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Assessment of storm surge risk in aquaculture in the Northern coastal area of Vietnam

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Abstract:

This research utilizes the disaster risk concept developed by the Intergovernmental Panel on Climate Change (IPCC) to determine and assess the storm surge risk in aquaculture in the coastal area from Quang Ninh to Ninh Binh province. The results indicated that the highest level of risk occurred in Thai Thuy district (Thai Binh province) and Quang Yen town (Quang Ninh province). The second highest level or risks occurred in Tien Hai district (Thai Binh province), Mong Cai city and Hai Ha district (Quang Ninh province). The lowest level of risk transpires in Uong Bi city (Quang Ninh province) and Kien An district (Hai Phong city). The results provide a scientific basis to support local government in establishing proactive response plans to storm surges, reduce and prevent storm surge damage to aquaculture, assist policy making and establish suitable development priorities for the coastal areas in the Northern region.

Keywords: **aquaculture, coastal area, risk assessment, storm surge.**

Classification number: **5.2**

Introduction

Aquaculture is the fastest-growing food sector globally, with an average annual growth rate of 6% over the past decade. According to the Food and Agricultural Organization (FAO), global aquaculture production has tripled from 1995 to 2014 and reached 74 million tons in 2014. Produce from Asia accounts for approximately 89% of total worldwide production [1]. In Vietnam, aquaculture is an important economic sector, which has a high export value; aquaculture contributes to the improvement of the livelihood of people, especially in coastal areas. According to the Vietnam Directorate of Fisheries, aquaculture production increased fourfold over a 10-year period between 2001 and 2011 from more than 700.000 tons to nearly 3 million tons, with an average annual growth rate of 15.7%. The volume of coastal aquaculture production (saline, brackish) is roughly 29% of the total aquaculture production [2].

The industry is heavily dependent on weather conditions and natural environments. The dependency poses a risk to millions of employees who are directly or indirectly involved in the sector. This attribute is engendered by the complexities of weather events, natural disasters, and environmental problems such as pollution. Such conditions create high-risk profiles and pose significant damages not only to property but also to the livelihood of people. This case is especially true for individuals living in the Northern coastal area that is directly affected by a large number of natural disasters such as storms, floods, extreme waves and storm surges. In particular, aquaculture is highly vulnerable to storm surges. Water level that increases to a certain point and overflows into aquaculture ponds could alter the salinity profile of these pounds, hence affecting the growth and production of aquatic species. Additionally, storm surges that occur rapidly (associated with higher tides) could inundate the area and eventually causing loss [3].

The volume of research on the topic of storm surge risk is abundant. The National Oceanic Information Service

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Center of India [4] identified the elements that affect the height of storm surges, such as wind speed, maximum wind radius, storm trajectory, centre pressure and shoreline elevation. The agency indicated three levels of disaster risk for coastal areas based on the height of storm surges, namely very high (>5 m), high (3-5 m) and medium (1.5-3 m). Storm surge risk in the coastal areas of India has since been classified. However, this method of determining risk caused by storm surges merely considered the effects of natural factors, including the height of the surge without any regard for socioeconomic and human aspects. ToRii and KaTo (Japan) appraised the risk of storm surge using four main approaches, namely 1) evaluation of the probability of tide and wave velocity, 2) assessment of sea dykes, 3) simulation of flood and 4) risk assessment based on evacuation and home safety; flood risk due to storm surges is evaluated according to flood simulation results [5].

