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ASSESSMENT OF VULNERABILITY DUE TO CLIMATE CHANGE ON THE AQUACULTIVATION ECOSYSTEM OF NAM PHU COMMUNE, TIEN HAI DISTRICT, THAI BINH PROVINCE

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Abstract. This paper describes an effective application of a method by the Intergovernmental Panel on Climate Change (IPCC) to calculate the level of vulnerability due to the impact of climate change on the aquaculture ecosystem in Nam Phu commune, Tien Hai district, Thai Binh province. Original data were collected from a series of surveys throughout the research area with information from interviews of people in Nam Phu commune using 95 questionnaires. Our results show that the aquaculture ecosystem in the study area has a high exposure index (E) and sensitivity index (S) with score of 0.76 and 0.71, respectively, while adaptive capacity (AC) is average with score of 0.42. The vulnerability index (V) is 0.68 and can be ranking at highly vulnerable.

Keywords: vulnerability, aquaculture ecosystem, climate change, Nam Phu commune.

1. Introduction

Climate change and extreme weather phenomena are major challenges for humans in the 21st century. The impacts of climate change on all economic aspects and other fields including agriculture have led to critical issues for humans. Floods and sea level rises are major causes of land loss for agriculture. Additionally, the area of agricultural land has also been narrowed and even lost by saline intrusion in coastal areas [1].

Nam Phu commune belonging to Tien Hai district, Thai Binh province, covers a large region with typical coastal characteristics. With alluvial land and coastal wetland areas, it contains favorable conditions for agricultural development, especially aquaculture. Unfortunately, results from previous studies and assessments indicated that Nam Phu commune is critically impacted by climate change with typical manifestations including storms, sea level rise, and increased flooding during the rainy season with water shortages in the dry season [2]. Remarkably, the sea level rise and saltwater intrusion occur rapidly and frequently. They affect the water sources and aquaculture critically. To date, saltwater intrusion has covered around 1‰ of the total land area of Tien Hai district [3]. On the other hand, approximately 67.5% of the total area of Tien Hai district will be flooded when the sea level rises to 50cm in comparison with the current sea level [4].

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According to the Intergovernmental Panel on Climate Change (IPCC) [5], vulnerability exhibits the impact levels of climate change which damages different ecosystems. Therefore, vulnerability depends on not only the system's sensitivity but also the community's ability to adapt to new climatic conditions. Vulnerability is also constituted by the level of sensitivity and ability to adapt to the negative impacts of climate change [6]. The Nam Phu commune has received attention from scientists but almost all previous studies focus on mangroves and selected coastal ecosystems with emphasis on basic assessments of biodiversity sensitivity. Many important agricultural ecosystems including farming, animal husbandry, and others were likely "ignored". In other words, these ecosystems have not received much attention from both scientists and authorities. Several studies were implemented in Tien Hai district for assessments of vulnerability to climate change but just focused on livelihoods [2, 7]. This paper provides the first scientific data with an evaluation of the vulnerability of the aquaculture ecosystem due to the impact of climate change in Nam Phu commune. Recommendations are also given to minimize the vulnerability of the aquaculture ecosystem and to increase the production efficiency of the aquaculture of local people in the study area.

2. Content

2.1. Data and methods

2.1.1. Data

A series of surveys were conducted between January and September 2023 in Tien Hai district, Thai Binh province, with an emphasis on the aquaculture ecosystem in Nam Phu commune. The elements of the Livelihood Vulnerability Index (LVI) with the component indices were regarded as major objects for investigation during our surveys. Data were collected from local authorities, publications, and information from local household surveys throughout the study area.

Primary data was also obtained from the surveys to understand the opinions of agricultural households in the study area. Obtained data from the survey questionnaires was analyzed and calculated using the following formula:

$$n = N1+N.e^2$$

Of which, n is the sample size, N is the total number of households in the study area and e is the probability of encountering type 2 error (usually from 5% to 10%) [8].

With a total number of households in Nam Phu commune of 1,552 households (2022), and according to calculations from the above formula, the number of households surveyed in the research was 95 households. The content of the survey was specific information about the locality such as extreme weather phenomena occurring in the last 5 years, the current status of agriculture, and aquaculture in particular, and social and community conditions.

The primary data was used to calculate sub-indicators: the proportion of people reporting extreme weather phenomena occurring in the locality (sub-indicators E_{42}, E_{43}, E_{44}), the proportion of households working in agriculture and aquaculture (S_{12}, S_{13}), the percentage of households not proactive in water sources in aquaculture (S_{32}), social conditions (AC_{21}, AC_{22}, AC_{23}) and local community (AC_{31}, AC_{32}, AC_{33}, AC_{34}).

