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VULNERABILITY ASSESSMENT OF AQUACULTURE TO CLIMATE CHANGE IN THE NORTHERN COAST OF VIETNAM

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ABSTRACT

Climate change is a major global concern that greatly affects people, including their source of living. It was reported that Vietnam, a country with 70 percent of total population lives along coastal areas and in islands, is one of the five countries most severely affected by climate change. Aquaculture may be vulnerable to variations in climate in multiple ways in such countries with the long coastline as Vietnam. In this study, the vulnerability of aquaculture to climate change in the northern coast of Vietnam was assessed at the local scale based on the concept of vulnerability as a function of sensitivity to climate change, exposure to climate change and adaptive capacity. A total of 15 detailed indicators were used to calculate exposure, sensitivity, and adaptive capacity. It was found that the vulnerability of the northern coastal area was mainly at medium level, however, the high level of vulnerability was detected in districts and cities with long coastline. No areas were also detected at very low and very high levels of climate change vulnerability. These results suggest adaptation strategies to these high levels of vulnerability of aquaculture areas can help to increase society's resilience to climate change.

Keywords: Vulnerability, Aquaculture, Fisheries, Climate change

1. INTRODUCTION

Developing countries, which contribute 90% of global aquaculture production, are consider global climate risk hotspots (Islam et al. 2019). A developing Asia dominates the world's aquaculture production, accounting for 88.9% of the total volume (FAO 2016). Most of the world aquaculture production comes from small-scale producers in the global south, with the top five producers being China, India, Indonesia, Vietnam and Bangladesh. Collectively, these five countries contributed 82.2% of the world production by quantity in 2016 (FAO 2016; FAO 2018). Asian countries such as China, Indonesia, India, Vietnam and Bangladesh lead world aquaculture production (FAO 2018). Climate change can bring unexpected impacts to these countries' labour-intensive aquaculture systems with their respective livelihoods and local economies (FAO 2018). Most of the studies focus on aquaculture production systems in Asia, where most aquaculture production takes place (Cai et al. 2019; FAO 2018). The country where the highest number of aquaculture-related case studies carried out is Vietnam. Tropical storms in coastal areas of Vietnam, especially in the northern coast of Vietnam have varied impacts on shrimp aquaculture through sea-level rise, floods and the progression of the low water line, and coastal erosion (Nguyen et al. 2017). It is therefore, vulnerability assessment of aquaculture to climate change in the northern coast of Vietnam plays a fundamental role in shaping and planning adaptation opportunities.

Many studies on the climate change vulnerability of aquaculture have been carried out mostly on a national scale (Allison et al. 2009; Bell et al. 2011; Cinner et al. 2013; Cinner et al. 2012; Handisyde et al. 2006; Handisyde et al. 2017) and a local scale (Lee et al. 2011). Typically, Allison et al. (2009) assessed the vulnerability of national economies to the impacts of climate change on fisheries based on indicators of global warming potential, relative importance of fisheries in the context of national economy and dietary life, and adaptive capacity to climate change in 132 countries. Later, Ding et al. (2017) assessed the vulnerability to impacts of climate change on marine fisheries and food security using complemented indicators of climate change proposed by Allison et al. (2009). Handisyde et al. (2017) selected water temperature change, population density, rainfall change, disaster risk, and aquaculture production as detailed indicators for the assessment of vulnerability of aquaculture on a national scale. Recent studies have assessed the vulnerability of fisheries or aquaculture on a national or local level using the indicator-based method and the IPCC's definition of vulnerability(Allison et al. 2009; Bell et al. 2011; Cinner et al. 2013; Cinner et al. 2012; Handisyde et al. 2006; Handisyde et al. 2017). Lee et al. (2011) applied the same analytical approach in a local region of Korea.

Vietnam's vulnerability to natural disasters and to climate change comes from interplay of climatic and geographic factors. The country has around 3,260 kilometers (km) of coastline and

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over 3,000 islands, where more than 70 percent of its population live (Thuy et al. 2017). Kim et al. (2019) indicated that the main reason why vulnerability assessments have only been conducted on a global scale and not with a focus on individual fisheries and regional aquaculture is the insufficiency of predictive data on the oceans' physical changes arising from climate change. The low-lying coastal areas, especially those in the northern region provinces of Quangninh, Haiphong, Thaibinh, Namdinh and Ninhbinh, highly vulnerable to water-related natural disasters and sea level rise were choosen. This study aims to assess the vulnerability of aquaculture to climate change in the northern coast of Vietnam is assessed by evaluating the vulnerability of aquaculture based on exposure, sensitivity and adaptive capacity.

