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Establishing the Method for Assessing Flood Vulnerability in Ho Chi Minh City, Vietnam—A Case Study in District 6

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Abstract: Urban flooding has impacted significantly on people's living: economic development, environmental pollution, etc.. It has been the serious problem of many cities in the world, especially in urban areas in developing countries because urbanization is too fast but lack of adaptive management planning and infrastructure. In Vietnam, the big cities, such as HCM (Ho Chi Minh) City, Hanoi, etc. have also been influenced severely by floods. By early 2017, HCM City has 171 flooded sites assigned by the district level; 40 submergence points assigned by Steering Center of Flooding Control Program, and 9 tidal flooded points. The paper will establish a suitable method for assessing flood vulnerability in HCM City from natural, social and environmental aspects. The results of a case study in District 6 show that there are four wards with high vulnerability and 10 wards with average vulnerability.

Key words: Vulnerability, flooding, District 6, HCM City.

1. Introduction

1.1 Natural Condition

1.1.1 Geography

Located in the transition zone between the southeast and the southwest, the city covers an area of 2,095.06 km², consisting of 24 districts.

HCM (Ho Chi Minh) City is located at 10°10'-10°38' north and 106°22'-106°54' east. The city borders Binh Duong Province to the North, Tay Ninh Province to the northwest, Dong Nai Province to the east and northeast, Ba Ria-Vung Tau Province to the southeast and Long An and Tien Giang Province to the west and northwest (Fig. 1) [1].

Thanks to its ideal location as the central of South East Asia region, HCM City is a critical transport hub of not only road transportation but also water and air transportation. The city is also the biggest international hub welcoming countless international airlines to and from Vietnam [1].

The city's terrain descends from north to south and from west to east. The uplands are in the north-northeast and partly northwest, with an average of 10 to 25 m. Alternatively, there are some hills, up to 32 m high, such as Long Binh hill in District 9. In contrast, the low areas are in the south-southwest and southeast cities, with an average height of about 1 m and the lowest area 0.5 m high. The central areas, the part of Thu Duc District, District 2 and the whole of Hoc Mon and District 12 have the average height of about 5 to 10 m [1, 2].

1.1.2 Hydrology

Located in the downstream of the Dong Nai River system—Saigon, HCM City has a very diverse network of rivers and canals. Dong Nai River which originates from Lam Vien Highland and connects to many other rivers, is a large basin, about 45,000 km².

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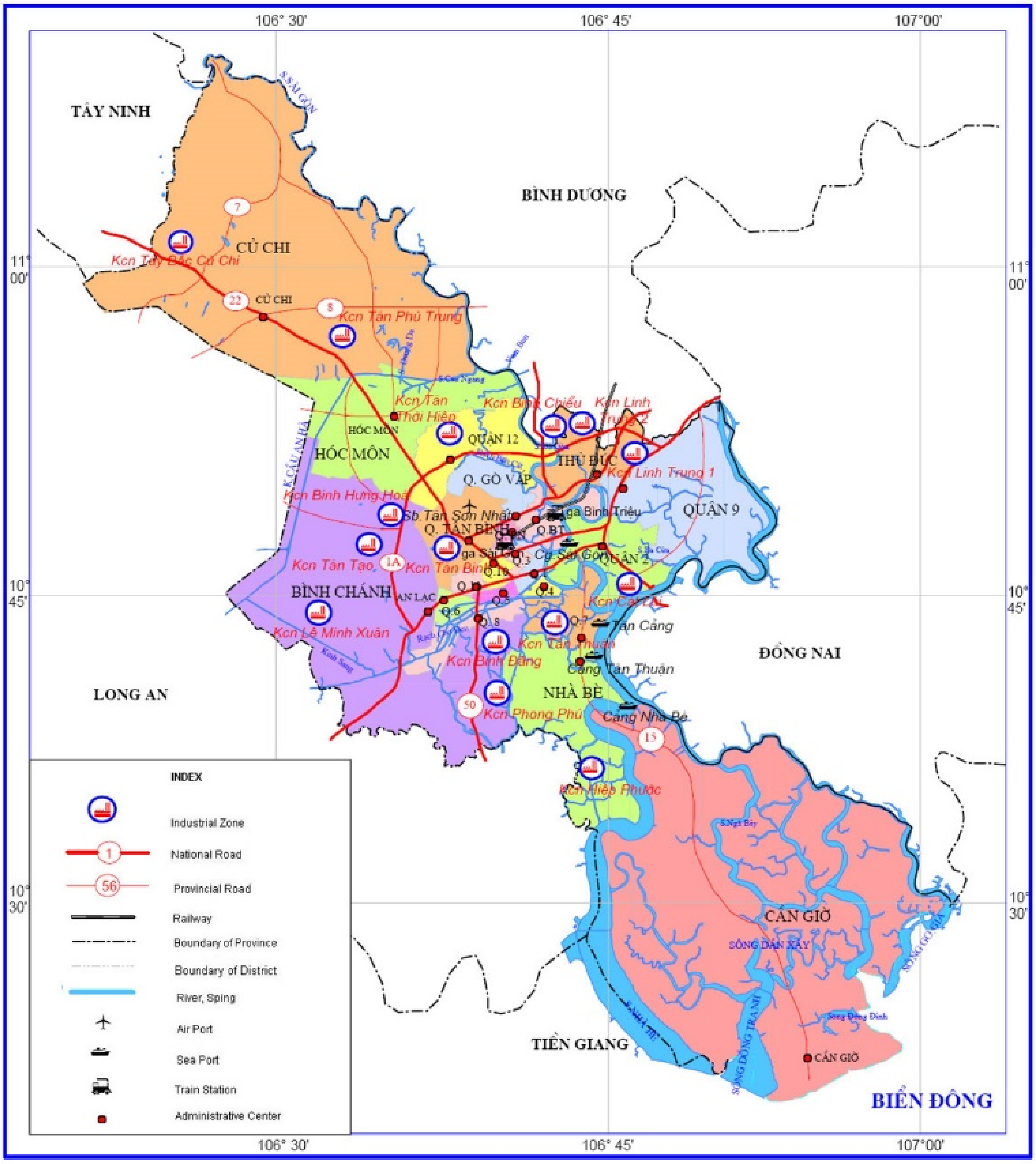

