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Climate change vulnerability indicators for agriculture in Ho Chi Minh city

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Abstract:

The term vulnerability has been used in a variety of contexts, including climate change impact assessment. This study aimed to set up and evaluate climate change vulnerability indicators (CCVI) of agricultural zones based on exposure, sensitivity, and adaptation capacity to climate change in Ho Chi Minh city. Data from consultations with 10 experts was collected and analysed by the analysis hierarchy process (AHP). The CCVI, which includes 3 primary indicators and 22 secondary indicators, was applied to the agricultural districts in Ho Chi Minh that have been demonstrated to be the most vulnerable to climate change under both current conditions and over a longer timescales under various climate change exposure scenarios. The CCVI was weighted to support the climate change vulnerability assessment and indicate comparatively low or high climate change vulnerability areas. Finally, the areas most needy of further adaptation activities for agriculture in Ho Chi Minh city were identified.

Keywords: **agriculture, AHP, climate change, vulnerability indicator.**

Classification number: **5.2**

Introduction

Climate change has clearly affected all areas of society and economy. In particular, Ho Chi Minh city is considered to be one of the 10 cities most affected by climate change [1]. Agricultural production in Vietnam, and in Ho Chi Minh city in particular, depends very much on the weather and faces several challenges such as changing water sources, rising temperatures, and droughts, among other extreme weather phenomena.

Ho Chi Minh city resides in the southeast region of Vietnam and has a total area of 2,095.01 km^2 [2]. The city is located in a transitional zone between the southeast and the Mekong delta. Ho Chi Minh city has lower elevations to the southeast. Located downstream of the Dong Nai river system, Ho Chi Minh city, also known as Saigon, has a very developed network of rivers and canals with a total length of 7,955 km (Fig. 1).

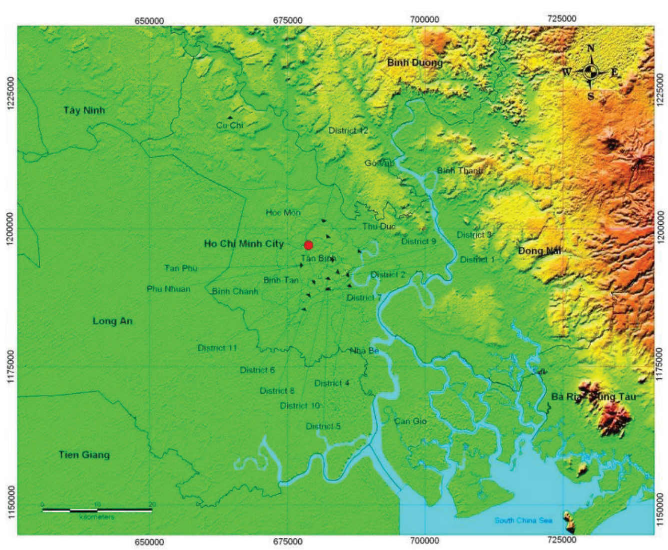

Fig. 1. Ho Chi Minh city, located within the Dong Nai river basin. Source: [3].

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According to the Ho Chi Minh city Department of Agriculture and Rural Development (2015), 14 out of the 24 districts have agricultural activities with the 5 main agriculture districts being Cu Chi, Hoc Mon, Binh Chanh, Nha Be, and Can Gio. In total, the agricultural land area amounts to 104,000 hectares, accounting for nearly 50% of the total city area. Although the area of agricultural land has decreased gradually due to civilization, the average production value is still high. The average growth rate of agricultural production over the period of 2006-2010 reached 4.14%, and between 2011-2015 it was 6.01% [4].

Due to climate change, the agricultural production area has become mainly concentrated in suburban districts such as Cu Chi, Hoc Mon, and Binh Chanh, which are the most low-lying areas along the river, and thus, the most affected by climate change. According to the report of the Steering Committee for Climate Change Adaptation and Mitigation Action Plan [5], over the past 6 years (2005-2010), climate change events, especially tropical storms, high tides, and heavy rain causing prolonged flooding, has caused damage to the agricultural production of Ho Chi Minh city. Specifically, 1,520 ha of rice and 2,970 ha of sugarcane are affected by inundation, 1,770 ha of rice and 2,970 ha of sugarcane are affected by saline intrusion, and over 1,101 hectares of rice and 545 hectares of vegetables are affected by drought.

These effects threaten sustainable city development if immediate and appropriate adaptations to these impacts are not established. Thus, it is necessary to assess the extent of vulnerability under the impact of climate change on agricultural production. This study was carried out with the aim of determining the climate change factors that cause damage to agricultural production and to determine a weight for each indicator. These results are an important basis for conducting vulnerability assessments for the city's agricultural sector.