2. MATERIALS AND METHODS

2.1. Materials

In this study, aquaculture reports of the northern coast of Vietnam were collected. Data used for vulnerability assessment include hydro meteorological data, topographic map, and data from annual abstracts of statistics 2016. In addition, field survey data was also collected based on questionnaires.

2.2. Identification of vulnerability

The Intergovernmental Panel on Climate Change (IPCC 2001; Parry et al. 2007) defines vulnerability (V) to climate change as a function of exposure (E), sensitivity (S), and adaptive capacity (AC), which considers both concepts-exposure corresponds to outcome vulnerability, whereas sensitivity and adaptive capacity correspond to contextual vulnerability. Kim et al. (2019) also classified vulnerability to climate change as either an outcome or contextual. Whereas the former is an economic or biological impact of climate change, the latter refers to susceptibility determined by socio-economic factors. In this study, indicator-based method is used for the assessment of vulnerability of aquaculture. This method selects and assesses proxy indicators of exposure, sensitivity, and adaptive capacity depending on the IPCC's definition of vulnerability. In the context of aquaculture, vulnerability to climate change is determined by a function of climate exposure, sensitivity, and adaptive capacity as follows:

$$\mathrm{V} = \mathrm{f}(\mathrm{E}, \mathrm{S}, \mathrm{AC}) = \frac{\mathrm{E} + \mathrm{S} + (1 - \mathrm{AC})}{3} \tag{1}$$

Where Vis vulnerability indexcomputed lies between 0 and 1, with 1 indicating maximum vulnerability and 0 indicating no vulnerability at all; Sis sensitivity indicators; ACis adaptive capacity indicators.

In this model, detailed indicators of exposure include number of storms, number of days with rainfall above 50 mm, number of days with temperatures below 10ºC, number of days with temperatures above 35ºC. Detailedindicators of sensitive include aquaculture area is affected by storms and floods, production value of aquaculture/hectares, aquaculture area, household size, the rate of dependent population and the rate of female workers. Detailedindicators of adaptive capacity include the rate of poor households, the rate of solid houses, asset index, capital borrowing capacity, experience in aquaculture. These detailed indicators for exposure, sensitivity, and adaptive capacity are first determined before combining these detailed indicators into an overall vulnerability score. In this way, all three determinants are represented in the vulnerability calculation. Each of the three determinants - E, S, and AC - was normalized to fall between 0.1 and 1. The minimum value of E, S, and AC was set to 0.1 to avoid final vulnerability scores of zero. The three determinants were weighted equally, as there was no consistent method or justification in the literature for selecting weighting schemes, with some studies using equal weighting (Antwi-Agyei et al. 2012; Ferrier and Haque 2003; Hahn et al. 2009; Shah et al. 2013; Silva and Lucio 2014) and others using unequal weighting (Iglesias et al. 2009; Perch-Nielsen 2010). It has been suggested in several studies that expert opinion, participatory consultations, and stakeholder discussion should be used to determine the weighting scheme (Hahn et al. 2009; Sullivan and Meigh 2005). Detailed indicators of exposure, sensitivity, and adaptive capacity are listed in Table 1 which are used to calculate exposure, sensitivity, and adaptive capacity.

Table 1: Summary table of weights of vulnerability indicators

Major indicators	Detailed indicators	Weight
Exposure (E)	Number of storms	0.4
	Number of days with rainfall above 50 mm	0.2
	Number of days with temperatures below 10ºC	0.2
	Number of days with temperatures above 35ºC	0.2
		Sum of weights = 1.0
Sensitivity (S)	Aquaculture area is affected by storms and floods	0.2
	Production value of aquaculture/hectares	0.2
	Aquaculture area	0.3
	Household size	0.2
	The rate of dependent population	0.1
	The rate of female workers	0.1
		Sum of weights = 1.0
Adaptive capacity	The rate of poor households	0.2

(AC)	The rate of solid houses	0.2
	Asset index	0.2
	Capital borrowing capacity	0.2
	Experience in aquaculture	0.2
		Sum of weights = 1.0

