainable tourism strategies to minimize climate-related risks. Additionally, enhancing disaster preparedness through community training and building adaptive capacity in local populations is crucial. This integrated approach would not only protect the tourism sector but also strengthen the overall resilience of Sam Son to climate change.

The classification of the Vulnerability Index into two categories low and high vulnerability was chosen based on both the geographical and socio-economic context of Sam Son. This simplified classification provides clear, actionable insights for policymakers and local stakeholders, helping them focus adaptation efforts on areas with the highest vulnerability. Previous studies, have employed similar classification approaches to streamline decision-making and adaptation planning, particularly in coastal areas vulnerable to climate change [7] and [16]. By grouping the regions into two categories, we aim to facilitate immediate action in high-vulnerability areas while still addressing the broader issues faced by less vulnerable regions. The Figure 9 shows that the medium vulnerability level includes the coastal wards from Quang Cu ward to Truong Son ward, which account for more than 45% of the total number of wards and nearly one-third of the entire city's area. This area serves as the tourism hub of Sam Son City, located close to the coastline, and is directly affected by various types of natural disasters, such as coastal erosion and storms. Among the wards with medium-level tourism vulnerability to climate change, the Truong Le mountain area has the highest vulnerability value (VI = 0.60), nearly double that of the other areas (Figure 10).

