GENERATION OF INDICATORS TO ASSESS THE FLOOD VULNERABILITY INDEX IN HOI AN CITY, VIETNAM

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ABSTRACT

Floods, which are among most-frequent types of natural disasters, have caused massive impacts on human health, socio-economic activities and the quality of the natural environment throughout the history. Undertaking research or assessment on flood risk was and has been extremely necessary in the context of more uncertainties and risk associated with the climate system. Identifying the vulnerability is one step moving forward the assessment of flood risk and is also a supporting tool for policymakers in proposing compatible response solutions. The identification of vulnerability is based on analyzing various indicators which form the scientific basis for mapping flood vulnerability. This research aims at establishing indicators for assessing the vulnerable level of 9 wards and 3 communes in Hoi An where has high exposure level to flood but has not yet have comprehensive assessment of vulnerability. A set of indicators including totally 9 indexes covering three main components which are exposure (E), sensitivity (S) and adaptive capacity (AC) were selected for flood vulnerability index (FVI) calculation and the creation of flood vulnerability map in Hoi An city.

1. INTRODUCTION

Among the most frequent and devastating natural hazards, floods are the one that has caused massive damages to human life and ecosystems (Wallemacq *et al.*, 2018). In Southeast Asia, flood management is more on the side of being reactive in responding to disaster situations, rather than being proactive in minimizing the possibility in advance. This way of management shows its limitations when floods still cause serious damage to human's life and property annually. There are several reasons for developing countries to follow such kind of management approach, including the lack of budget, facilities, human resources, and more importantly the limitation in the number of comprehensive research (with integrated approaches to all aspects of the vulnerability) on flood vulnerability assessment in this region. During thousands of years of history, Vietnam has faced many floods with severe consequences across the country. The frequency and intensity of floods have caused significant difficulties in planning and management in Vietnam. In recent years, flood control actions have been more effective by applying flood risk assessment. Although it is difficult to quantify the risk of flooding because risks are the consequences of natural phenomena, flood risk can be minimized by reducing the vulnerability of the object or region which is affected by floods. This study applied the definition which has been agreed among most researchers that the vulnerability of a system is determined by three components: exposure, susceptibility, and resilience (Balica and Wright, 2010; UNISDR, 2009). In Vietnam, though there is still a limit on the number of research on vulnerability and assessment of flooding risks, the so far achievements have significantly contributed to the tightening of flood management. Studies on flood vulnerability in Vietnam mainly conducted in major river basins region while studies on urban level have not yet received the deserved attention. This study aims at building spatial distribution of flood vulnerability (FVI map) in Hoi An city and recognizing the importance of adaptive actions, and propose some recommendations that can be taken to reduce vulnerability before the possible harm is realized.

2. METHODS AND DATA SELECTION

2.1 Methods

Multi-criteria decision analysis employing the analytical hierarchy process (AHP) was used in this flood vulnerability evaluation. AHP has been considered as practical technique to address a broad decision-making problem involving a wide range of criteria (Saaty, 1990). However, indicators have different units, so after being selected, all data were normalized to a standard scale from 0 to 1 employing Krajnc and Glavic approach (Krajnc & Glavič, 2005) before the ranking process. Afterward, the FVI was calculated following the formular of IPCC, 2014:

$$FVI = f\,(E, S, AC)$$

Where: FVI is the flood vulnerability index; E is exposure; S is susceptibility; AC is adaptive capacity.

2.2 DATA SELECTION

Different types of data set from varied sources were collected for constructing spatial criterion layers employing geospatial calculation actions, for example, percentage of flooded area, distance to rivers. Population data was obtained from the 2020 statistical yearbook of Hoi An city, 10m Digital Elevation Model (DEM), land use map, The Open Street Map (OSM).