2.3. Normalization of indicators

Detailed indicators are measured in different scales and units. It is therefore, they need to be normalized to values between 0 and 1 to ensure that they are comparable. Where, 1 being the highest value and 0 with being the least vulnerable area for the indicators with positive relationship with climate changes vulnerability. This was important to identify the two possible types of functional relationship between the indicators and vulnerability. In addition, it is ensured that the index values are always in positive correlation with vulnerability and that higher value means higher vulnerability and vice versa (Žurovec et al. 2017). If vulnerability increases with an increase in the value of the indicator (positive correlation), and therefore has a positive functional relationship with vulnerability. Normalization of indicators was carried out by using the the methodology developed for the calculation of the Human Development Index (UNDP 2006) as shown inequation (2),

$$x_{ij} = \frac{X_{ij} - \text{Min}(X_{ij})}{\text{Max}(X_{ij}) - \text{Min}(X_{ij})} \quad (2)$$

Where X is the separated value in the distribution, $\text{Min}(X_{ij})$ is the minimum value in the distribution; $\text{Max}(X_{ij})$ is the maximum value of the mean of the distribution i is the sub-city; and j is number of indicators. Unless if the indicators are assumed to be negative relationship with vulnerability, the above formula will be changed to the following as described in equation (3):

$$y_{ij} = \frac{\text{Max}(X_{ij}) - X_{ij}}{\text{Max}(X_{ij}) - \text{Min}(X_{ij})} \quad (3)$$

2.4. Identification of vulnerability levels

A meaningful characterization of the vulnerability profiles should be in terms of a fractile classification based on an assumed distribution of R_i(Iyengar and Sudarshan 1982). It is assumed that R_i follows a Beta distribution in the range (0, 1) which is skewed and relevant to characterize positive valued random variables (Bucaram et al. 2016). This distribution has the probability density as follows:

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$$f(z) = \frac{z^{a-1}(1-z)^{b-1}dx}{B(a,b)}, 0 < z < 1 \text{ } and \text{ } a, b > 0 \quad (4)$$

Where

$$B(a,b) = \int_0^1 x^{a-1}(1-z)^{b-1}dx \quad (5)$$

The parameters *a* and *b* can be estimated by solving the following two simultaneous equations:

$$\begin{gathered}(1-y)a - yb = 0 \\ (y-m)a - mb = m - y\end{gathered} \quad (6)$$

where y is the overall mean of the localities indicators and m is defined as:

$$m = s_y^2 + y^2 \quad (7)$$

Where s_y^2 is the variance of the indicator by locality.

Let (0, z_1), (z_1, z_2), (z_2, z_3), (z_3, z_4), (z_4, z_5) be the linear intervals such that each one has the same probability weight of 20 per cent. Five classes of vulnerability are obtained and districts were ranked accordingly: (i) very low, if $0 < y_i < z_1$; (ii) low, if $z_1 < y_i < z_2$; (iii) medium, if $z_2 < y_i < z_3$; (iv) high, if $z_3 < y_i < z_4$ and (v) very high, if $z_4 < y_i < 1$.

3. RESULTS AND DISCUSSION

3.1. Climate change impacts on the aquaculture vulnerability in Quangninh province

Data in Figure 1 and Table 2 shows that the vulnerability of Quangninh coastal area was mainly at medium level. The medium level of vulnerability was detected in 6 districts including Vandon, Tienyen, Hoanhbo, Haiha, Coto, Binhlieu and Bache which account for 50 percents of total of Quangninh area.The high level of vulnerability was found in the areas of Halong, Mongcai, Quangyen, Vandon and Damha accounting for 28.57 percents of total area. A total of 3 districts (Campha, Uongbi and Dongtrieu) as at low level of vulnerability accounting for 21.43 percents of the area. No areas were detected at very low level and very high level of vulnerability. According to statistics in 2016, the largest fishery area was reported in the Quangninh province was Quangyen city with an area of 2,700 hectares, of which the aquaculture area converted from agricultural land was 721 hectares and the area of saltwater intrusion in Quangyen was 124 hectares. In addition, high vulnerability indexes were also found at districts which have large

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aquaculture areas such as Mongcai city of 2,100 hectares, Vandon district of 2,000 hectares and Damha district of 1,400 hectares.