Literature review

Vulnerability is an implicit concept and has been addressed in many works. There are various ways to define the concept of vulnerability. Vulnerability is usually addressed with respect to specific types of risks such as flood, drought, and poverty. Dwyer, et al. (2004) [6] stated that there have been many concepts of vulnerability and each concept can be defined based on specific domains. Vulnerability assessments are investigated over diverse scales such as national, regional, local, or in a specific ecosystem. In its beginning stages, vulnerability assessments were concentrated on assessing physical risks [7-9]. Such an approach was also applied to many other aspects such as food security [10, 11] or socio-economic development [12].

In 1992, vulnerability was defined as the extent to which a system cannot cope with the effects of climate change and sea level rise [13]. From 1996 to 2007, the Intergovernmental Panel on Climate Change's (IPCC) second assessment report issued many definitions of climate change vulnerability. In general, vulnerability can be understood to be the degree to which "a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity". According to these new concepts, vulnerability can decrease when more adaptation options are implemented.

According to the IPCC, vulnerability is a function of the character, magnitude, and rate of climate change and can vary depending on which system is exposed, its sensitivity, and its adaptive capacity. Vulnerability is dependent on the exposure to risks (E), sensitivity (S), and adaptive capacity (AC) of a system that deals with climatic impacts. In particular, the exposure component is made up of the factors reflecting the physical changes of climate such as weather condition, hydrology, etc. Sensitivity is the vulnerability magnitude of each system when no adaption options are implemented or is the extent to which each system depends on certain conditions. Adaptive capacity is the extent to which each system can ease the adverse impacts of climate change or utilize the opportunities from beneficial effects.

Vulnerability (V) can be described as follows:

$$V = f(E, S, AC)$$

where:

- E: exposure is the extent of a system that is exposed to significant changes in climate.

- S: sensitivity is the extent of a system affected both negatively and positively by climate change (including change of means, extremes, and climate variability).

- AC: adaptive capacity is the capacity of each organization or each system that can ease risks related to climate change or can utilize benefits from such changes.

The vulnerability assessment method uses an index or a set of indicators with weights or average weights for each indicator to assess vulnerability [14]. Vulnerability is a positive correlation to exposure and sensitivity of the exposed system. This means that an increase in exposure leads to an increase in vulnerability.

A wide range of research based on vulnerability assessment index has been conducted [8, 15-21]. This index is made up of many indicators that make a region vulnerable.

A set of indicators has been developed specifically for exposure, sensitivity, and adaptability, or for all three factors combined like in the studies by UNESCO-IHE [21]. However, developing an appropriate set of indicators remains an important challenge [17].

Recently, a group of authors conducted vulnerability assessments on residential, industrial, and agricultural services using GIS tools combined with AHP [22-24]. Factors of exposure, sensitivity, and adaptive capacity were weighted and used for building a vulnerability map. However, almost all research was concerned with the impact assessment of flood damage [22, 25, 26].

Therefore, in order to assess the overall impact of all the factors on agriculture in Ho Chi Minh city, research and development of suitable and measurable CCVI based on exposure, sensitivity, and adaptive capacity is crucial.

Methodology

CCVI

According to the objectives of vulnerability assessments to climate change, the first step is to synthesize necessary factors that can influence vulnerability in the study area. To achieve this task reliably and effectively, a literature review and file survey is used. In particular, the literature review approach enables the researcher to draw a general picture of vulnerability in the study area from the past to present day. Meanwhile, fieldwork makes it possible for the researcher to have insights into the real situation of climate change impacts, local livelihood and their relationships, and the potential effects of climate change in the future.

From the above literature review and field survey results, a list of influential factors in the zone vulnerable to climate change are developed. These factors are subdivided into four groups as follows: nature, economy, society, and infrastructure.

The process of developing CCVI for agriculture is done through a literature review process on climate change variability and its impacts on the agricultural sector in Ho Chi Minh city. In addition, economic and social factors are also considered to assess the system's sensitivity to climate change. Consultation with experts at a workshop facilitated the determination of the indicators important to the assessment of the vulnerability of the agriculture in Ho Chi Minh city. The selection of indicators was informed by a set of four factors provided by Gbetibouo, et al. (2010) [27], namely, relevance, adequacy, ease, and data availability.