2.2.1 *Exposure*

- *Average elevation of terrain (AET):* AET is considered to has the most priority in AHP flood hierarchy since the topography directly influence on the level damage and the ability to recover after flooding (Tran *et al.*, 2014); therefore, this indicator was discussed and given the highest weight (an equal priority to flood frequency). The 10m Digital Elevation Model (DEM) data source provided by Quang Nam Department of Natural Resource and Environment (DONRE) was used to calculated AET. The administrative map and DEM surface were imported to GRASS GIS open-source software (the r.stats.zonal command, https://grass.osgeo.org/) for elevation calculation for each commune and ward.

- *Average distance to the mainstream of Thu Bon River (DIST_R):* The excess waterflow of Thu Bon mainstream cause most floods in Hoi An. The DIST_R data was generated by calculating the Euclidean distance to the river channel using the r.grow.distance tool in GRASS GIS. The river network was extracted from hydrology data by Quang Nam DONRE and then was used as input data source for calculation of DIST_R. The zonal statistical method (r.stats.zonal) has been applied for calculation of average distance to river channel by commune/ward.

- *Flood frequency (EF):* Since the FF values represent for flood occurrence history, this indicator was considered to have the very strong importance as AET. Because the local community in Hoi An has not really taken radical measures to reduce flood risks and has not really adapted to this natural disaster, FE in this research is considered as an indicator that can increase the vulnerability rather than an indicator that reflects people's past experiences. EF was calculated by summing the total number of floods that occurred from 2016-2020 in Hoi An according to local statistics.

2.2.2 ***Susceptibility***

- *Population density (P_DENS):* The population growth and distribution, especially increased population density can increase the vulnerability to disasters (Perrow, 2007). In this research, P_DENS was considered as a strong important indicator due to its direct impact to the level of loss of life in a disaster. P_DENS was taken from Hoi An Statistical Yearbook 2020.

- *Number of historical sites (HIS):* Historical sites in Hoi An need particular attention in flood management due to their irreplaceable cultural value, and their sensitive constructive typologies (Fabiana and Tiago, 2019). In consequence of that, considering historical sites as a vulnerable indicator is necessary. HIS was taken from Statistical Yearbook 2020. Hoi An has 23 sites that have been certified as national historical sites and 47 sites that have been certified as provincial historical sites by the Ministry of Culture, Sports and Tourism of Vietnam as in 2020. The higher HIS value in the ward, the greater the risk of damage, so this was given the highest weight in AHP hierarchy.

- *Number of households in vulnerable groups categorized by economic status (VUL_ECO):* VUL_ECO covers the number of poor and near-poor households in the research area. According to Article 2, Decision No. 59/2015/QD-TTG of Vietnamese Government on the poverty line applied for the period 2016-2020, in rural areas, households with average income per month less than 700.000 VND are considered poverty; meanwhile, near-poor households are those with monthly income of 700.000 VND to 1 million VND along with lacking no more than 3 out of 5 accessibilities to social services (health, education, housing, clean water and information). Based on this difference, the research applied a weight of 2:1 respectively to poor and near-poor households to calculate the value of vulnerable groups categorized by economic status.

2.2.3 ***Adaptive capacity***

- *Number of working age adults (W_AGE):* Children and the elderly are more vulnerable to flood hazard while people in working age are less vulnerable to flood due to the health status. Moreover, this group of people are the main source labor force to recoup economic losses. Therefore, the ward or commune with the larger number of working age adults will be better able to cope with floods. W_AGE was taken from Hoi An Statistical Yearbook 2020.

- *Road density (R_DENS):* The Open Street Map (OSM) data was downloaded and then imported to GIS environment for updating the total road length and the road density by commune. The zonal statistics method was applied in GIS to take the road length by commune with the based map is the administrative map and the cover map is the road map for Hoi An. These values of road length by commune then were divided into the area of each commune/ward to get the read density.

- *Annual average income per capital:* Income contributes to an individual's ability to prepare for a flood and rebuild (Rasch, 2015). Due to the uneven impact of covid-19 on different wards and communes, the data of average income per person per year in 2019 was used in this assessment to evaluate the degree of vulnerability.