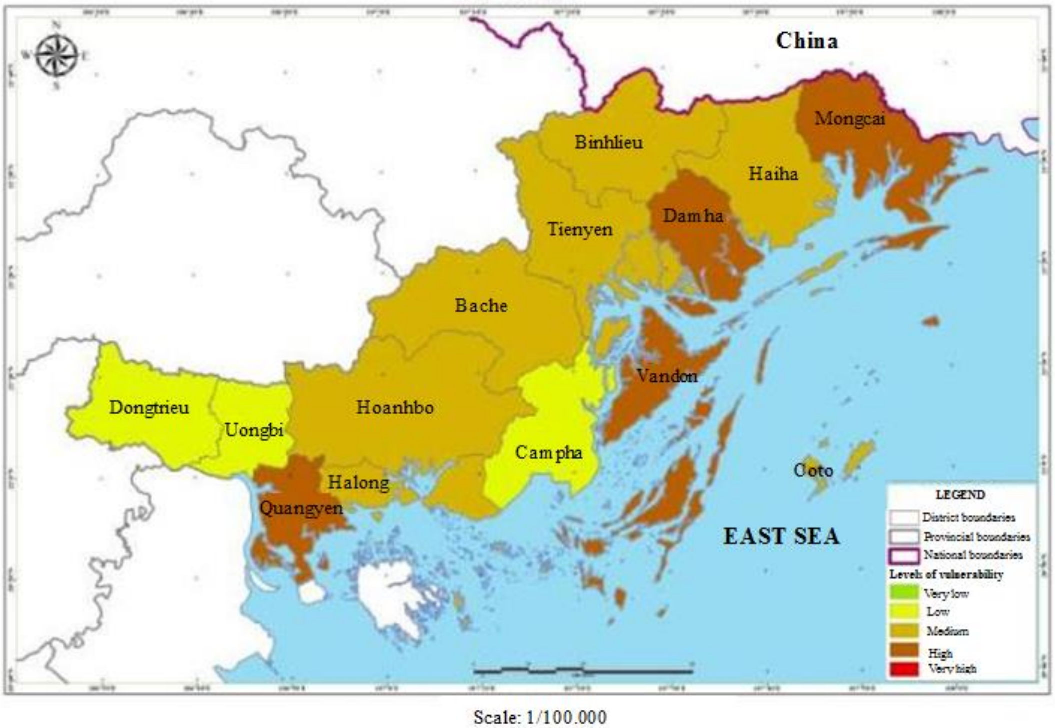

Figure 1: Map of climate change vulnerability to aquaculture in Quangninh province

Table 2: Climate change vulnerability to aquaculture in Quangninh province

Districts/Cities	Exposure	Sensitivity	Adaptive capacity	C_{vi}	Levels of vulnerability
Halong	0.75	0.82	0.12	0.61	High
Campha	0.65	0.71	0.23	0.37	Low
Mongcai	0.72	0.72	0.26	0.60	High
Uongbi	0.50	0.13	0.35	0.37	Low
Dongtrieu	0.47	0.14	0.42	0.37	Low
Quangyen	0.82	0.64	0.24	0.62	High
Vandon	0.77	0.61	0.47	0.65	High
Tienyen	0.65	0.63	0.41	0.58	Medium
Hoanhbo	0.54	0.60	0.57	0.56	Medium
Haiha	0.57	0.64	0.39	0.54	Medium
Coto	0.48	0.52	0.29	0.44	Medium
Damha	0.70	0.57	0.52	0.62	High

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Binhlieu	0.40	0.15	0.93	0.47	Medium
Bache	0.44	0.12	1.00	0.50	Medium

3.2. Climate change impacts on the aquaculture vulnerability in Haiphong province

The climate change vulnerability to aquaculture in the Haiphong coastal area was shown in Figure 2 and statistically summarised in Table 3. It can be seen that, similar to those detected in Quangninh province, the vulnerability of Haiphong coastal area was also mainly at medium level. The medium level of vulnerability was detected in 10 districts including the coastal areas of Doson, Haian, Lechan, Ngoquyen, Anduong, Anlao, Bachlongvi, Thuynguyen, Tienlang and Vinhbao. These areas account for 66.67 percents of the Haiphong area.The high level of vulnerability was detected in the coastal areas of Cathai and Kienthuy which account for only 13.33 percents of total area. Low level of vulnerability was found at three districts (Duongkinh, Hongbang and Kienan) which account for 20 percents of the area.