The expert consultation method is commonly used in many fields and research directions, such as in studies on vulnerability assessment [28, 29], on climate change adaptation [30, 31], and in agricultural [32] and fishery studies [33]. The list of experts is based on the team's discussion. The team invited 9 experts with a variety of expertise such as economics, environmental resource management, water resource management, and hydrometeorology to consult about vulnerability indicators and their respective weights. The experts had general knowledge about climate change and over 5 years research experience on climate change. The review of Rowe and Wright (1999) [34] suggests that the number of experts can range from 3 to 98.

The literature review provided a list of climate exposure, sensitivity, and adaptive capacity indices typical in agriculture sectors. The consultation in vulnerability indicators was conducted over 3 steps including: (i) forming a list of experts to invite for consultation; (ii) sending questionnaires to the experts, and (iii) the expert consultation. Experts were requested to assess the degree of impact of climate change variabilities and indices. A Likert scale was used to assess impact degree from 1 (very light) to 5 (very serious) and the rating scale of certainty was from 1 (not sure) to 3 (very sure). The evaluation is described in more detail in Table 1. The weighted average score was used to measure the degree of impact.

Table 1. Description of the assessing scale of climate change degree of impact and scale of certainty.

Scale	Definition	Explanation
Scale of climate change impact degree		
1	Very light	... has very light impact to agriculture production
2	Light	... has light impact to agriculture production
3	Average	... has average impact to agriculture production
4	Seriously	... has serious impact to agriculture production
5	Very seriously	... has very serious impact to agriculture production
Scale of certainty		*Degree of certainty*
1	Not so sure	0-30%
2	Sure	>30-70%
3	Very sure	>70%

Weighting by Analytic Hierarchy Process (AHP)

The established CCVI are expressed through the integrated climate change risk index. In essence, each indicator and its components have a certain role in shaping the vulnerability level. Consequently, the weight of each CCVI factor is identified by the AHP [12, 35]. AHP descends from the theoretical measurement of priority and is based on mathematics and psychology. There are three prime principles of AHP: analyzing, comparing, and synthesizing. When assessing vulnerability to climate change, there are multiple factors that contribute to each vulnerability level. In addition, the interconnection between these factors is complicated. However, the imperative question that needs to be clearly addressed is which factor could be considered as most influential to vulnerability in a certain area, and the other urgent question is how to estimate these factors quantitatively. Therefore, applying AHP is a suitable and effective approach. After consideration of how AHP was applied in previous studies, the procedure of AHP in this study is shown in Fig. 2.

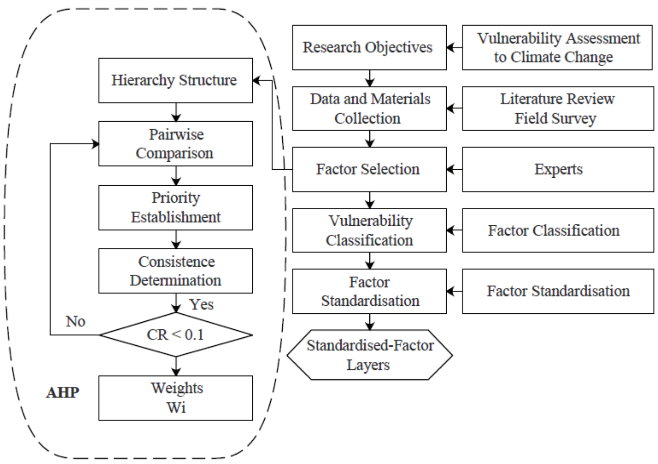

Fig. 2. The AHP procedure.

To determine the most influential factors, a questionnaire was sent to experts and the final pair-wise comparison values for each indicator was discussed and resolved by the experts. In the AHP procedure, the values of the pair-wise comparison matrix are qualitative, so these values must be converted into quantitative ones. Further, it is also necessary to check the consistency of each matrix through the consistency ratio (CR). Finally, in the case where the CR is less than 10%, the results of computing weights can be approved. If CR is greater than 10%, it will be necessary to return to the expert to check the answer.

Results and discussion

Vulnerability assessment indicators for Ho Chi Minh city agriculture

Exposure index is understood as a direct threat, including the nature and extent of changes in extremes of the region [27]. The National Target Program to Respond to Climate Change in Vietnam [15] has identified the impacts of climate change in areas that can be affected. In particular, the Southern delta (including Ho Chi Minh city) and the Mekong river are currently affected by the phenomena of saline water intrusion, flood, storm, and drought. According to the results of the expert consultations, it is believed that the agricultural sector in most severely damaged by the impacts of climate change. The weighted average of heavy rain exposure was 3.88, temperature rise was 3.50, and the flooding was 4.13. The expert was certain of his assessment with a weighted average of 2.38 points (Table 2).