3. RESULTS AND DISCUSSION

Before the normalization process, each indicator was identified their relationship with FVI. In which EF, P_DENS, HIS and VUL_ECO have positive relation to FVI (an increase in the indicator value lead to an increase in FVI value); and AET, DIST_R, R_DENS, W_AGE and INC have an inverse relation to FVI (an increase in the indicator value lead to a decrease in FVI value). The normalized values and weights for 9 indicators of FVI's components are shown in table below.

Table 1. Normalization value and weights of vulnerability's indicators

Wards	AET	DIST_R	EF	P_DENS	HIS	VUL_ECO	W_AGE	R_DENS	INC
Minh An	0.49	0.04	1.00	0.96	0.95	0.00	0.84	0.16	0.00
Tan An	0.00	0.40	0.00	0.84	0.16	0.02	0.61	0.38	0.16
Cam Pho	0.45	0.14	1.00	1.00	1.00	0.00	0.41	0.39	1.00
Thanh Ha	0.36	0.25	1.00	0.18	0.53	0.04	0.00	0.95	0.55
Son Phong	0.52	0.14	0.93	0.73	0.37	0.07	1.00	0.00	0.03
Cam Chau	0.94	0.43	0.93	0.16	0.53	0.04	0.15	0.55	0.06
Cua Dai	0.97	0.36	0.33	0.21	0.00	0.74	0.67	0.69	0.09
Cam An	0.56	1.00	0.33	0.12	0.11	0.31	0.79	0.72	0.09
Cam Nam	0.91	0.00	1.00	0.11	0.11	0.24	0.62	1.00	0.42
Cam Ha	0.38	0.72	0.33	0.05	0.37	0.37	0.55	0.98	0.81
Cam Kim	0.82	0.03	1.00	0.01	0.21	1.00	1.00	0.94	0.67
Cam Thanh	1.00	0.18	0.93	0.00	0.58	0.63	0.43	0.98	0.64
Weight	0.40	0.20	0.40	0.31	0.46	0.23	0.40	0.40	0.20
RI = 0.58, λmax = 3; CR = 0									

The value of E, S, AC were calculated by multiply the normalized value of each indicator with its corresponding weight. In order to analyzing the impact of AC on the flood vulnerability result, the flood susceptibility map was calculated by integrating of flood exposure (E) and susceptibility (S) components (equation 1). Subsequently, the flood vulnerability index was determined based on the investigation of flood susceptibility and the adaptive capacity (AC) as shown below (equation 2).

$$FSI = ½*(E+S) \quad (1)$$

$$FVI = 1/3(E+S+AC) \quad (2)$$

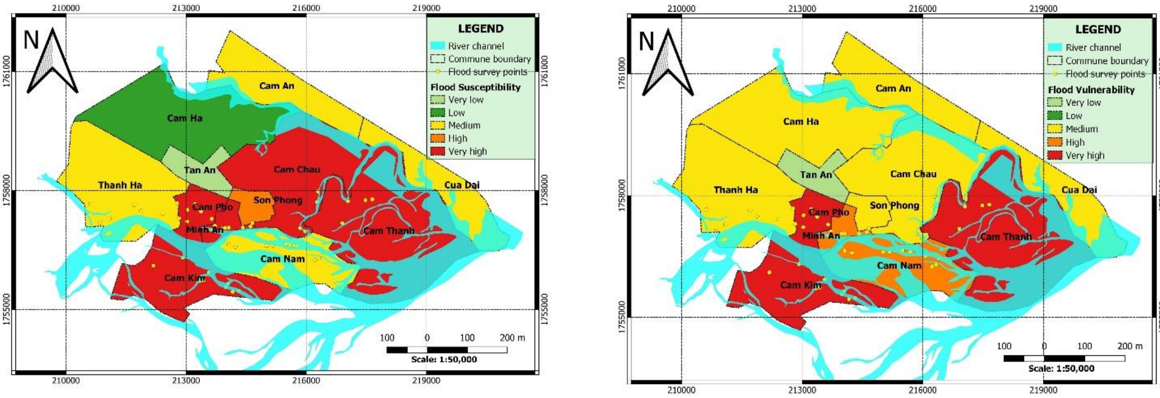
Where: FSI is *Flood susceptibility index*