In Vietnam, a large number of studies have also assessed the risk of storm surges. Viet Lien Nguyen (2010) classified storm surge risk into 15 levels, with frequencies of 1, 2, 5, 10 and 20%. Storm surge risk were then further evaluated by exploring sea level rise of 0 cm, 30 cm and 75 cm representing different impact levels of climate change. The research provided an overview of the level of risk, of which economic and social factors have been evaluated in addition to hazard-related aspects [6]. In their study on "Assessing the risks of climate change and sea level rise in Binh Thuan province", Xuan Hien Nguyen, et al. (2013) overlapped hazard maps with potential damage to assess the risks of Binh Thuan to natural disasters, including flood, agricultural drought, water shortage and sea level rise in the context of climate change. The study categorized risk into five levels, namely very high, high, medium, low and very low, corresponding to the possible effects and various degrees of potential damage [7]. The Vietnam Institute of Meteorology, Hydrology and Climate Change (IMHEN) built the programme on "Updating the disaster risk disaster, mapping disaster warning, especially disaster related to storms, storm surges, floods, flash floods, landslides, droughts, saline intrusion", including the content of disaster risk assessment and disaster warning surge mapping [8].

As for aquaculture in Vietnam in general and the coastal area of the Northern region in particular, the potential impact and risk of storm surges have not been fully evaluated. Only a limited number of studies have investigated the effect of climate change on aquaculture. These studies include "Assessing the economic impact of climate change on fisheries in the North and proposing solutions to mitigate damages caused by climate change" by Ngoc Thanh Nguyen (2015) [9], "Impact of climate change on agricultural and fishery production" (for two selected provinces of Phu Tho and Hoa Binh province) by Quang Ha Pham (2011) [10] and "Impact of salinity intrusion and adaptation in aquaculture in the Mekong Delta" (under the impact of climate change and sea level rise) by Thi Phuong Mai Le (2017) [11]. Moreover, research on extreme weather events, especially storm surges, in aquaculture in coastal areas is lacking.

The implementation of the risk assessment of storm surges associated with aquaculture in the coastal area of the Northern region is therefore necessary to minimize the damage caused by this natural hazard on aquaculture. The objective of this study is to determine the magnitude of storm surges and risk assessment and to develop storm surge risk maps for aquaculture in the coastal area from Quang Ninh to Ninh Binh province.

Method and procedure for assessing the storm surge risk in aquaculture in the coastal area from Quang Ninh to Ninh Binh province

Data sources

The evaluation of storm surge risk in aquaculture is based on two major sources. The first source consists of storm surge data, including "Updating partition storm, storm risk assessment, storm surges and wind division for inland areas when the heavy storm, super storm landed" in 2016 [12] and "Flooding risk caused by strong storm, super storm surges for coastal provinces" from Quang Ninh to Ninh Binh in 2016 [13]. These data are used in calculating hazard and exposure. The second source comprises Societal, economic and aquaculture data, especially aquaculture data, including Quang Ninh Statistical Yearbook 2016 [14], Hai Phong Statistical Yearbook 2016 [15], Thai Binh Statistical Yearbook 2016 [16], Nam Dinh Statistical Yearbook 2016 [17] and Ninh Binh Statistical Yearbook 2016 [18]. These data are utilized in calculating exposure and vulnerability.

Method

The storm surge risk in aquaculture is appraised based on IPCC's risk assessment approach to natural disasters (Fig. 1). The risk index of this approach is determined based on the following equation [19]:

$$R = f(H, E, V)$$

In particular, hazard (H) connotes the occurrence probability of storm surge with adverse effects on vulnerable objects within the area affected by this natural phenomenon. Exposure (E) refers to the geographical presence of individuals, livelihood activities, natural resources, infrastructure and economic, social and other forms of property at locations that may be adversely affected by storm surge hazards, and hence deal with potential damage, loss or damage in the future. Vulnerability (V) refers to the susceptible tendency of the elements of storm surge hazards and comes in various forms such as human, economic and social vulnerability. Vulnerability is a function of sensitivity and resilience.

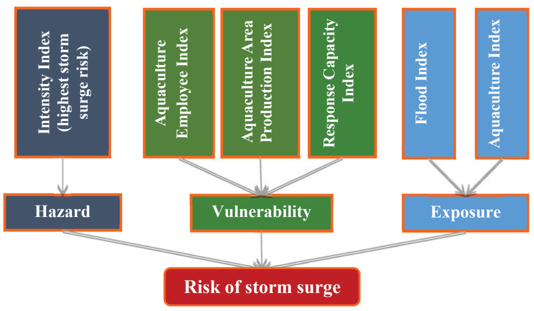

Fig. 1. Methodology for disaster risk assessment with R = f (H, E, V).

