VULNERABILITY ASSESSMENT OF CROPS DUE TO SALINE INTRUSION IN VINH LONG PROVINCE

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Abstract: *Saline intrusion has become one of the most serious threats to agriculture in the Mekong Delta, yet most existing studies have focused on regional or river-basin scales, with limited attention to local-level differences. Vinh Long Province, where crop structures are diverse and highly sensitive to salinity, has received little systematic vulnerability assessment despite being increasingly exposed to salinity stress. This study aims to fill this gap by assessing the vulnerability of major crops to saline intrusion in Vinh Long Province, focusing on dry-season cultivation during 2021-2023. Input data include statistical yearbooks, expert consultation, and 128 field questionnaires. The methodology applies the AHP-based Vulnerability Index approach, integrating three components: Exposure, Sensitivity, and Adaptive Capacity. Results show that Vung Liem and Tra On districts exhibit high vulnerability (Vi > 0.6), while Vinh Long city is least affected. The findings not only highlight spatial differences in vulnerability but also provide a scientific basis for designing locally tailored adaptation strategies in agriculture.*

Keywords: *Exposure, sensitivity, adaptive capacity, vulnerability, Vinh Long.*

1. Problem statement

Major crops in Vinh Long include rice, pomelo, mango, and vegetables. These vary in salinity tolerance, with traditional rice varieties being the most sensitive (≥2‰), followed by fruit trees (3-5‰).

Vinh Long has many favorable conditions for agricultural production and is one of the three main pillars of the provincial economy, especially cultivation. With favorable conditions located between the Tien and Hau rivers, fertile land, and abundant water resources, Vinh Long Province has allocated crop production in the mainland such as rice, fruit trees, vegetables, and short-term industrial crops. According to a study by the Department of Agriculture and Rural Development of Vinh Long Province, in 2023, the area of annual crops will be about 159,421 hectares, with an output of 1,603,677 tons, and vegetables about 46,722 hectares, an increase of 0.2% over the previous year. The area of perennial crops is 70,327 hectares; of which the area of fruit trees is estimated at 59,184 hectares. To ensure sufficient irrigation water, water sources on rivers play an important role in providing irrigation water for crops. However, in recent years, due to the impact of climate change and increasing water demand, water resources in rivers have decreased. Along with the phenomenon of rising sea levels, saltwater has increasingly penetrated deeper into the fields, significantly affecting crop yields in the area.

Vulnerability assessment is a crucial tool, particularly when addressing seasonal changes in saline intrusion and crop cycles from 2021 to 2023.

While numerous studies have examined the impacts of saline intrusion on agriculture in the

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Mekong Delta, most have focused on regional or river-basin scales. However, systematic vulnerability assessments at the provincial level remain limited, particularly for Vinh Long - a province characterized by diverse crop structures and increasing exposure to salinity. This study addresses this research gap by developing a locally tailored vulnerability assessment, thereby providing scientific evidence to support district-specific adaptation planning.

2. Research methods and data used

2.1. Research methods

a. Collection method

Meteorological and hydrological factors; crop damage; economic and social planning in the study area were collected from management agencies, organizations, and departments in Vinh Long Province.

b. Sociological investigation method:

Conduct field surveys to identify research subjects along established routes and areas, and conduct sociological surveys of local people on the manifestations and impacts of climate change in Vinh Long Province, including awareness of climate change and salinity intrusion, as well as access to information related to climate change and salinity intrusion.

c. Vulnerability assessment methods

To quantitatively assess vulnerability, this study applied the Vulnerability Index (VI) approach, which integrates three components: Exposure (E), Sensitivity (S), and Adaptive Capacity (AC). The assessment framework was constructed following IPCC guidelines and national technical guidance [4].

Step 1. Selection of indicators (see Table 1)

A total of 17 indicators were selected to represent the three main components (3 for E, 8 for S, and 6 for AC). The selection was based on (i) Relevance to crop vulnerability under saline intrusion, (ii) Data availability, and (iii) Expert consultation. Indicators such as distance to the sea or dike protection were considered but excluded due to strong correlation with salinity indicators or lack of reliable data [6], [8].