FVI *is Flood vulnerability index*

Table 2. FVI value applying AHP weights

Wards	E	S	AC	FSI (without AC)	FVI (with AC)
Minh An	0.60	0.66	0.40	0.63	0.55
Tan An	0.08	0.27	0.43	0.18	0.26
Cam Pho	0.61	0.69	0.52	0.65	0.61
Thanh Ha	0.59	0.29	0.49	0.44	0.46
Son Phong	0.61	0.36	0.41	0.49	0.46
Cam Chau	0.84	0.29	0.29	0.56	0.47
Cua Dai	0.59	0.28	0.57	0.44	0.48
Cam An	0.56	0.17	0.62	0.37	0.45
Cam Nam	0.77	0.15	0.73	0.46	0.55
Cam Ha	0.43	0.30	0.77	0.36	0.50
Cam Kim	0.73	0.41	0.91	0.57	0.68
Cam Thanh	0.81	0.46	0.69	0.64	0.65

By applying the manual classification method (Samanta et al., 2016) with equal interval, the FVI value were categorized into 5 ranges. Without considering AC employing AHP: very low (0.18 - <0.27), low (0.27 - <0.37), medium (0.37 - <0.46), high (0.46 - <0.55), very high (>= 0.55); Considering AC employing AHP: very low (0.26 - <0.35), low (0.35 - <0.43), medium (0.43 - <0.51), high (0.51 - <0.59), very high (>=0.59).



a) Flood Susceptibility Map of Hoi An (without AC component)

b) Flood Vulnerability Map of Hoi An by integrating AC component

Figure 1. Integrated flood vulnerability map in Hoi An city

The flood susceptibility map of Hoi An generated by Equation (2) shown that there is a large area under very high level including the communes of Cam Kim, Minh An, Cam Pho, Cam Chau and Cam Thanh. These areas are located nearby the mainstream of Thu Bon River with relatively low elevation. The high level areas include Son Phong and Cam Nam wards which are also located along the mainstream of Thu Bon river. Thanh Ha, Cua Dai has medium level of vulnerability while Cam Ha, Cam An are communes under low level of flood susceptibility due to the location in the opposite side of main river and nearby the coastline which is usually well-drainage. Tan An is the ward with very low susceptibility level due to its specific location and topography. Taken into account the AC, the flood vulnerability map has slightly change in the categories compared to the flood susceptibility map. Minh An is the centered ward of the Hoi An City with relatively high economic condition as well as adaptive capacity, therefore these areas has fallen into the lower level compared to the flood susceptibility map. Son Phong, Cam Chau are the wards under the high speed of economic development and their AC are also increasing, therefore these areas have down to the medium level in the flood vulnerability map. Cam Pho, Cam Nam still remain their high level of vulnerability and Thanh Ha, Cua Dai have seen no changes in their medium rank. On the contrary, the Cam Ha, Cam An are the communes located in the suburban of Hoi An downtown with the considerable lower AC compared to other areas, hence they have become the medium flood vulnerability areas. These communities need to be enhanced both in awareness as well as the adaptive capacity to the flood and other disasters for the sustainable development. Cam Kim and Cam Thanh are always under very high level both in flood susceptibility or vulnerability map. This indicates that there is an urgent need for promoting the local adaptive capacity as well as protecting these areas to the flood susceptibility. Tan An is the only ward which always under very low level of flood susceptibility as well as vulnerability.

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