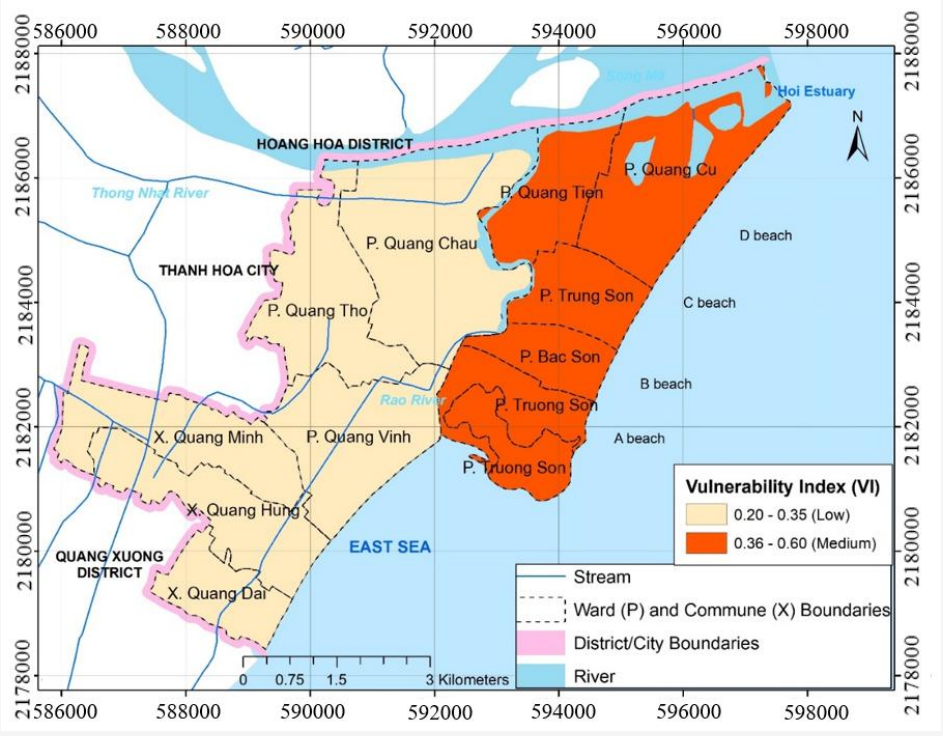

Figure 9: Vulnerability Index

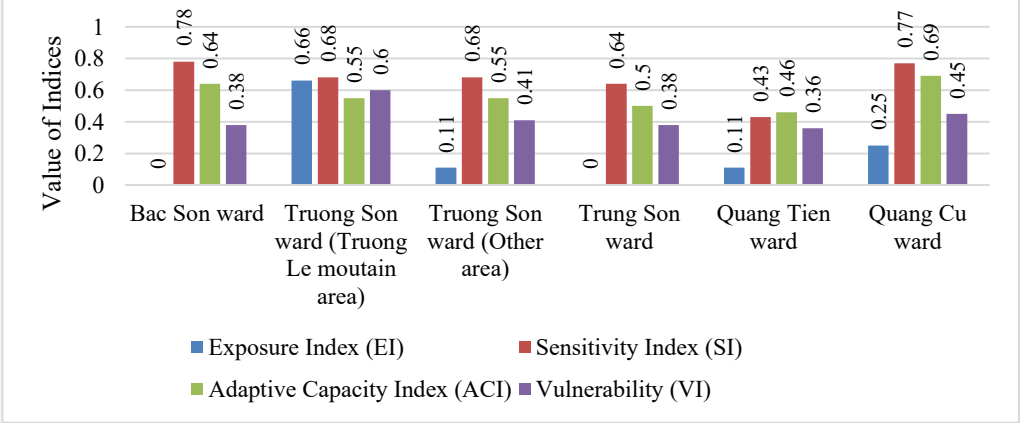

Figure 10: The wards with medium vulnerability

The reason for this is that the Truong Le mountain area is more severely impacted by natural disasters and climate change, resulting in an exposure value of 0.66 (more than twice that of Quang Cu ward and about six times higher than the other districts). Meanwhile, its adaptive capacity is not as high as that of the other wards due to lower socio-economic conditions. Quang Cu ward has a vulnerability value of 0.45, with exposure at a medium level (EI = 0.25), which is more than twice as high as the wards of Bac Son, Truong Son, Trung Son, and Quang Tien. This value is entirely accurate as it is an area with a highly sensitive environmental position, located along the coast and near a major river mouth (Ma River), with a relatively high annual coastal erosion rate.

Although they fall within the medium vulnerability range, the areas of Quang Tien, Trung Son, Truong Son (excluding the Truong Le mountain area), and Bac Son have much lower sensitivity values, only approximately one-sixth the sensitivity of Quang Cu and the Truong Le mountain area because of three reasons: Firstly, this region has significant tourism development potential, with the city's most beautiful beaches (Beaches B, C, and D) located here (Figure 9). Although it is situated close to the coast, the geological structure and ocean currents prevent these beaches from eroding, unlike those in the Quang Cu area. In fact, these beaches have experienced accretion, with the coastline expanding annually. During the 10-year period (2012-2022), the A, B, and C beaches have shown stable coastal conditions, with the greatest accretion measured at approximately 17.01 meters. Secondly, this area is part of the Sam Son tourism development center, where the city has made substantial investments. The transportation infrastructure is well-developed, wide, and open, with the elevation of structures raised significantly compared to previous years. Many hotels and guesthouses have been upgraded and built with solid, modern designs, especially in the C beach area, which has significantly reduced damage caused by storms, rising sea levels, and flooding. Thirdly, significant investments have been made in disaster prevention efforts, and the local population has better disaster response skills due to regular training and preparedness programs.

The areas with low vulnerability account for more than 55% of the total number of communes across the entire region, including three inland wards and three coastal communes in the southern part of Sam Son (Figure 11). Quang Vinh is a coastal ward located in the southern part of Sam Son city, an area less affected by climate change, as indicated by an Exposure Index value of 0. Although Quang Vinh has not been a major focus in the city's tourism development, it is home to two cultural and historical sites: the Hoang Minh Tu General's Temple and the Du Vinh Temple. As a result, its Sensitivity Index is at a medium level, reaching 0.31. Additionally, Quang Vinh benefits from high adaptive capacity, with a value of 0.72. Therefore, the tourism sector in this area experiences low vulnerability.