To calculate the storm surge risk in aquaculture, a set of criteria for H, E and V components is established. These criteria are presented in Table 1.

Table 1. Indicators and the types of relationship to the levels of risk.

No.	Criterion	Risk assessment indicator	Relationship type with R
(1)	***Hazard***		
1	Hazard index (H)	Maximum storm surge risk (H)	↑
(2)	***Exposure***		
2	Flood index (E1)	Flooding ratio due to storm surges in typhoon level 14 (E1-1)	↑
3		Flooding ratio due to storm surges in typhoon level 13 (E1-2) during high tide	↑
4		Flooding ratio due to storm surges in typhoon level 13 (E1-2) during average tide	↑
5	Aquaculture index (E2)	Aquaculture area by administrative units (E2-1)	↑
6		Number of aquaculture farms by administrative unit (E2-2)	↑
(3)	***Vulnerability***		
7	Aquaculture employee index (V1)	Number of people employed in aquaculture (V1-1)	↑
8		Number of people working additional jobs (V1-2)	↑
9		Number of non-aquaculture workers engaged in aquaculture activities (V1-3)	
10	Aquaculture index (V2)	Aquaculture area ratio (V2-1)	↑
11		Aquaculture development index (V2-2)	↑
12		Aquaculture production (V2-3)	↑
13		Output/1 ha of aquaculture (V2-4)	↑
14	Response ability index (V3)	Monthly income per capita (V3-1)	↓

Note: all the sub-indices use the 2016 data.

The set of indices used to estimate storm surge risk in aquaculture is summarized in Table 1. Data standardization entails the conversion of the collected raw data with different units to the dimensionless values ranging from 0 (minimum value) to 1 (maximum value) to facilitate the comparison of administrative units. The unequal weighted method proposed by Iyengar and Sudarshan (1982) is applied to weight the indicators [20]. The final result is an average quantitative (risk index) that allows for relative comparisons between coastal districts and creates a storm surge risk map for aquaculture in the coastal area from Quang Ninh to Ninh Binh province.

Risk assessment procedure for storm surges

The assessment of storm surge risk in aquaculture consists of the following steps:

<u>Step1:</u> standardizing the data

In this step, data are standardized by converting the different value and unit indicators to dimensionless values within the range of 0 to 1 to compare the various administrative units. Standardization is conducted for each individual indicator. Prior to standardization, the relationship between each indicator and the risk index should be determined based on the reference, expert input or community experience. According to the study, the majority of hazards (H), exposures (E) and sensitivities in vulnerability (V) are positively associated with risk (R), whereas response indicators (in V) are inversely related to the (R) risk index.

The following standardized formula is applied if the relationship between the indicator and the risk index is covariated:

$$x_{ij} = \frac{X_{ij} - \underset{i}{\mathrm{Min}}\{X_{ij}\}}{\underset{i}{\mathrm{Max}}\{X_{ij}\} - \underset{i}{\mathrm{Min}}\{X_{ij}\}} \quad (1)$$

If the relationship is inverse, the normalized formula is:

$$y_{ij} = \frac{\underset{i}{\mathrm{Max}}\{X_{ij}\} - X_{ij}}{\underset{i}{\mathrm{Max}}\{X_{ij}\} - \underset{i}{\mathrm{Min}}\{X_{ij}\}} \quad (2)$$

where: X_{ij} is the value of the i indicator in the j administrative unit in the matrix of the data set; Max $\{X_{ij}\}$ and Min $\{X_{ij}\}$ are the maximum and minimum values of the i indicator in the whole administrative unit of the study area, respectively.

