Determining the vulnerability index in the context of high floods in An Giang province

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Abstract. The vulnerability, flood hazards, and exposure are three indicators to calculating and assessing flood risk in the Mekong Delta river. Flood risk assessments allows managers to understand the probability and implications of potential damage caused by floods. The vulnerability index is based on three criteria, including sensitivity and adaptive capacity related to the economic, social, and environmental aspects and benefits that floods bring to the Mekong Delta river. The flood events occurred in the years that the flood peak at Tan Chau was over 4 m, causing the most severe damage in this area. This paper will use the vulnerability index method which is the sum of the components including the sensitivity, resilience and benefits of floods to calculate and assess the flood vulnerability of 155 communes in 11 districts of An Giang province. The results showed that there are four communes were affected by average vulnerability and 151 communes with high vulnerability.

1. Introduction

For thousands of years, Vietnamese people have faced heavy floods. Mekong River Delta, especially the downstream of the Mekong River Basin, has been severely impacted by upstream disturbance due to the presence of upstream reservoirs. That has caused considerable difficulties for flood management in this area [1]. Recently, flood controls have improved effectively through flood risk management. Flood risk refers to the harm that a flood actually causes with a certain frequency over a specified period of time. Therefore, flood risk management should be studied particularly for each area in order to prevent the loss of properties, assets and life caused by floods [1, 2]. From the point of view, the natural properties of flood risk are not determined. It is difficult to quantify the risk of flooding because risks are the consequences of natural phenomena that affect human life, including life, property, and vulnerability. The potential risk is the overlapping common area of three circles where each circle is a representative for one risk component namely hazard, vulnerability, and exposure. The potential risk can be lessened in three ways: (1) by decreasing the level of vulnerability, (2) by reducing the exposure, and (3) by reducing the hazard. Huge flood damage in terms of its effects

exerting on people and the economy emphasizing the need to apply an integrated approach to carry out flood risk assessment [3, 4]. There are many studies on vulnerability and flood risk assessment in different basins throughout the country, mainly in the Northern [3, 4] and the Central region [5, 6]. However, these basins are very different from those in the Mekong Delta, especially flood characteristics [7]. Particularly, the floods in the Mekong Delta also have certain differences in vulnerability due to flood levels which bring to the benefits for human lives. Therefore, the establishment of a set of criteria, the method for flood vulnerability assessment with variables related to social, economic and environmental aspects as well as flood benefits for An Giang is very essential in flood control. This study selected the high flood season in 2011 to calculate and evaluate the vulnerability of An Giang province.

2. Methodology

2.1. Flood characteristics of An Giang province

The Mekong Delta has an important role in socio-economic development with the greatest potential for agricultural development, especially in food production, aquaculture, fisheries, fruit and vegetable which has great export values to the whole country and exchanges with other regions and around the world (figure 1) [8]. In addition, the Mekong Delta has the most outstanding natural features in the world with nearly half of the flooded area of 3-4 months per year. This causes many difficulties for agriculture, however, there are many benefits though such as an increase in natural aquatic resources, supplementation of silt for farmland and the cleaning of environment [9].

Every year, the average rainfall in the Mekong Delta is about 1,400-1,800 mm. The West Coast of the Mekong Delta rainfall is greater than the East Coast rainfall, 2,000-2,400 mm and 1,400-1,600 mm respectively. Flood season in the Mekong Delta began in July and lasts until November. Floods slow down with the average flood intensity of 10 - 15 cm/day and the highest one is of only 20 cm/day. Flood amplitude is 3-4 m and the difference between high- low flood peaks is only 0.5 - 1.0 m. The speed of flood transmission is slow, for example takes 3 days from Phnom Penh to Tan Chau (200 km). In case of high tide, the rate of flood transmission is slower. Fluctuations in flood timing and peak in years are not large. In the event that the flat plain combine with high floods, floods will be extensive and prolonged. Unlike the northern and central regions, there is a concept of "beautiful floods" in the Mekong Delta in case of the maximum water level (H_{max}) in Tan Chau from 400 cm to 420 cm. If this range is over $\pm$ 30 cm, floods do more harm than good. If the water level in Tan Chau is over 450 cm, it will be dangerous in terms of deep security, population security and other economic entities (In the period of 87 years from 1929-2015, every five years H_{max} > 450 cm). In contrast, if the H_{max} water level in Tan Chau is lower than 370 cm, it is called "shortage of flooding". The level of damage in this case is not lower than that of H_{max} > 450 cm, such as: no wash-outing of polluted water, mice reproduction, lack of water in the next year, etc (there are 3 of 10 years that happened this situation).