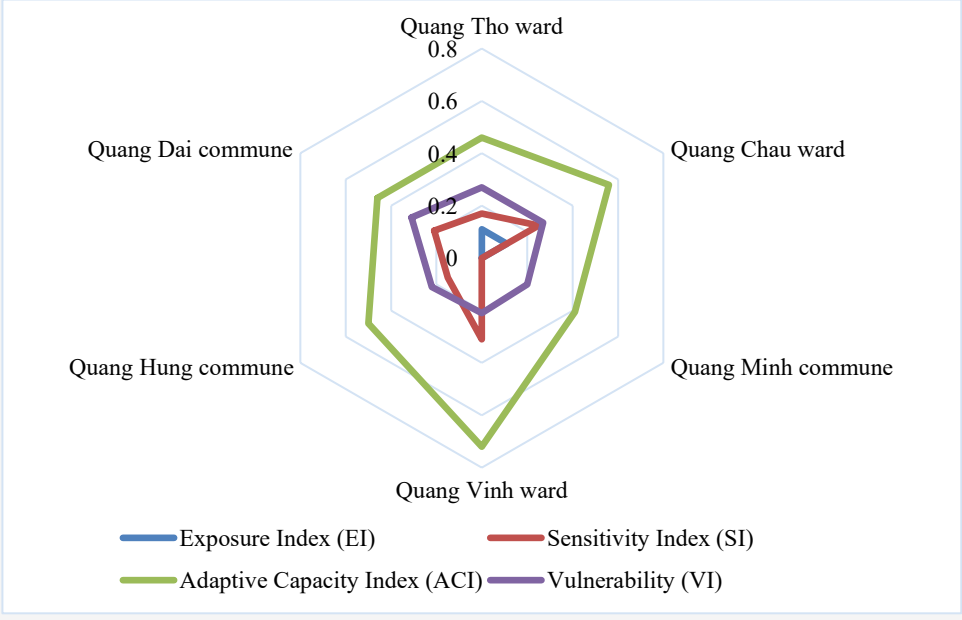

Figure 11: The wards and communes with low vulnerability

Quang Dai commune has a coastline of 1 km, a total land area of 210.88 ha, with approximately 75 ha dedicated to agricultural production, and is comprised of 5 villages. The population of the commune is 1,593 households, corresponding to 6,948 individuals, distributed across the five villages. The local population primarily depends on agricultural and fisheries activities for their livelihoods. The area lacks attractive beaches and historical sites, leading to underdeveloped tourism. Consequently, the tourism sector is minimally affected by climate change, with a low vulnerability rating.

The wards of Quang Tho, Quang Chau, and the communes of Quang Minh and Quang Hung are primarily located inland (except for Quang Hung) and are less affected by climate change, resulting in low exposure levels, with Exposure Index values close to 0. Due to the limited tourism resources, tourism activities in these areas are underdeveloped, and their Sensitivity Index is relatively low, ranging from 0 to 0.31. The adaptive capacity of these wards and communes is currently at a medium level, with adaptation index values ranging from 0.41 to 0.56. The local economy is primarily based on agricultural production, fishing, and aquaculture, which leads to a low proportion of non-agricultural employment, and investment in climate change adaptation measures has not been given significant attention.

5. Conclusion

This study employed a structured AHP-based framework combined with a composite Vulnerability Index to evaluate the susceptibility of Sam Son City's coastal tourism sector to climate change. The results reveal notable spatial heterogeneity in vulnerability levels across wards and communes, driven by variations in exposure, sensitivity, and adaptive capacity. Coastal areas such as the Truong Le mountain zone and Quang Cu ward face medium levels of vulnerability due to increased exposure to natural hazards and comparatively weaker adaptive infrastructure. Conversely, areas with limited tourism activities or better socio-economic conditions, such as Quang Vinh and Quang Dai communes, demonstrate lower vulnerability. While this study provides a comprehensive analysis of the vulnerability of Sam Son's tourism sector, there are several avenues for future research. Long-term monitoring of climate impacts, including studies on seasonal variations, visitor behavior, and economic consequences, will provide more robust data for future adaptation planning. Additionally, research integrating local knowledge and multi-criteria decision analysis (MCDA) will offer deeper insights into practical adaptation strategies. Expanding the scope of vulnerability assessments by including social and cultural factors will be essential to develop more inclusive adaptation policies in the future.

This study highlights the vulnerability of Sam Son's coastal tourism, particularly in areas like Truong Le Mountain and Quang Cu ward. To address these challenges, it is crucial to invest in coastal protection infrastructure, such as sea walls and beach nourishment, in high-risk areas. Additionally, enhancing disaster preparedness through regular training for local communities and tourism businesses will improve resilience. Promoting sustainable tourism by diversifying into eco-tourism and cultural tourism can help reduce dependency on vulnerable beach tourism. Establishing climate monitoring systems will provide valuable data for informed decision-making, while supporting economic diversification in sectors like aquaculture and agriculture will reduce reliance on tourism. Finally, allocating specific funds for climate adaptation and offering financial incentives for resilient infrastructure are essential steps to ensure the long-term sustainability of the tourism sector in Sam Son.

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