Table 2. Score of the various climate change effects.

No	Climate change effects	Score	Certainty
1	Saline intrusion	3.63	2.38
2	Drought	3.50	2.38
3	Heavy rain	3.88	2.38
4	High temp.	3.50	2.38
5	Flooding	4.13	2.38
6	Sea level rise	2.38	2.38
7	Storm	1.96	2.38

Based on the climate change trend of Ho Chi Minh city and expert consultant results, this study selected 6 climatic indicators that often occur and affect agricultural production, high temperature, heavy rain, meteorological and hydrological drought, flood, and saline intrusion to determine exposure.

The sensitivity index describes human environmental conditions that can exacerbate the level of danger, improve hazards, or cause an impact [22, 24]. Researchers on climate change have pointed out the relationship between socio-economic factors, as well as infrastructure, that affect the impacts of climate change, such as income, poverty, and employment, among others [12, 16, 17]. Therefore, the study also classifies factors affecting climate change impacts into 3 economic, social, and infrastructure groups [36]. Based on the statistical yearbook and other vulnerability assessment studies, this study uses 12 indicators within the economic, social, and infrastructure groups to determine sensitivity.

Adaptative capacity index is the ability to implement adaptation measures that can prevent potential impacts [22, 24]. In order to assess resilience, this study had two focus directions: government support and citizen self-response [12]. This study used the following 4 indicators to assess resilience: awareness of urban climate change (flooding), experience of coping with flooding, heavy rain, and high temperature, government support, and accessibility to resources.

Table 3 presents all the CCVI for the agriculture in Ho Chi Minh city and their functional relationship with indicators.

Table 3. Climate change vulnerability assessment indicators for agriculture.

Indicator	Index	Sub_index	Description	Functional relationship with indicator
Exposure	High temperature	Trend of high temperature day	Day is over 35°C	+
	Heavy rain	Trend of heavy rain day	Rainfall day in 95 percentile	+
	Hydrological drought	Trend of hydrology drought	Drought day base on K/SDI index	+
	Meteorological drought	Trend of meteorology drought	Drought day base on SQI index	+
	Flood	Depth of flood	Depth of flood	+
	Saline intrusion	Salinity	Salinity	+
Sensitivity	Society	Worker in agriculture	Ratio per district	+
		Dependent inhabitant	Ratio per district	+
		Female	Ratio per district	+
		Poor household	Ratio per district	+
		Population density	Number people of km^2 per district	+
	Economy	Rice area	m^2 per district	+
		Plant area	m^2 per district	+
		Aquaculture area	m^2 per district	+
		Proportion of households with the main income from agriculture	Ratio per district	+
	Infrastructure	The rate of irrigation system is modernized	Ratio per district	-
		Road density is concreted	Ratio per district	-
		Rate of using electricity grid	Ratio per district	-
Adaptive capacity		Climate change awareness and urban flooding	Score per district	+
		Experience coping with floods, heavy rain, high temperatures	Score per district	+
		Government support	Score per district	+
		Access to support	Score per district	+

+: positive functional relationship; -: negative functional relationship.

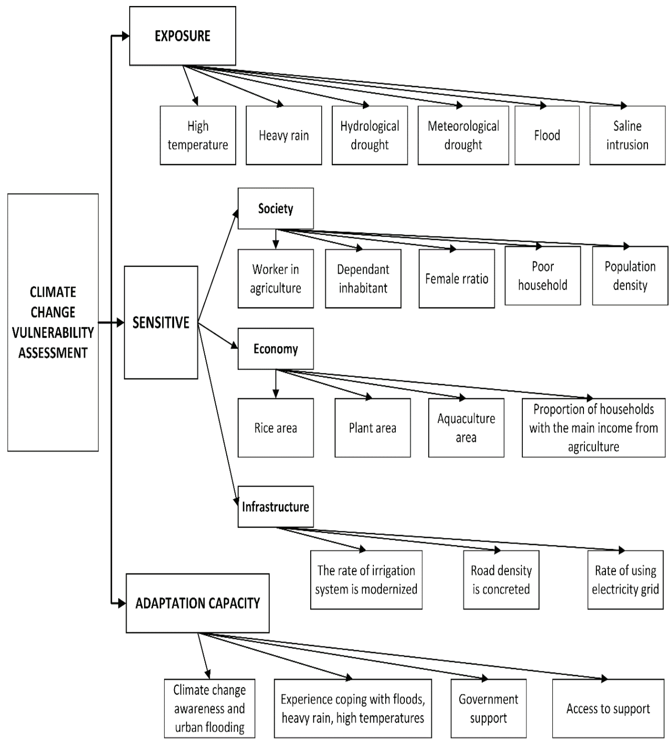

Fig. 3. Hierarchy structure of climate change vulnerability assessment.