The collected data was processed using SPSS 2.20 software. All processed data was extracted into an Excel file which was then added to the vulnerability assessment index table.

2.1.2. Methods

To assess the vulnerability of aquaculture ecosystems, the present study applied a set of 3 factors (exposure, sensitivity, and resilience) according to the Intergovernmental Panel on Climate Change (IPCC) using the following formula:

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

Of which:

+ Exposure (E) is the direct hazard, nature, and scale of changes in the climate of a region. Indicators of exposure include temperature changes, rainfall changes, salinity, and weather phenomena (sea level rise, storm surge, floods, drought).

+ Sensitivity (S) includes indicators on population, livelihoods, natural conditions, effects of natural disasters, and climate change.

+ Adaptive capacity (AC) demonstrates the ability to apply adaptive solutions to help prevent and minimize impacts. Indicators of AC include government, society, and community.

The vulnerability assessment for the aquaculture ecosystem in Nam Phu commune was carried out through the following steps:

Step 1: Identify main indicators and sub-indicators

Step 2: Standardize the data to remove the dimensionality of the sub-indicators

Step 3: Determine weights for indicators

Step 4: Calculate 3 factors according to IPCC

Step 5: Calculate the V index, assessing the level of vulnerability due to climate change

To standardize the data, the relationship between the indicators and the vulnerability index was determined. Two types of data were commonly used: the index value of increased factors together with the increase (or decrease) of respective indicators. Dependencies between criteria and variables in positive–negative relationships were assigned while determining vulnerability [9]. The positive relationship function was mainly used in calculating the indicator of E and S factors. That means the higher E or S factors, the greater the vulnerability. In contrast, the inverse relationship function was used in calculating the indicator of AC factor.

The study applies the method used in the Human Development Index Report (UNDP, 2007) to standardize data (formula 1.1 and 1.2).

$$[S_d] = \frac{S_d - S_{min}}{S_{max} - S_{min}} \quad (1.1)$$

$$[S_d] = \frac{S_{max} - S_d}{S_{max} - S_{min}} \quad (1.2)$$

Of which:

+ Formula 1.1 was used for positive factors (an indicator of E and S) while formula 1.2 was used for negative factors (an indicator of AC);

+ [Sd] is the standardized value of Sd which exhibits the original values (real values) of indicators of the studied ecosystem d; Smax and Smin are the minimum and maximum values of the data series, respectively.

In this method, the standardization process was performed for the lowest level of data, which are indicators. The obtained data was standardized to range from 0 to 1.

After being standardized, the value of the indicators represented the average of the standardized value of indicators and was calculated based on formula 1.3 below:

$$Md = \frac{\sum_{i=1}^{n} S_{di}}{n} \quad (1.3)$$

Of which: M is the main component of ecosystem d, Sdi represents the standardized indicator indices i, and n is the number of indicators in a component factor.

To determine the weights for the indicators, the analytical hierarchy method (AHP), developed by Saaty, (1980) was used [10] for pairwise comparison matrices between indicators relevant and criteria for determining fair value.

The 3 factors according to the IPCC were calculated using the following formula:

$$CFd = \frac{\sum_{i=1}^{n} W_{mi} M_{di}}{\sum_{i=1}^{n} W_{mi}} \quad (1.4)$$

CFd is IPCC factors; Mdi is the main indicator of ecosystem d, indexed by i and Wmi is the weight of each indicator.

After calculating the values of the main factors, the vulnerability index of an agricultural ecosystem was calculated according to the IPCC formula.

$$V = \frac{\mathrm{E} + \mathrm{S} + (1 - \mathrm{AC})}{3} \quad (1.5)$$

Of which: V is vulnerability index; E is exposure; S is sensitivity; AC is adaptive capacity.

The V value ranges from 0 to 1, value 0 corresponds to the least level of damage, value 1 corresponds to the highest level of damage. The study referred to previous studies as well as consulted experts to classified the level of vulnerability as follows:

Table 1. Classified the level of vulnerability

Value range	Level of vulnerability
0 - < 0.2	Very low
0.2 - < 0.4	Low
0.4 - <0.6	Medium
0.6 - <0.8	High
0.8 - 1	Very high

Source: Compiled by the author and consulted with experts

2.2. Results

2.2.1. Building a set of indicators to evaluate vulnerability for aquaculture ecosystems

Through surveys and field research, it has been shown that factors related to temperature and rainfall have an important impact on aquaculture in Nam Phu commune. Inheriting different data sources on natural conditions and extreme weather phenomena of climate change, along with consulting of experts and local managers, indicators for assessment the vulnerability of the aquaculture ecosystem are well recognized (Table 2).