Table 1. Calculation indexes to assess the level of susceptibility to saline intrusion

Factor	Index	Component Indexes	Unit	Symbol
Exposure	Area of land affected by saline intrusion	Area affected by salinity below 1‰	Ha	E.1
		Area affected by salinity below 8‰	Ha	E.2
		Area affected by salinity below 10‰	Ha	E.3
Sensitivity	Population	Total population	People	S.1
		Number of agricultural workers	People	S.2
	Livelihood	Rice growing area	Ha	S.3
		Annual crop land growing area (except rice)	Ha	S.4
		Perennial crop growing area	Ha	S.5
		Rice yield	Tons/year	S.6
		Annual crop land yield	Tons/year	S.7
		Perennial crop yield	Tons/year	S.8
Adaptive capacity	Community	People's awareness of climate change and saline intrusion	%	AC.1
		Access to information related to climate change and farming techniques	%	AC2
	Society	Number of medical facilities	Facilities	AC.3
		Percentage of people participating in health insurance	%	AC.4
		High school graduation rate	%	AC.5
		Rate of communes meeting new rural standards	%	AC.6

For the Exposure component, three salinity thresholds (1‰, 8‰, and 10‰) were applied to calculate affected land areas. The 1‰ threshold does not represent the physiological damage level of crops; rather, it serves as an early-warning indicator of saline intrusion, allowing spatial differentiation across districts. In contrast, the 2-5‰ thresholds mentioned in the Introduction indicate the actual tolerance limits of major crops, while 8‰ and 10‰ represent severe and extreme salinity stress that can lead to crop mortality. This distinction ensures that the Exposure indicators capture both the onset and the severity of saline intrusion risks.

Step 2. Normalization of indicators

All indicators were normalized using min-max rescaling to ensure comparability. For indicators positively correlated with vulnerability, a direct normalization formula was applied, while for those negatively correlated, an inverse transformation was used [12].

Step 3. Weighting of indicators and components

The Analytic Hierarchy Process (AHP) was used to determine the weights of both the sub-indicators and the three main components (E, S, AC). The procedure was as follows:

- A hierarchical structure was established with three main components and 17 sub-indicators.
- Pairwise comparisons were conducted using Saaty's 1-9 scale [3] A panel of 12 experts in hydrology, agriculture, and climate change participated in this process.
- The experts' judgments were aggregated using the geometric mean to construct the group comparison matrix [12].
- The eigenvector method was applied to extract the relative weights of the criteria.
- Consistency of expert judgments was tested by calculating the Consistency Ratio (CR). A CR of 0.083 (< 0.1) confirmed acceptable consistency [3].

The final weights for the three main components were WE = 0.38, WS = 0.52, and WAC = 0.10, indicating that Sensitivity was considered the most influential factor, followed by Exposure, while Adaptive Capacity contributed the least.

Step 4. Calculation of component indices

The standardized values of indicators were aggregated using their respective weights to calculate E, S, and AC indices at the district level:

$$M_i = \sum_{j=0}^{n} W_j \ , y_{ij} \, , i = 1, .. m$$

Where, M_i is the calculation index, exposure (symbol is E_i), sensitivity (symbol is S_i), adaptation capacity (symbol is AC_i));

i is the spatial unit;

j is the component index;

n is the sum of the component indices;

m is the total number of spatial unit;

w_j is the weight of component index j in the entire spatial units;

y_{ij} is the standardized value of component index *j* [4].

$$V_i = W_E\, E_i + W_S\, S_i - W_{AC} AC_i$$

Where, V_i is vulnerability index, risk under the impact of climate change in spatial unit *i*;

E_i is exposure value in spatial unit *i;*

S_i is sensitivity value in spatial unit *i*;

AC_i is adaptive capacity value in spatial unit *i*;

W_E, W_S, W_{AC} is the weights of exposure, sensitivity and adaptive capacity indices [2].

Step 6. Classification of vulnerability levels

The calculated V_i values were classified into five categories: Very Low (0.00-0.20), Low (0.21-0.40), Medium (0.41-0.60), High (0.61-0.80), and Very High (>0.80) [6], [7].

This methodological framework ensures that both quantitative data and expert knowledge are integrated, providing a robust basis for assessing crop vulnerability under saline intrusion in Vinh Long Province.

2.2. Data used

The calculated data is based on the annual Statistical Yearbook, socio-economic reports and natural disaster prevention work of the People's Committees of districts, towns and cities in Vinh Long Province. Within the scope of this study, the research team conducted a sociological survey in the form of a questionnaire for the subjects of management staff and people. The total number of questionnaires is 128, distributed to 8 districts, towns and cities in the province [5-12]. The data were analyzed using descriptive statistics and incorporated into the Adaptive Capacity indicators AC.1 and AC.2.

Indicators were selected based on literature review, expert consultation, and data availability. Other potential indicators, such as distance to the sea or dike protection level, were excluded due to data unavailability or high correlation with included salinity indicators.

The analysis was conducted at the district level due to consistent data availability across administrative units. Due to data limitations, crops were grouped into general categories.

The selection of component indicators was based on data availability, relevance to the local context, and expert consultation. For example, indicators such as distance to the sea or protected dike area were considered but ultimately excluded due to limited data availability and overlapping effects with existing indicators (e.g., salinity levels already reflect proximity to saline sources). The selected indicators represent measurable and relevant factors that significantly impact crop vulnerability under saline intrusion.

3. Results and discussion

3.1. Exposure calculation results

Exposure factors include the saline-affected land area at different thresholds, reflecting the extent of inundation caused by saline intrusion [5-12].