<u>Step 2:</u> determining the weights of indicators

This study selected the unequal weighted method proposed by Iyengar and Sudarshan (1982), in which each indicator receives weight based on the standard deviation per indicator. A brief formulation of the method is as follows:

The weight of each indicator is determined by:

$$w_j = \frac{c}{\sqrt{Var(x_j)}} \quad (3)$$

where: w_j is the weight of the j indicator of component H/E/V, and $Var(x_j)$ is the variance of the j indicator defined by:

$$Var_{x_j} = \sum_{i=1}^{n} \frac{(x_{ij} - \overline{x_j})^2}{(n-1)}$$

c: is determined by the following formula:

$$C = \left[\sum_{j=1}^{m} \frac{1}{\sqrt{Var(x_j)}} \right]^{-1}$$

where: *m* is the number of indicators of the indicator group (criteria).

The total weight of the indicator group must be 1, $0 < w_j < 1$.

After determining the weight, the value of indicator groups (criteria) for each administrative unit is calculated according to the following formula:

$$M_{i,j} = \sum_{j=1}^{m} w_j x_{ij} \quad (4)$$

where: $i = 1 \div n$, number of administrative units of the computed area, $M_{i,j}$ is the value of the j indicator group of the i administrative unit, and W_j is the weighted value of the j indicator.

Step 3: developing the risk index

After determining the weights and values of the indicator group (criteria), the value of each key component of the risk index per administrative unit is identified. An example of the value of the exposure level component E is as follows:

$$E_i = (\sum_{i=1}^{n} M_{i,j} \times m_{M_{i,j}})/m \quad (5)$$

where: E_i is the value of the exposure component for the i unit; $m_{M_{i,j}}$ is the number of indicators of the indicator group $M_{i,j}$, and *m* is the total indicator of component E.

A similar procedure is applied to determine the hazard (H) and vulnerability (V) components. Finally, the risk index per the i administrative unit is:

$$R_i = \frac{(H_i + E_i + V_i)}{3} \quad (6)$$

Results and discussion

H_{ij}, E_{ij} and V_{ij} for each coastal district administrative unit are calculated and standardized according to Formula (1) or (2), respectively. The weight of each indicator is given by Formula (3). H_i, E_i and V_i are calculated according to Formula (4). The values of components H, E and V are calculated by Formula (5), whereas R is calculated according to Formula (6). Calculation results for H_i, E_i, V_i and R risk indicators for the coastal districts of Bac Bo are presented in Table 2.

Table 2. Storm surge risk index on aquaculture for the coastal area from Quang Ninh to Ninh Binh province.

City/District/Town	H	E	V	R
Ha Long	0.569	0.218	0.129	0.306
Mong Cai	0.941	0.225	0.267	0.477
Uong Bi	0.005	0.117	0.103	0.075
Quang Yen	0.559	0.582	0.465	0.536
Tien Yen	0.490	0.095	0.144	0.243
Dam Ha	0.777	0.168	0.208	0.384
Hai Ha	1.000	0.133	0.247	0.460
Van Don	0.584	0.133	0.276	0.331
Co To	0.510	0.001	0.263	0.258
Hai An	0.540	0.558	0.069	0.389
Kien An	0.282	0.043	0.047	0.124
Do Son	0.495	0.165	0.248	0.303
Duong Kinh	0.525	0.032	0.273	0.277
Thuy Nguyen	0.277	0.192	0.347	0.272
Kien Thuy	0.480	0.147	0.227	0.285
Tien Lang	0.406	0.247	0.207	0.287
Cat Hai	0.554	0.217	0.135	0.302
Thai Thuy	0.356	0.696	0.558	0.537
Tien Hai	0.183	0.699	0.566	0.483
Nghia Hung	0.059	0.258	0.363	0.227
Giao Thuy	0.134	0.424	0.457	0.338
Hai Hau	0.000	0.248	0.413	0.221
Kim Son	0.094	0.532	0.444	0.357

Note: H, E, V and R are standardized and divided into five levels: very low, low, medium, high and very high.