Table 2. Indicators of aquaculture ecosystem vulnerability in Nam Phu commune

STT	Factors	Unit	Real value
I	**EXPOSURE (E)**		
I.1	**Temperature change (E_1)**		
(1)	Average temperature change in Spring season (E_{11}) (1961-2022)	^0C	23.4
(2)	Average temperature change in Summer season (E_{12}) (1961-2022)	^0C	28.9
(3)	Average temperature change in Autumn season (E_{13}) (1961-2022)	^0C	24.4
(4)	Average temperature change in Winter season (E_{14}) (1961-2022)	^0C	17.2
I.2	**Rainfall change (E_2)**		
(5)	Rainfall change in Spring season (E_{21}) (1961-2022)	mm	-20.4
(6)	Rainfall change in Summer season (E_{22}) (1961-2022)	mm	-13.0
(7)	Rainfall change in Autumn season (E_{23}) (1961-2022)	mm	-17.3
(8)	Rainfall change in Winter season (E_{24}) (1961-2022)	mm	14.4
I.3	**Salinity (E_3)**		
(9)	Percentage of salinity area over 1 ‰ (E_{31}) (2018)	‰	100
(10)	Percentage of salinity area over 4 ‰ (E_{32}) (2018)	‰	100
I.4	**Extreme weather phenomena (E_4)**		
(11)	Area flooded due to sea level rise (E_{41}) (Sea level rise scenario 50 cm in 2016)	%	100
(12)	Tides (E_{42}) (Survey questionnaires in 2023)	%	9.7
(13)	Storms, floods (E_{43}) (Survey questionnaires in 2023)	%	90.5
(14)	Droughts (E_{44}) (Survey questionnaires in 2023)	%	56.4
II	**SENSITIVITY (S)**		
II.1	**Population (S1)**		
(1)	Population density (S_{11}) (Statistical Yearbook in 2022)	People/ km^2	184
(2)	Proportion of people working in agriculture in Nam Phu commune (S_{12}) (Survey questionnaires in 2023)	%	96.8
(3)	Proportion of people working in aquaculture in Nam Phu commune (S_{13}) (Survey questionnaires in 2023)	%	11.0
II.2	**Livelihoods (S2)**		

(4)	Ratio of aquaculture land area/total natural area (S_{21}) (2022)	%	54.2
(5)	Aquaculture area (S_{22}) (2018 - 2022)	Ha	1,021
(6)	Quantity of aquaculture/per year (S_{23}) (2018 - 2022)	Ton	2,157
(7)	Value of aquaculture/per year (S_{24}) (2018 - 2022)	Billions dong	64
II.3	**Natural condition (S_3)**		
(8)	Coastline length (S_{31})	Km	7.0
(9)	Percentage of households that are not proactive in water sources in aquaculture (S_{32})	%	100
II.4	**Effects of natural disasters and climate change (S4)**		
(10)	Aquaculture area affected by storms and floods (S_{41}) (2018 - 2022)	Ha	152
(11)	Aquaculture area affected by sea level rise (S42) (2018- 2022)	Ha	300
(12)	Damage caused by increased temperature (S43) (2018-2022)	Billions dong	5
(13)	Damage caused by storms and floods (S_{44}) (2018 - 2022)	Billions dong	10
III	**ADAPTIVE CAPACITY (AC)**		
III.1	**Local government (AC1)**		
(1)	Awareness of management officials about natural disasters and climate change (AC_{11})	%	100
(2)	Number of agricultural officers of Nam Phu (AC_{12})	Person	1
III.2	**Social conditions (AC2)**		
(3)	Percentage of population using centralized water supply (AC_{21})	%	98.9
(4)	Percentage of population participating in health insurance (AC_{22})	%	90.0
(5)	Percentage of schools meeting national standards (AC_{23})	%	66.67
III.3	**Local community (AC3)**		
(6)	Awareness of people about climate change (AC_{31})	%	90.0
(7)	Percentage of households receiving support from local authorities related to natural disasters and climate change (AC_{32})	%	31.6
(8)	Percentage of households accessing information about responding to natural disasters and climate change (AC_{33})	%	68.4
(9)	Percentage of households participating in providing comments on climate change adaptation measures (AC_{34})	%	20.2

Source: [11], [12], [13].