This is data on the natural area affected by salinity below 3‰, below 8‰ and below 10‰ in recent years in Vinh Long Province. The results of calculating the exposure component index (E) for crops due to salinity intrusion are presented in Table 2.

Table 2. Exposure component indexes (E) for crops due to saline intrusion in Vinh Long Province

Component factors	E.1	E.2	E.3
Weight	0.11	0.26	0.63
Vinh Long City	0.01	0.00	0.00
Long Ho District	0.00	0.00	0.01
Mang Thit District	0.00	0.05	0.07
Vung Liem District	0.04	0.26	0.51
Tam Binh District	0.03	0.05	0.24
Binh Minh Town	0.01	0.03	0.35
Tra On District	0.11	0.26	0.63
Binh Tan District	0.01	0.00	0.11

3.2. Sensitivity calculation results

Sensitivity (S) indicators include population size, number of agricultural workers, and crop areas/yields. Vung Liem and Tam Binh districts are the most sensitive due to their large agricultural areas and dependence on farming [5-12].

Indicators on agricultural subjects and especially crop cultivation will be the main subjects affected by the impact of saline intrusion on crops. Because crops play an important role in the province's agriculture, saline intrusion will greatly affect crop yields. Livelihood indicators including annual output and production value have been assessed. The results of the sensitivity component index (S) are shown in Table 3.

Table 3. Sensitivity component indexes (S) for crops due to saline intrusion in Vinh Long Province

Component factors	S.1	S.2	S.3	S.4	S.5	S.6	S.7	S.8
Weight	0.10	0.12	0.21	0.12	0.13	0.11	0.08	0.13
Vinh Long City	0.06	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Long Ho District	0.10	0.07	0.14	0.03	0.05	0.01	0.08	0.05
Mang Thit District	0.00	0.07	0.14	0.02	0.04	0.01	0.06	0.07
Vung Liem District	0.07	0.12	0.21	0.03	0.07	0.11	0.07	0.07
Tam Binh District	0.08	0.11	0.19	0.05	0.07	0.01	0.06	0.07
Binh Minh Town	0.00	0.01	0.04	0.05	0.03	0.00	0.00	0.05
Tra On District	0.05	0.11	0.04	0.03	0.13	0.00	0.07	0.13
Binh Tan District	0.00	0.07	0.09	0.12	0.03	0.00	0.03	0.04

3.3. Adaptive Capacity calculation results

The Adaptation Capacity (AC) is based on factors such as infrastructure development conditions, social conditions, local support policies, and the interest and attention of the government and local people [5-13] (Table 4).

Data is collected from monitoring statistics and information from survey questionnaires. People's awareness indicators show the level of interest and attention, from which there will be efforts to improve and solutions to adapt to saline intrusion. In addition, medical and educational conditions also play an important role in Adaptive Capacity.

Table 4. Adaptation component indexes (AC) for crops due to saline intrusion in Vinh Long

Component factors	AC.1	AC.2	AC.3	AC.4	AC.5	AC.6
Weight	0.10	0.14	0.16	0.23	0.19	0.19
Vinh Long City	0.08	0.14	0.04	0.01	0.19	0.19
Long Ho District	0.00	0.11	0.09	0.04	0.19	0.00
Mang Thit District	0.04	0.14	0.05	0.03	0.19	0.00
Vung Liem District	0.00	0.11	0.16	0.05	0.00	0.00
Tam Binh District	0.10	0.05	0.12	0.03	0.19	0.01
Binh Minh Town	0.04	0.14	0.00	0.01	0.19	0.01
Tra On District	0.00	0.05	0.00	0.23	0.16	0.00
Binh Tan District	0.00	0.00	0.03	0.00	0.19	0.01

3.4. Vulnerability calculation results

Vulnerability (V) is made up of 3 factors: Exposure (E), Sensitivity (S) and Adaptation Capacity (AC). The results of calculating the values of component variables and vulnerability for crops for each district of Vinh Long Province are shown in Table 5 [5-13].

In recent years, saline intrusion has occurred in Vinh Long, the reason is that the water level from the upper Mekong River to the Mekong Delta is very low, at times reaching a record low, leading to saline intrusion in the dry season, seriously affecting the Mekong Delta in general and Vinh Long in particular. The spatial distribution of vulnerability is illustrated in Figure 1.

The results highlight clear spatial differences in crop vulnerability to saline intrusion across Vinh Long Province. Vung Liem district recorded the highest vulnerability (V = 0.67, High), reflecting its extensive agricultural land, high dependence on rice cultivation, and relatively limited adaptive capacity. The district is highly exposed to salinity, while its communities face constraints in awareness, infrastructure, and access to adaptation resources. These interacting factors explain why vulnerability is substantially higher in Vung Liem compared to other districts.