Calculated results indicated that with typhoon category 13, 14, the highest risk of water level rise decreases from Quang Ninh's districts to Ninh Binh's districts. Simulated storm surges ranges from 2.68 m to 4.70 m. In the coastal area of Quang Ninh province, large water storage areas such as Hai Ha, Mong Cai and Dam Ha districts exhibit the highest storm surge levels of 4.70 m, 4.58 m and 4.25 m, respectively. The districts of Nam Dinh province and Kim Son district of Ninh Binh province demonstrate very low levels of risk. Uong Bi city, Kien An district and Thuy Nguyen district are also at very low risk levels because they are not directly adjacent to the sea.

One of the criteria for assessing aquaculture's exposure to storm surge is the inundation rate of coastal districts, which corresponds to storm category scenarios. For example, with typhoon category 13, Thai Thuy district of Thai Binh province exhibited the highest proportion of area flooded (46.05%); by contrast, Co To district displayed very little flooding, and Duong Kinh district did not demonstrate any flooding. In addition, criteria related to aquaculture should be given consideration. The largest aquaculture areas are located in the districts/towns, namely Quang Yen, Giao Thuy, Tien Hai, Kim Son and Thai Thuy. On the contrary, the smallest aquaculture areas are situated in Co To and Kien An districts. At the same time, Tien Hai and Giao Thuy districts also host the largest number of aquaculture farms, followed by Quang Yen town, Nghia Hung district, Mong Cai city, Cat Hai district and Hai Hau district. Accordingly, the districts with a very high level of exposure are Tien Hai, Thai Thuy and Quang Yen town; by contrast, the exposure values for Hai An, Kim Son and Giao Thuy district are at a high level. Meanwhile, the districts of Co To, Duong Kinh, Kien An, Tien Yen, Hai Ha and Van Don have a very low level of exposure.

In terms of vulnerability, very high levels are displayed at Tien Hai, Thai Thuy districts and Quang Yen town. Giao Thuy, Kim Son, Hai Hau and Nghia Hung districts exhibit high levels of vulnerability. The districts with very low levels of vulnerability include Kien An, Hai An, Uong Bi, Ha Long, Cat Hai and Tien Yen. Areas of high sensitivity and low response capacity are likely to be highly vulnerable. For example, Tien Hai and Thai Thuy districts have the largest number of workers in aquaculture, the highest aquaculture output in all districts and a relatively high proportion of aquaculture area; however, the average monthly income (response capacity) is low, thus resulting in a very high level of vulnerability. The converse is true with districts with low levels of vulnerability. Hai An and Kien An districts have the lowest number of employees in the aquaculture sector and a very low percentage of aquaculture area and aquaculture production; however, the average monthly income per capita is high, which consequently results in a very low level of vulnerability. As Uong Bi city is not directly adjacent to the sea, the aquaculture indices comparatively low and the monthly income per capita is relatively high; hence, the city's aquaculture sector is less vulnerable to storm surges. The vulnerability of Hai Phong's coastal districts is very low, as the indicators related to aquaculture are not high; moreover, monthly income per capita is higher than other areas.

The levels of storm surge risk in aquaculture in the Northern coastal area are identified based on the calculation of H, E, V and R components. These risk levels are summarized in Table 3.

Table 3. Levels of storm surge risk in aquaculture in the coastal districts in the Northern region.

No.	Standardized value	Level of risk	District/City
1	0.0 - ≤0.2	Very low	Uong Bi, Kien An
2	>0.2 - ≤0.4	Low	Hai Hau, Nghia Hung, Tien Yen, Co To
3	>0.4 - ≤0.6	Medium	Thuy Nguyen, Duong Kinh, Kien Thuy, Tien Lang, Do Son, Cat Hai, Ha Long City, Van Don, Giao Thuy
4	>0.6 - ≤0.8	High	Kim Son, Dam Ha, Hai An
5	>0.8 - ≤1.0	Very high	Hai Ha, Mong Cai, Tien Hai, Quang Yen, Thai Thuy

The hazard, exposure, vulnerability and risk maps for the aquaculture sector of the coastal area from Quang Ninh to Ninh Binh are subsequently developed. These maps are depicted in Fig. 2.