2.2.2. Assessing the vulnerability of the aquaculture ecosystem in Nam Phu commune, Tien Hai district

Based on the set of research indicators used to calculate the vulnerability due to climate change of aquaculture ecosystems (table 2); the exposure factor (E) includes 4 indicators: temperature, rainfall, salinity, and wealth phenomena with 14 indicators. Indicators of the exposure factor have the potential to directly affect on aquaculture ecosystem. The sensitivity factor includes population, livelihoods, natural conditions, and impacts of natural disasters and climate change with 11 indicators. The selected indicators represent the subjects affected positively as well as negatively because of climate change. The adaptive capacity factor includes local government, social conditions and the local community with 9 indicators. The selected indicators are the adaptive capacity of a system to minimize harmful effects of climate change. The author has calculated values of indicators and weights of constituent indicators which formed 3 factors (Table 3).

Table 3. Values of indicators contributing vulnerability index for aquaculture ecosystem in Nam Phu commune

Factors	Indicators	Weight of indicator	Value	Sub-indicators	Standardize value
E	Temperature change (E_1)	0.21	0.47	Average temperature change in Spring season (E_{11}) (1961-2022)	0.49
				Average temperature change in Summer season (E_{12}) (1961-2022)	0.41
				Average temperature change in Autumn season (E_{13}) (1961-2022)	0.46
				Average temperature change in Winter season (E_{14}) (1961-2022)	0.51
	Rainfall change (E_2)	0.13	0.29	Rainfall change in Spring season (E_{21}) (1961-2022)	0.22
				Rainfall change in Summer season (E_{22}) (1961-2022)	0.28
				Rainfall change in Autumn season (E_{23}) (1961-2022)	0.33
				Rainfall change in Winter season (E_{24}) (1961-2022)	0.34
	Salinity (E_3)	0.37	1.00	Percentage of salinity area over 1 ‰ (E_{31})	1.00
				Percentage of salinity area over 4 ‰ (E_{32})	1.00
	Extreme weather phenomena (E_4)	0.29	0.86	Area flooded due to sea level rise (E_{41}) (Sea level rise scenario 50cm)	1.00
				Tides (increase) (E_{42})	0.96
				Storm, flood (increase) (E_{43})	0.91
				Drought (increase) (E_{44})	0.56

S	**Population (S_1)**	**0.10**	**0.36**	Population density (S_{11})	0.00
				Proportion of people working in agriculture in Nam Phu commune (S_{12})	0.97
				Proportion of people working in aquaculture in Nam Phu commune (S_{13})	0.11
	Livelihoods (S_2)	**0.28**	**0.41**	Ratio of aquaculture land area/total natural area (S_{21})	0.54
				Aquaculture area (S_{22}) (2018 - 2022)	0.00
				Quantity of aquaculture/per year (S_{23})	0.56
				Value of aquaculture/per year (S_{24})	0.55
	Natural condition (S_3)	**0.19**	**1.00**	Coastline length (S_{31})	1.00
				Percentage of households that are not proactive in water sources in aquaculture (S_{32})	1.00
	Effects of natural disasters and climate change (S_4)	**0.49**	**0.84**	Aquaculture area affected by storms and floods (S_{41})	0.95
				Aquaculture area affected by sea level rise (S_{42})	0.93
				Damage caused by increased temperature (S_{43})	0.60
				Damage caused by storms and floods (S_{44})	0.88
AC	**Local government (AC_1)**	**0.31**	**0.50**	Awareness of management officials about natural disasters and climate change (AC_{11})	0.00
				Number of agricultural officers of Nam Phu (AC_{12})	1.00
	Social conditions (AC_2)	**0.19**	**0.15**	Percentage of population using centralized water supply (AC_{21})	0.01
				Percentage of population participating in health insurance (AC_{22})	0.10
				Percentage of schools meeting national standards (AC_{23})	0.33
	Local community (AC_3)	**0.51**	**0.47**	Awareness of people about climate change (AC_{31})	0.10
				Percentage of households receiving support from local authorities related to natural disasters and climate change (AC_{32})	0.68

				Percentage of households accessing information about responding to natural disasters and climate change (AC_{33})	0.32
				Percentage of households participating in providing comments on climate change adaptation measures (AC_{34})	0.79

Source: Author's calculations

* *Exposure (E)*

The exposure of aquaculture ecosystem due to climate change in Nam Phu commune, Tien Hai district is affected by 4 indicators: temperature changes, rainfall, salinity and extreme weather phenomenon. These are the main indicators showing the exposure level of aquaculture ecosystem in the context of climate change. These indicators have a positive ralationship with vulnerability.