2.2. Method for assessing flood vulnerability in An Giang province

2.2.1. General concepts

Flood vulnerability index (FVI) is a factor to estimate the hazards and vulnerability including adaptive capacity, exposure, and sensitivity. The analysis of multi-standard flood vulnerability is that integrates the economic, social and ecological aspects of flood risk and adaptive capacity: from an initial point of view towards an end point of vulnerability. Social vulnerability assessments describe human interactions and their adaptive capacities in the context of major disasters with both geographical and temporal changes [1, 2].

Flood vulnerability is determined through three criteria: sensitivity (VS), adaptive capacity (VC) and benefits from floods (VB) which is considered as natural, economic, social and environmental factors [7]. This study will establish values of sensitivity, adaptive capacity, and benefits from floods which is a special characteristic in Mekong Delta. It includes social sensitivity, environmental sensitivity, predictability and vulnerability to hazards, as well as ecological and environmental benefits. The taken steps are shown in figure 2 [10].

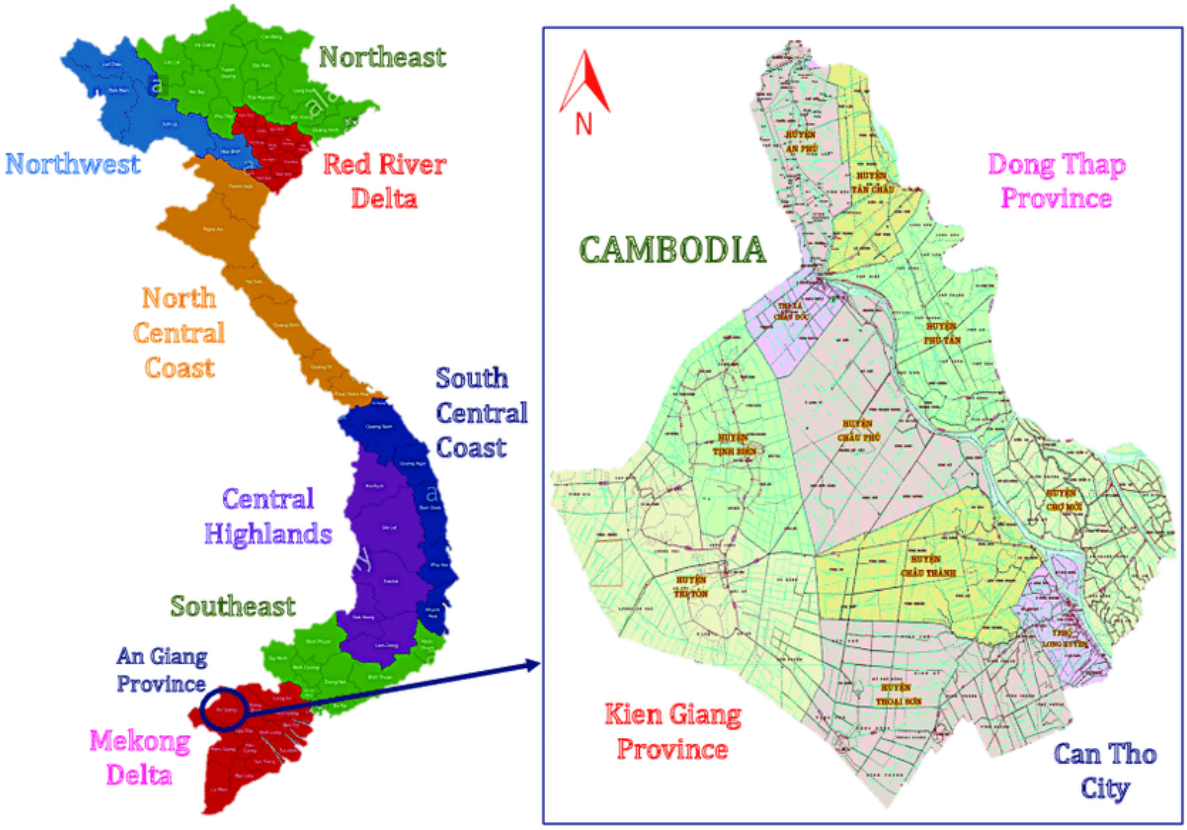

Figure 1. Study location at An Giang Province.

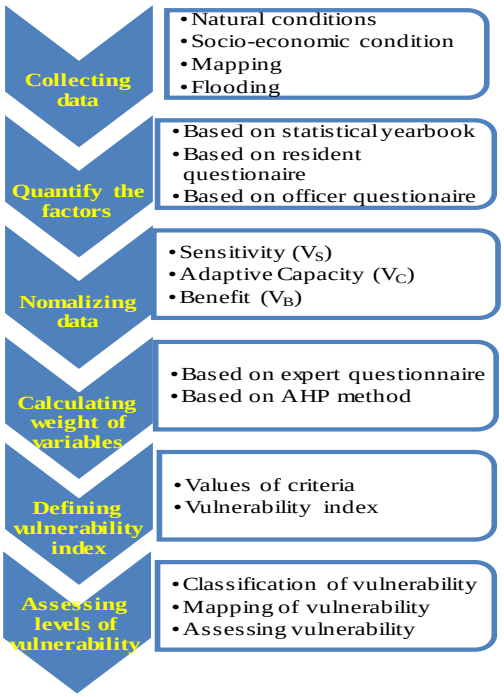

Figure 2. Chart of steps for assessing flood vulnerability.

Establishing variables for vulnerability index

These criteria of flood vulnerability index are described below:

1) Sensitivity (S) is characterized by economic, social and environmental characteristics on the way how they react to floods. Variables of sensitivity include population, ethnicity, education, sex, age, and the environment. Each variables of the sensitivity have different effects on the flood risk (at the same level of flood risk), for example, residents with higher levels of education will be at lower risk of vulnerability. The characteristics of the sensitivity criterion can be determined from the statistical yearbook (at the time of calculation with other characteristics), the sociological questionnaire or the interview (audio and video records) for institutional and