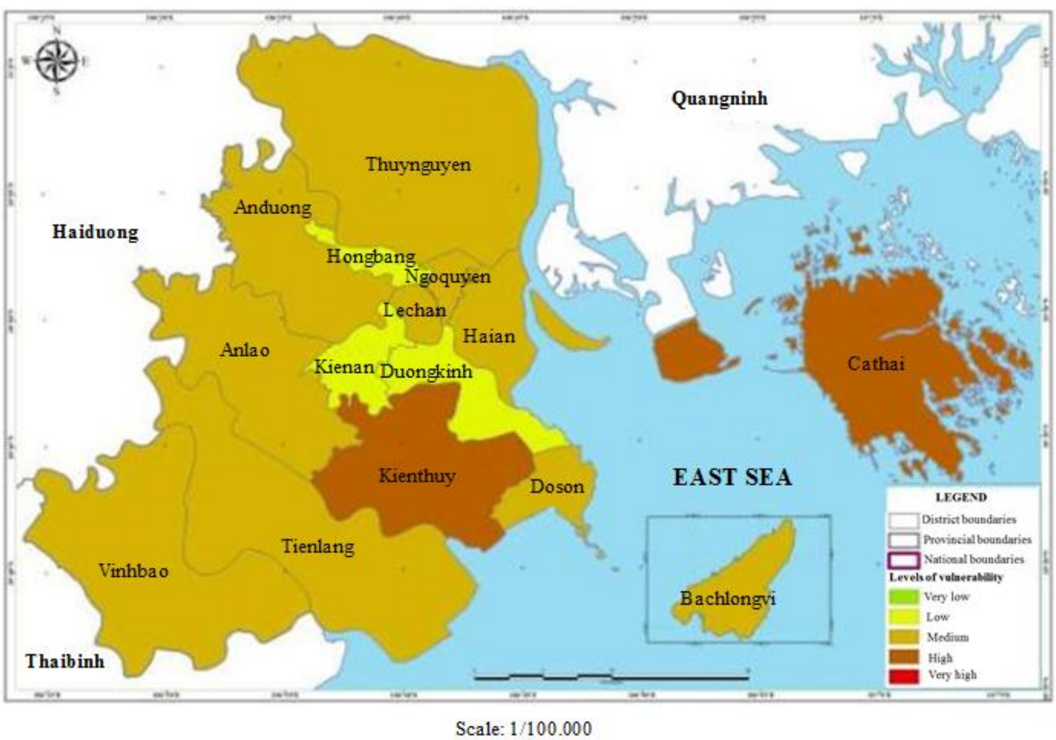

Figure 2: Map of climate change vulnerability to aquaculture in Haiphong province

Similar to those found in the coastal area of Quangninh province, no areas were also detected at very low level and very high of vulnerability. The medium vulnerability index shows that other districts and cities remained vulnerable to climate change impacts. The districts with very high

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vulnerability indexes in the coastal area of Haiphong was at Cathaiand Kienthuy which are coastal plain districts of the province. The economic structure of these districts is mainly based on agriculture with a relatively large area of aquaculture. According to statistics in 2016, the largest fishery area was reported was in the Cathai island with an area of 1,989hectares and 1,211 hectares in the area of Kienthuy. In addition, high vulnerability indexes were also found at districts which have large aquaculture areas such as Mongcai city of 2,100 hectares, Vandon district of 2,000 hectares and Damha district of 1,400 hectares. With the characteristics of annually climate and topography, these districts have been attacked by many types of natural disasters such as storms, floods and droughts. Heavy damage to the agricultural sector of the Haiphong province was reported in 2016 due to an large area of drought. In addition, floods in these districts caused damage to agricultural production, fisheries and people's lives were also reported in 2017.