The results of calculating the indicators show that the proportion of saline soil has the greatest influence on exposure (maximum score is 1). This can be explained by the phenomenon of sea level rise. Climate change scenarios and local statistics show that if the sea level rises by 50cm, the land area of Tien Hai district will be flooded to 67.5%, while Nam Phu commune will be 100%. Increasing extreme weather phenomenon also affects the aquaculture ecosystem in Nam Phu with a score of 0.86. These are two indicators that directly affect people's aquaculture activities. Besides, temperature and rainfall change also contribute to the exposure factor with score of 0.47 and 0.29, respectively. The exposure value (E) of the aquaculture ecosystem in Nam Phu commune is 0.76, ranking as high exposure (Table 4).

* *Sensitivity (S)*

The sensitivity of the aquaculture ecosystem in Nam Phu commune includes indicators such as population, livelihoods, natural conditions and effects of natural disasters and climate change. These indicators show the level of sensitivity, impact of climate change in the of aquaculture ecosystem.

Nam Phu is a purely agricultural commune. The proportion of the population participating in aquaculture accounts for 11% of the commune's total population. With 7 kilometres of coastaline length, the locality has conditions to develop clam, fish and shrimp farming in saltwater, fresh and brackish water. In 2022, the aquaculture area in Nam Phu commune will be 1,021 hectares, accounting for 18.5% of the total aquaculture area of Tien Hai district, ranking second in the entire district after Nam Thinh commune. The average quantity of aquaculture reached 2,157 tons with a value of up to 64 billion VND, accounting for 31.4% of the value of the entire commune's agricultural sector. Aquaculture has become an important livelihood for the people of Nam Phu commune.

The indicator contributing the most to the sensitivity of aquaculture ecosystem in Nam Phu commune is the effects of natural disasters and climate change, with the indicator's weight 0.49. The indicator with the lowest weight is population (including three sub-indicators: population density, proportion of people working in agriculture, proportion of people working in aquaculture) with score of 0.1. The author's calculation results show that the sensitivity level of aquaculture ecosystem is high with a score of 0.71/1.

* *Adaptive capacity (AC)*

The adaptive capacity of aquaculture ecosystem is often linked to the power of the local agricultural sector. After surveying and consulting with experts, officials and people in the study area, the author selected three indicators to calculate the adaptive capacity of aquaculture ecosystem in Nam Phu: local government, social condition and local community. Awareness of local authorities and communities plays an important role in promoting them to take action to climate change adaptation.

According to calculation results in Table 3, the indicator with the highest weight is the local community, at 0.51. This demonstrates important role of aquaculture people in adapting to climate change. Next is the local government indicator with a weight of 0.31 and the lowest is the social condition with weight of 0.19. Local government awareness and action plans play a guiding role in climate change adaptation plans.

The value of adaptive capacity (AC) to climate change in aquaculture ecosystem is 0.42, ranked at the average level (Table 1). This is caused by a weakness of social condition (having a weight of only 0.19/1), average power of local communities and government in adapting to climate change (with weights of 0.51 and 0.31 respectively).

* *The vulnerability of aquaculture ecosystem in Nam Phu*

Calculation results show that the vulnerability index from climate change in aquaculture ecosystem in Nam Phu commune is **0.68**, ranking as highly vulnerable. This is due to the contribution of the constituent factors. Two factors favorable to the vulnerability index are high exposure and sensitivity, reaching 0.76 and 0.75, respectively. Meanwhile, the adaptive capacity only reached **0.42**, ranking average in terms of adaptability and resistance to adverse environmental conditions.

Table 4. The vulnerability index of aquaculture ecosystem due to climate change in Nam Phu

E		**S**		**AC**	
Value	**Exposure level**	**Value**	**Sensitivity level**	**Value**	**Adaptive capacity level**
0,76	High	0,71	High	0,42	Average
V = 0,68 - High level of damage					

3. Conclusions

In this research, based on the IPCC's assessment method, the author has synthesized and built a set of three factors, eleven indicators, and thirty-six sub-indicators to assess vulnerability of aquaculture ecosystem due to the impact of climate change. Calculation results show that, the aquaculture ecosystem in Nam Phu commune has a high level of vulnerability to climate change, with V = 0.68.

Recommendations: From the analysis of the factors contributing to the vulnerability index of aquaculture ecosystem due to climate change, this study has some recommendations to improve vulnerability as follows:

- Monitor and repair sea and river dyke systems to improve effectiveness in responding to climate change, especially natural disasters such as storms, floods in Nam Phu.

- Enhance social powers to improve adaptation to climate change. In addition, it is necessary to raise awareness of and role of local governments and communities in the impact of climate change on people's livelihoods. Therefore, coastal communities have plans and take action to respond to the increase in extreme weather phenomena and their effects on people's lives and livelihoods.

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