administrative organizations at all levels, etc. Specific factors used that were: population, percentage of female population, percentage of the elderly, rate of literate people, percentage of poor households (social sensitivity); environmental status, stability of river bank, flood water, disease, ecosystem (environmental sensitivity).
2) Adaptive capacity (C) is the ability of a system of the people, the community, the government and the nature itself to adjust to floods. Variables of adaptive capacity are experiences; conditions and capabilities of flood prevention; abilities of flood forecasting and warning; community supports; self-recoveries, etc. These variables are also obtained from sociological surveys (questionnaires, interviews, audio-video recordings ...) and data from statistical yearbook in the study area. Adaptive capacity is defined by two indicators of coping and preventing damage (or protecting property). Specific factors which are used are: experiences and abilities of flood control, rescue and forecast, government support (flood response component); public works, transport works, irrigation works, communications, educational restoration and self-cleaning environment (flood prevention and recovery).
3) Benefits (B): The Mekong Delta has a characteristic that bring benefits to people and the environment. Therefore, the determination of criteria for risk assessment for the Mekong Delta is also different from other basins.
In particular, the benefits of flood for An Giang province are natural aquatic resources in the river, sediment from the upstream for increasing crop productivity in An Giang. Moreover, the decrease in salt water in the fields is good for the cultivation and breeding, especially for aquaculture. However, these benefits depend on the levels of flooding: high, moderate or low. Specific factors to be used that are: natural aquatic resources, productivity of aquaculture and agricultural crops, soil cleaning, sediments, and fresh water. Thus, the total number of criteria of the vulnerability index in the context of high floods is 30 variables of sensitivity (12), adaptive capacity (12), and flood benefits (06).