Table 3: Climate change vulnerability to aquaculture in Haiphong province

Districts/Cities	Exposure	Sensitivity	Adaptive capacity	C_{vi}	Levels of vulnerability
Doson	0.68	0.64	0.19	0.529	Medium
Duongkinh	0.45	0.09	0.37	0.359	Low
Haian	0.63	0.68	0.14	0.498	Medium
Hongbang	0.41	0.12	0.46	0.369	Low
Kienan	0.51	0.12	0.29	0.373	Low
Lechan	0.50	0.21	0.43	0.421	Medium
Ngoquyen	0.50	0.23	0.36	0.409	Medium
Anduong	0.48	0.19	0.56	0.448	Medium
Anlao	0.50	0.21	0.72	0.505	Medium
Bachlongvi	0.40	0.02	0.68	0.409	Medium
Cathai	0.61	0.69	0.52	0.601	High
Kienthuy	0.65	0.67	0.48	0.607	High
Thuynguyen	0.56	0.26	0.60	0.516	Medium
Tienlang	0.54	0.70	0.55	0.574	Medium
Vinhbao	0.34	0.21	0.66	0.408	Medium

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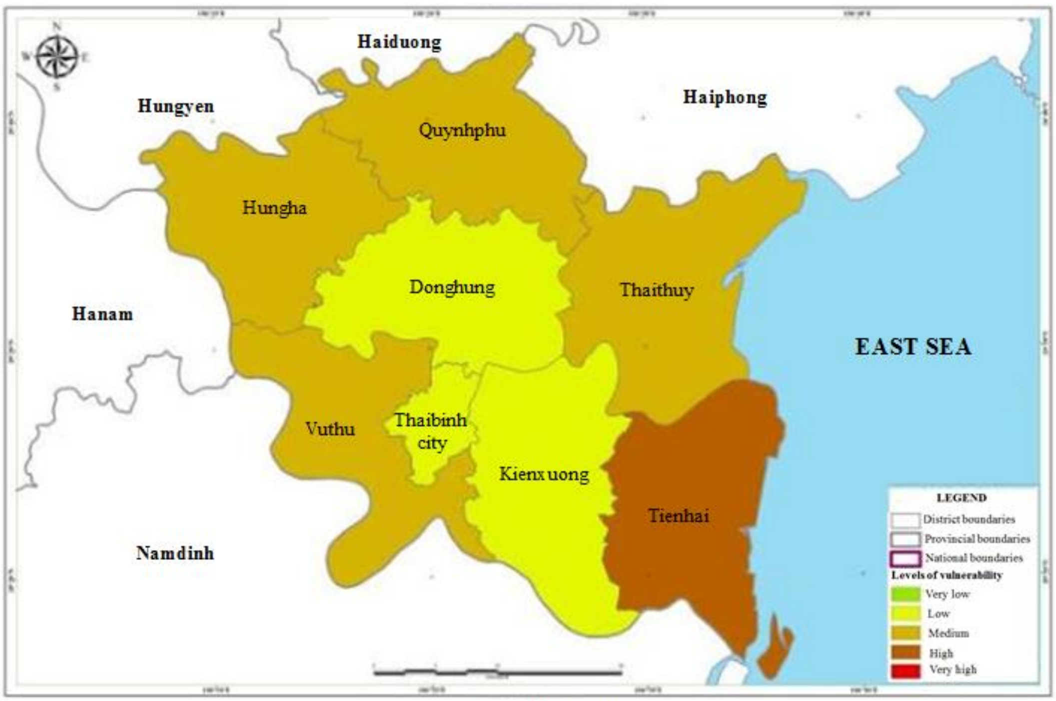
3.3. Climate change impacts on the aquaculture vulnerability in Thaibinh province



Scale: 1/100.000

Figure 3: Map of climate change vulnerability to aquaculture in Thaibinh province

Data in Figure 3 and Table 4 illustrates that the vulnerability of Thaibinh coastal area was mainly at medium level. The medium level of vulnerability was detected in 4 districts including Hungha, Quynhphu, Thaithuy and Vuthu. The areas of these districts account for 50 percents of total area of Thaibinh province. The high level of vulnerability was in the coastal area of Tienhai district accounting for 15.2 percents of total area. Low level of vulnerability was found in three districts of Thaibinh, Donghung and Kienxuong accounting for 37.5 percents of the area. Similar to those of Quangninh and Haiphong province, no areas were also detected at very low level and very high level of vulnerability. The highest vulnerability index was also detected in the coastal plain district of Tienhai. According to statistics in 2016, the largest aquaculture area was reported in the Thaibinh province was in the Tienhai district an area of 1,387hectares, of which the aquaculture area converted from agricultural land was 218 hectares and converted from the area of saltwater intrusion was74 hectares. In addition, high vulnerability indexes were also found at districts which have large aquaculture areas such as Mongcai city of 2,100 hectares, Vandon district of 2,000 hectares and Damha district of 1,400 hectares. The medium vulnerability indexes of other districts and cities in the Thaibinh province show that these areas remained vulnerable to climate change impacts.