Weighting by AHP

After building a comparison matrix pair with the main and secondary indices, the AHP algorithm calculates the weight for each of the abovementioned indicators as in Fig. 3. The result of the 9 questionnaires are synthesized and the consistency ratio is calculated for each table. The computed weights of the indicators with a consistency ratio less than 10% are presented in Tables 4 and 5.

Table 4. Weights for exposure indicators.

Exposure	Weight	
	In crop activities	*In aquaculture activities*
High temperature (E_1)	0.1532	0.1986
Heavy rain (E_2)	0.1149	0.1467
Meteorology drought (E_3)	0.1572	0.1436
Hydrology drought (E_4)	0.1668	0.145
Flood (E_5)	0.2210	0.1841
Saline intrusion (E_6)	0.1869	0.1819

Two sets of weights for exposure indicators that are formulated separately for Ho Chi Minh city's cultivation and aquaculture agricultural sectors. In particular, flooding was found to have the most impact on cultivation and hot weather had the greatest impact on aquaculture.

Table 5. Weights for sensitivity and adaptive capacity indicators.

Indicator	Index	Sub_index	Weight
Sensitivity	***Society***		***0.1794***
		Worker in agriculture	0.2118
		Dependent inhabitant	0.2167
		Female	0.1246
		Poor household	0.2898
		Population density	0.1571
	Economy		***0.3206***
		Rice area	0.3193
		Plant area	0.2151
		Aquaculture area	0.2131
		Proportion of households with the main income from agriculture	0.2525
	Infrastructure		***0.5000***
		The rate of irrigation system is modernized	0.3588
		Road density is concreted	0.3198
		Rate of using electricity grid	0.3214
Adaptive capacity		Climate change awareness and urban flooding	0.1833
		Experience coping with floods, heavy rain, high temperatures	0.3303
		Government support	0.2889
		Access to resources	0.1976

For Ho Chi Minh city's agriculture, the survey findings show that infrastructure investment on agriculture, including irrigation systems, power grids, and concrete roads, had the highest impact on vulnerability. Meanwhile, social factors also contributed to vulnerability but at a lower level.

Besides, weighting calculations also showed that experience with coping with floods, heavy rain, and high temperatures was the most important factor behind decreasing climate change vulnerability in agriculture.

After the E, S, and A indicators are defined, V is calculated by the formula as following:

$$V = \sum w_{Ei} \times E_i + \sum w_{Sn} \times S_n - \sum w_{Ae} \times A_e$$

where w: weight, i: number of E; n: number of S; e: number of A.

Then, the value of V will show Ho Chi Minh city's agricultural sector's vulnerability to climate change. The CCVI for agriculture is a method of vulnerability analysis through integrated aspects of a system.

Finally, the calculation results from the vulnerability index will be normalized from 0 to 1. The areas with avulnerability value near 1 are highly vulnerable to climate change and a value of V near zero indicates that the area is not vulnerable.

After the CCVI is calculated for each exposure, vulnerability can be assessed through synthesis or a separate analysis of each exposure for each specific area. From the set of vulnerability indicator assessments to climate change for agriculture, it is possible to establish thematic maps and digital data tables for managers and citizens to easily access.

Conclusions

There are many perspectives, concepts, and definitions of vulnerability, but on the basis of multiple perspectives and concepts, vulnerability is strongly dependent on exposure, sensitivity, and adaptive capacity. In particular, weights for each indicator were also established to assess the level of contribution to the overall system. By referring to prior literature on natural influences, socio-economic conditions, and climate change impacts on Ho Chi Minh city, the 22 vulnerability assessment indicators for Ho Chi Minh city's agriculture were established including 6 exposure, 12 sensitivity, and 4 adaptability indicators.

Applying CCVI to agriculture can make inhabitants and governments aware of vulnerability in Ho Chi Minh city's agricultural areas. With the CCVI, vulnerability assessment by index development is an effective method to convert qualitative factors into quantitative factors so that climate change impacts can be predicted in different scenarios. Additionally, CCVI and their weights are powerful tools for mapping vulnerable agricultural areas within the city. In this way, it will provide policymakers with a broad overview of the agriculture components affected and of possible adaptation options that should be taken.

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