2.2.2. Formulation for flood vulnerability index

Once the variables have been set up, the next steps will be to standardize the data, calculate the weights, calculate the exposure index, and classify the vulnerability levels. Values of variables, components are normalized and added values from 0 to 1. Here, the adaptive capacity and benefits is normalized by an inverse method (as inverse values with vulnerability) [11]. Thus, the vulnerability is a function of vulnerability, adaptive capacity and the flood benefits:

$$\mathrm{FVI} = \mathrm{f}\left(\mathrm{S},\mathrm{C},\mathrm{B}\right) \tag{1}$$

$$\mathrm{V} = \mathrm{S}.\mathrm{w}_{\mathrm{S}} + \left(1-\mathrm{C}\right).\mathrm{w}_{\mathrm{C}} + \left(1-\mathrm{B}\right).\mathrm{w}_{\mathrm{B}} \tag{2}$$

where FVI is the flood vulnerability index; S, C, B are the Sensitivity, Adaptive Capacity and Benefits; w_S, w_C, w_B are the weights of S, C, B; S, C, B are calculated by the equation (3):

$$\mathrm{X} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{X}_{\mathrm{i}}.\mathrm{w}_{\mathrm{i}} \tag{3}$$

where X is the criteria V_S, V_A, V_B; X_i is the value of variables S, C, B; w_i is the weight of S, C, B.
The value of weights is calculated by the AHP (analytic hierarchy process) method [1, 2, 12].

3. Results and discussion

3.1. Results of weights calculation

After collecting and analysing data from experts on grading the importance level of the factors, the results of the weight calculation for factors are shown in table 1 to table 6.

Table 1. Weights of social sensitivity.

Variable	Population	Female ratio	Children ratio	Elderly ratio	Poor households	Literacy rate	Income
Weight	0.049	0.089	0.135	0.137	0.124	0.082	0.383
			$\lambda = 7.60$	CR = 7.4%			

Table 2. Weights of environmental sensitivity.

Variable	Environmental state	Stability of river bank	Domestic water	Disease outbreak	Ecosystem
Weight	0.154	0.087	0.278	0.426	0.055
			$\lambda = 5.23$	CR = 4.2%	

Table 3. Weights of response capacity.

Variable	Experience of flood prevention	Ability of flood prevention	Rescue ability	Flood forecast	Government support
Weight	0.141	0.315	0.367	0.071	0.106
			$\lambda = 5.11$	CR = 2.4%	

Table 4. Weights of prevention capacity.

Variable	Communication	Public works	Transportation	Irrigation	Disease prevention	Educational recovery	Self-cleaning environment
Weight	0.120	0.178	0.198	0.111	0.242	0.092	0.059
			$\lambda = 7.20$	CR = 3.5%			

Table 5. Weights of benefits.

Variable	Increased seafood quantity	Increased seafood productivity	Increased agricultural productivity	Increased Alum cleaning	Increased silt quantity	Freshwater supplementary
Weight	0.121	0.120	0.092	0.156	0.151	0.359
			$\lambda = 6.09$	CR = 1.4%		

Table 6. Weights of criteria.

Variable	Sensitivity	Adaptive capacity	Benefit
Weight	0.507	0.229	0.264
		$\lambda = 3.00$ CR = 0.6%	

3.2. Results of vulnerability index in the event of high flood in An Giang province

After calculating the indicators and weights of the three critera, the vulnerability index of An Giang province is determined for 155 communes of 11 districts as shown in table 7.