At the other end of the spectrum, Vinh Long city exhibited a very low vulnerability index (V = 0.01). This outcome is consistent with the city's economic structure, where agriculture represents a small share of livelihoods. Greater diversification into services and industry, combined with better infrastructure, education, and health facilities, strengthens adaptive capacity. As a result, the city remains far less sensitive to saline intrusion despite being geographically located within the same province. This contrast shows that vulnerability depends not only on physical exposure but also on socio-economic conditions and adaptive capacity.

These findings are consistent with previous studies in the Mekong Delta. For example, Tran et al. (2018) reported that rural districts dominated by rice cultivation in Can Gio exhibited higher vulnerability than urban centers. Similarly, Le et al. (2021) highlighted that salinity intrusion disproportionately affects areas with high agricultural dependence and limited adaptive capacity. Compared to these studies, the present research contributes a finer-scale assessment at the provincial level, highlighting intra-provincial heterogeneity in vulnerability. This underscores the importance of localized adaptation strategies rather than uniform regional approaches. This spatial heterogeneity can be clearly observed in Figure 1.

Table 5. Crop vulnerability index in Vinh Long Province

Factors	**E**	**S**	**AC**	**V**	**Level**
Weight	0.38	0.52	0.10		
Vinh Long City	0.015	0.143	0.648	0.01	Very Low Vulnerability
Long Ho District	0.013	0.530	0.428	0.24	Low Vulnerability
Mang Thit District	0.119	0.414	0.445	0.22	Low Vulnerability
Vung Liem District	0.814	0.749	0.316	0.67	High Vulnerability
Tam Binh District	0.319	0.644	0.489	0.41	Medium Vulnerability
Binh Minh Town	0.398	0.183	0.383	0.21	Low Vulnerability
Tra On District	0.995	0.552	0.443	0.62	High Vulnerability
Binh Tan District	0.119	0.379	0.223	0.22	Low Vulnerability

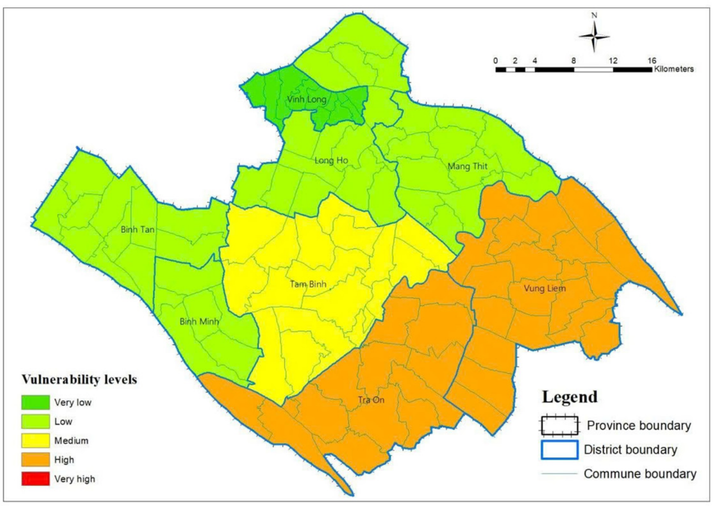

Figure 1. Spatial distribution of crop vulnerability to saline intrusion in Vinh Long Province

4. Conclusion and recommendations

Saline intrusion is a natural disaster that has a significant impact on agriculture, especially crop cultivation in Vinh Long.

The results are intended to support local authorities in developing targeted adaptation strategies. For example, Vung Liem and Tra On districts require urgent investment in salinity-tolerant crop varieties, community awareness programs, and freshwater storage infrastructure.

Based on the approach to assessing vulnerability by exposure, sensitivity and Adaptive Capacity, the assessment results show that Vinh Long city has very low vulnerability; Long Ho, Mang Thit, Binh Tan districts and the town of Binh Minh have low vulnerability, Tam Binh district has medium vulnerability; Tra On and Vung Liem are areas with high vulnerability. Although the results of the assessment of vulnerability to saline intrusion on crops in this study are consistent with actual data, these are only initial results. The selection of criteria and weighting methods still has many limitations, so more in-depth research is needed to perfect the criteria as well as determine the weights in the calculation, in order to achieve higher results in assessing the vulnerability to natural disasters in general and saline intrusion in particular in the region.

Despite providing valuable insights, this study has several limitations. First, the assessment was conducted at the district level, which may overlook intra-district heterogeneity in vulnerability. Second, the weighting of indicators in the AHP process relied on expert judgment, which, although consistent, still entails subjectivity. Third, the analysis focused on biophysical and socio-economic indicators but did not directly account for economic losses or long-term adaptation costs. Future research should incorporate higher-resolution data, consider economic damage assessments, and explore dynamic modeling of salinity intrusion under different climate change scenarios.

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