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Table 4: Climate change vulnerability to aquaculture in Thaibinh province

Districts/Cities	Exposure	Sensitivity	Adaptive capacity	C_{vi}	Levels of vulnerability
Thaibinh	0.26	0.09	0.44	0.302	Low
Donghung	0.33	0.24	0.47	0.374	Low
Hungha	0.29	0.23	0.69	0.457	Medium
Kienxuong	0.23	0.19	0.59	0.381	Low
Quynhphu	0.24	0.24	0.62	0.415	Medium
Thaithuy	0.75	0.83	0.31	0.575	Medium
Tienhai	0.66	0.81	0.48	0.617	High
Vuthu	0.15	0.17	0.80	0.447	Medium

3.4. Climate change impacts on the aquaculture vulnerability in Namdinh province

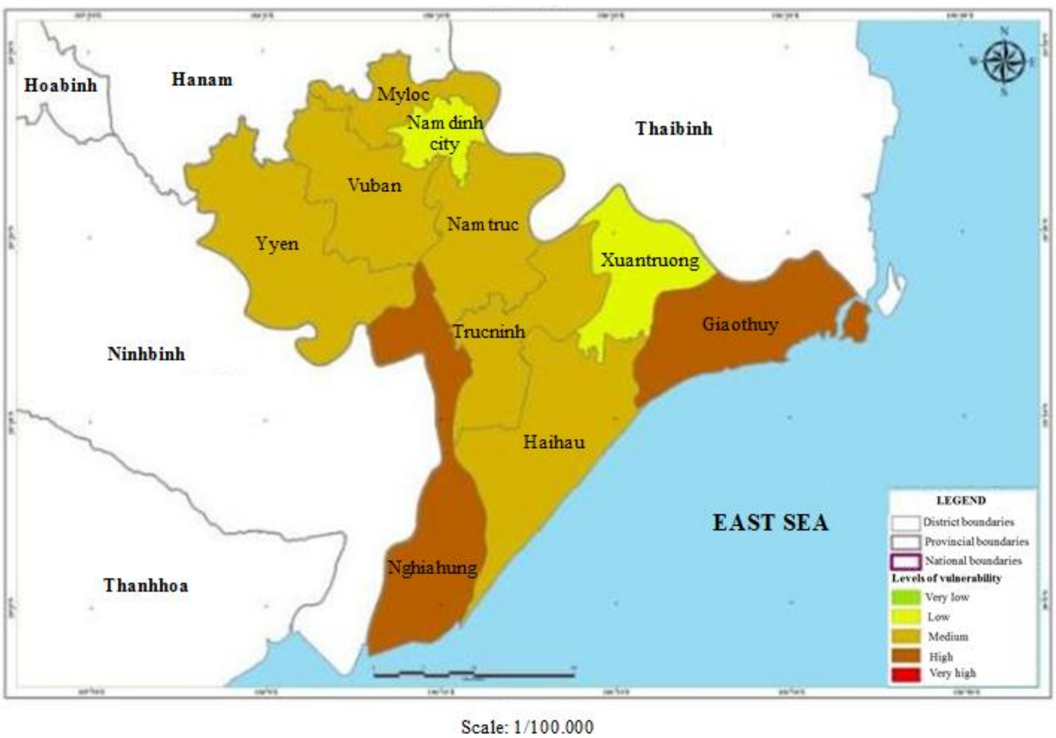

Figure 4: Map of climate change vulnerability to aquaculture in Namdinh province

The climate change vulnerability to aquaculture in the Namdinh coastal area was shown in Figure 4 and statistically summarised in Table 5. It can be seen that the vulnerability to aquaculture in the Namdinh coastal area was mainly at medium level. The medium level of vulnerability was detected in 7 districts (Myloc, Yyen, Trucninh, Haihau, Namtruc and Vuban).