The vulnerability index of high flood in An Giang is shown in figure 3. The levels of vulnerability are as follows: (i) Low vulnerability (FVI < 0.2); (ii) Medium vulnerability (0.2 < FVI < 0.4); (iii) High vulnerability (0.4 < FVI < 0.6); (iv)Very high vulnerability (0.6 < FVI < 0.8); (v) Extremely serious vulnerability (FVI > 0.8). It is shown that there are four communes in the province belonging to the medium level of vulnerability with the values from 0.36 to 0.39 in Tan Chau district such as Vinh Xuong, Tan An, Long An and Long Chau. The other communes (151 communes) have high vulnerability with the values from 0.42 to 0.58, in which the communes with the very high level namely Van Giao, Vinh Trung, Nui Voi commune of Tinh Bien district and An Tuc, Co To, Luong An Tra, Luong Phi communes of Tri Ton district. None of the surveyed communes are low vulnerability, high vulnerability and extremely serious vulnerability. Moreover, the majority of communes in districts such as An Phu and Tan Chau are located at the upstream of Mekong Delta from Cambodia and frequently inundated in the flood season often have high vulnerability. However, although they have high sensitivity but high benefit criterion, it has reduced vulnerability. In addition, districts such as Tan Phu and Cho Moi have a high vulnerability because they are located between the two main

rivers, the Tien and Hau Rivers, which are low ground and are often affected by flood. Similarly, Long Xuyen city, located on the bank of Hau River, has isle communes with a high vulnerability.

Table 7. Results of vulnerability index in the event of high flood in An Giang province.

District-Commune	S	C	B	FVI	District-Commune	S	C	B	FVI
AP - Vinh Loc	0.42	0.46	0.65	**0.430**	TC - Phu Loc	0.37	0.48	0.55	**0.426**
AP - An Phu	0.49	0.58	0.63	**0.443**	TC - Vinh Hoa	0.40	0.46	0.64	**0.423**
AP - Long Binh	0.56	0.58	0.76	**0.444**	TC - Vinh Xuong	0.36	0.48	0.77	**0.360**
AP - Da Phuoc	0.45	0.48	0.52	**0.471**	TC - Tan An	0.36	0.48	0.68	**0.388**
AP - Phu Huu	0.45	0.48	0.60	**0.451**	TC - Tan Thanh	0.36	0.48	0.43	**0.450**
AP - Vinh Hau	0.43	0.46	0.61	**0.446**	TC - Long An	0.36	0.49	0.64	**0.392**
AP - Vinh Truong	0.41	0.49	0.64	**0.420**	TC - Le Chanh	0.38	0.47	0.58	**0.424**
AP - Phuoc Hung	0.45	0.46	0.66	**0.443**	TC - Chau Phong	0.50	0.48	0.49	**0.505**
AP - Vinh Hoi East	0.52	0.57	0.57	**0.477**	TC - Phu Vinh	0.43	0.53	0.61	**0.428**
AP - Quoc Thai	0.45	0.46	0.70	**0.433**	TC - Long Thanh	0.30	0.48	0.43	**0.423**
AP - Khanh An	0.44	0.46	0.72	**0.418**	TC - Long Hung	0.30	0.48	0.44	**0.420**
AP - Khanh Binh	0.42	0.46	0.70	**0.416**	TC - Long Chau	0.37	0.51	0.65	**0.390**
AP - Nhon Hoi	0.43	0.46	0.60	**0.447**	TC - Long Son	0.39	0.46	0.57	**0.434**
AP - Phu Hoi	0.43	0.46	0.58	**0.454**	TC - Long Phu	0.39	0.49	0.58	**0.426**