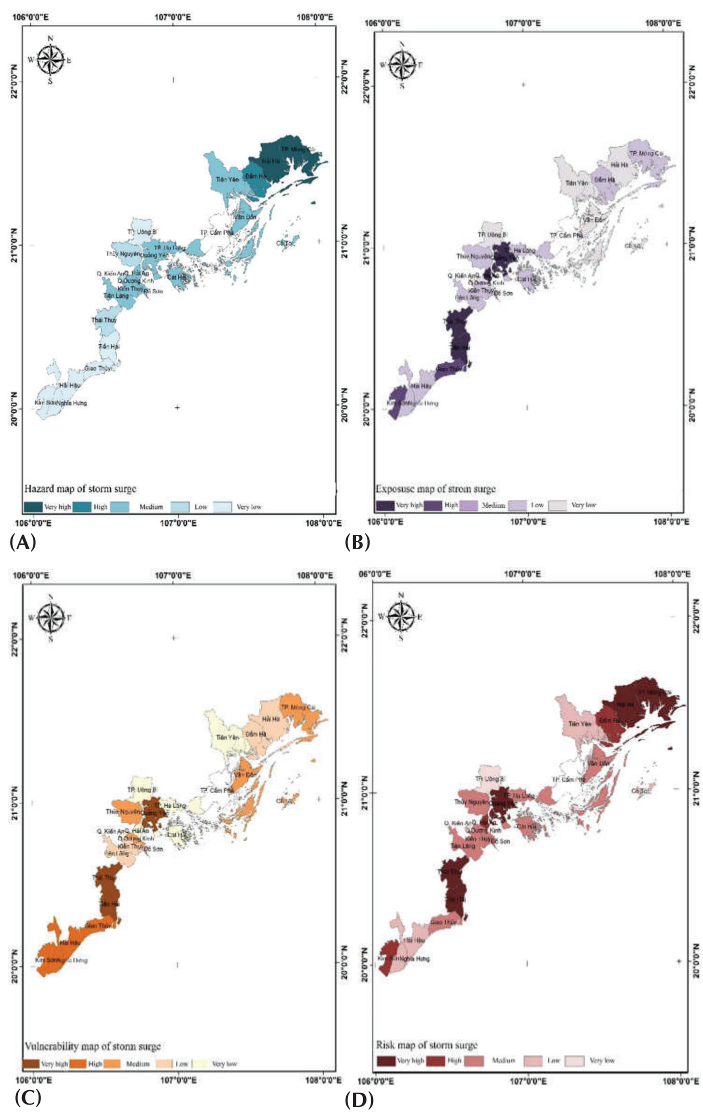

Fig. 2. Storm surge risk maps for the aquaculture sector of the coastal area from Quang Ninh to Ninh Binh: (A) hazard map, **(B)** exposure map, **(C)** vulnerability map and **(D)** risk map.

Conclusions and recommendation

The study presented a methodology for assessing the storm surge risk in aquaculture in the coastal area from Quang Ninh to Ninh Binh province in Vietnam. The method is applied in Vietnam and is based not only on the nature of the storm surge but also on the exposure level and the storm surge's capacity to affect life in economic, social and human terms. The components that contribute to the risk level of storm surges have been evaluated comprehensively; the natural and human factors have been appraised simultaneously. The study collected data, combined with the development of computational models, to ensure the accuracy of the results. The report indicates that data sources (completeness and reliability) play an important role in the risk calculation process. As a result, this study recommends the updating of statistical data every five years. Moreover, taking into account a number of specific indicators that are related to aquaculture is necessary for a more comprehensive assessment.

Local authorities could develop a response plan from hazard, exposure, vulnerability and risk maps. This approach could prevent and mitigate the damage caused by storm surges on aquaculture in the coastal area from Quang Ninh to Ninh Binh. In addition, research results provide a scientific basis to support policy making and rational development priorities for the Northern coastal area.

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