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These areas account for 60 percents of the total area. The high level of vulnerability was detected in the coastal districts of Nghiahung and Giaothuy which account for 20 percents of total area. Low level of vulnerability was found in the Namdinh city and Xuantruong district accounting for 20 percents of the Namdinh area. Similar to those found in the Thaibinh province, no areas were also detected at very low level and very high of vulnerability. The districts with very high vulnerability indexes were in the coastal areas of Giaothuy and Nghiahung which are coastal plain districts of the Namdinh province. The aquaculture area in these two districts accounts for the majority of the total area. According to statistics in 2016, the largest aquaculture area in the province was in the Haihau district with an area of 3,120 hectares, of which the aquaculture area converted from agricultural land was 98 hectares and the land area of saltwater intrusion aquaculture was 32 hectares.

Table 5: Climate change vulnerability to aquaculture in Namdinh province

Districts/Cities	Exposure	Sensitivity	Adaptive capacity	C_{vi}	Levels of vulnerability
Namdinh	0.18	0.18	0.36	0.25	Low
Giaothuy	0.87	0.76	0.40	0.67	High
Myloc	0.25	0.12	0.79	0.41	Medium
Yyen	0.50	0.17	0.86	0.54	Medium
Xuantruong	0.44	0.08	0.55	0.38	Low
Trucninh	0.40	0.15	0.77	0.47	Medium
Haihau	0.68	0.73	0.25	0.54	Medium
Namtruc	0.45	0.17	0.59	0.43	Medium
Nghiahung	0.68	0.76	0.51	0.64	High
Vuban	0.37	0.11	0.86	0.48	Medium

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3.5. Climate change impacts on the aquaculture vulnerability in Ninhbinh province

Figure 5: Map of climate change vulnerability to aquaculture in Ninhbinh province

Data in Figure 5 and Table 6 shows that the vulnerability of Ninhbinh coastal area was mainly at medium level. The medium level of vulnerability was mainly detected in five districts including Giavien, Hoalu, Nhoquan, Yenkhanh and Yenmo. The areas of these districts account for 62.5 percents of total area of Ninhbinh province. The high level of vulnerability was in the coastal area of Kimson district accounting for only 12.5 percents of total area. Low level of vulnerability was found in the Ninhbinh city and Tamdiep district which account for 25 percents of the area. Similar to those of the above-discussed provinces, no areas were also detected at very low level and very high level of vulnerability. The highest vulnerability index was in the coastal plain district of Kimson. According to statistics reported in 2016, the largest aquaculture area was in the Kimson district with an area of 1,201hectares, of which the aquaculture area converted from agricultural land was 87 hectares and 31 hectares of saltwater intrusion land. The medium vulnerability indexes of other districts in the Ninhbinh province show that these areas remained vulnerable to climate change impacts.

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Table 6: Climate change vulnerability to aquaculture in Ninhbinh province

Districts/Cities	Exposure	Sensitivity	Adaptive capacity	C_{vi}	Levels of vulnerability
Ninhbinh	0.432	0.131	0.233	0.312	Low
Tamdiep	0.374	0.063	0.563	0.386	Low
Giavien	0.437	0.173	0.600	0.448	Medium
Hoalu	0.390	0.151	0.659	0.442	Medium
Kimson	0.697	0.823	0.384	0.611	High
Nhoquan	0.444	0.161	0.547	0.432	Medium
Yenkhanh	0.516	0.734	0.547	0.564	Medium
Yenmo	0.402	0.172	0.666	0.454	Medium

4. CONCLUSION

In this study, the vulnerability of aquaculture to climate change in the northern coast of Vietnam was evaluated at the local scale based on the function of sensitivity to climate change, exposure to climate change and adaptive capacity proposed by The Intergovernmental Panel on Climate Change. A total of 15 detailed indicators were used to calculate exposure, sensitivity, and adaptive capacity. It was found that the vulnerability of the northern coastal area was mainly at medium level, however, the high level of vulnerability was detected in districts and cities with long coastline. No areas were also detected at very low and very high levels of climate change vulnerability. These results suggest that the strategies for the adaptation to climate change in areas with high levels of vulnerability of aquaculture areas need to be focused to increase society's resilience to climate change. In the future, studies on predicting long-term socio economic variables should be continued to update vulnerability assessment results.

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