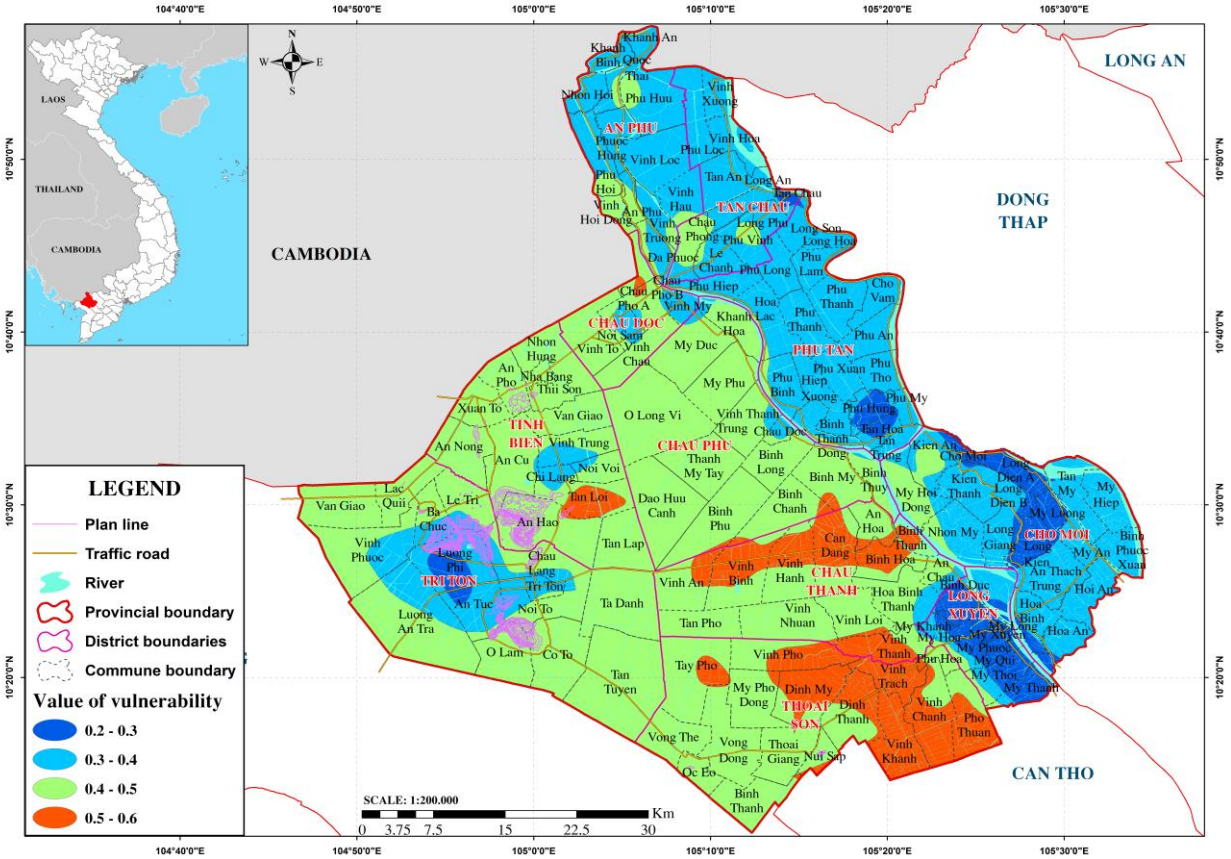

Figure 3. Map of vulnerability index of high flood in An Giang province

4. Conclusion

This study aims to improve a method for calculating and assessing flood vulnerability in An Giang province. Values of sensitivity, adaptive capacity, and benefits of floods which is a special characteristic in Mekong Delta are set up. The total number of criteria of the vulnerability index in the context of high floods is 30 variables of sensitivity (12), adaptive capacity (12), and flood benefits (06). The steps of calculation: quantifying the variables → standardizing the variables → calculating weights of the variables of criteria → calculating the vulnerable index → classifying of flood vulnerability for a total of 155 communes of 11 districts of An Giang province. The results show that the communes have the flood vulnerability levels. In the context of high floods in 2011, there are four communes with medium vulnerability and 151 communes with high vulnerability. The districts located at the upstream of the Mekong River such as An Phu and Tan Chau as well as the districts in the middle of the Tien and Hau River always have high levels of vulnerability. The study results can help in management, planning, and decision-making to reduce the risk of flood in study area.

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