Fig. 1 HCM City map.

With an average flow of 20-500 m³/s and an annual supply of 15 billion m³ of water, the Dong Nai River becomes the main freshwater source of the city. The Saigon River originates from the Hon Quan area, flows through Thu Dau Mot to HCM City, with a length of 200 km and flows along 80 km long of the city. The Saigon River has an average flow of about 54 m³/s, with a width of 225 m to 370 m and a depth of 20 m. Thanks to the Rach Chiec canal system, the two rivers of Dong Nai and Saigon connect in the expanded inner city. Another river of HCM City is the Nha Be River, formed at the confluence of the two rivers of Dong Nai and Saigon, flows into the East Sea by two main ways, Soai Rap and Ganh Rai. In particular, Ganh Rai is the main waterway for the ships to the port of Saigon [1].

1.1.3 Meteorology-Climate

As in some other southern provinces, HCM City has two seasons: dry season and rain season. Rainy season starts from May to November (hot and humid climate, high temperature and heavy rain), while dry season is from December to April of next year (dry climate, high temperature and low rainfall). On average, HCM City has 160 to 270 hours of sunshine a month. The average temperature is 27 °C, the highest is up to 40 °C and the lowest is 13.8 °C. Every year, the city has 330 days with an average temperature of 25 to 28 °C. The average rainfall of the city reached 1,949 mm/year, of which the year 1908 reached the highest of 2,718 mm, the lowest was 1,392 mm in 1958. In one year, the city has an average of 159 rainy days, the most rainfall from May to November, accounting for about 90%, especially in June and September. In the city space, rainfall distributes unevenly, trends to increase along the southwest-northeast. Urban districts and districts in the north have higher rainfall than the rest [1].

HCM City is affected by the two main wind directions which are west-southwest and north-northeast monsoon. West-Southwest wind from the Indian Ocean has an average speed of 3.6 m/s in the rainy season. North-Northeast wind from the East Sea has an average speed of 2.4 m/s in the dry season. There is also a south-southeast trade wind from March to May, an average of 3.7 m/s. It can be said that HCM City is located in the region without storms. As rainfall, the air humidity in the city rises in the rainy season (80%), and low in the dry season (74.5%). Average air humidity reaches 79.5% per year [3].

1.2 Flooding Situation

In addition to the main rivers, HCM City also has a diverse network of canals: Lang The, Bau Nong, Can Tra, Ben Cat, An Ha, Tham Luong, Cau Bong, Nhieu Loc-Thi Nghe, Ben Nghe, Lo Gom, Ken Te, Tau Hu, Kenh Doi, etc.. Rivers and canals help HCM City to irrigate, but due to fluctuations in the tidal range of the East Sea, tidal floods have impacted badly on agricultural production and water drainage in the inner city.

Total length of the river system is 7,955 km. Total area of water surface is 16%. The lowland terrain is less than 2 m high and the water surface is 61% of the natural area. It also is located in the estuary with many large dams in the upstream. Therefore, the risk of flooding is high.

The average rainfall in HCM City is quite high, ranging from 1,800 mm to 2,700 mm in seven months from May to November, accounting for 90% of rainfall.

Due to the two main seasons of the rainy season and the dry season, the flow regimes in the two rivers of Saigon and Dong Nai rivers also form two corresponding flow regimes. At the same time, because of the impact of the East Sea, rivers and canals in the inner city of HCM City are strongly influenced by tides all the year.

By early 2017, HCM City has 171 flooded sites assigned by the district level; 40 submergence points assigned by Steering Center of Flooding Control Program, and 9 tidal flooded points.

In recent decades, tides have been more and more irregular due to many causes, including climate change. Climate change causes sea level rise and sea level rise creates high tide. The flooded points are very volatile. The rapid urbanization makes tides become violent, high and swirl [2].

2. Methodology

2.1 Criteria Selection

According to the IPCC Third Assessment Report: “Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity” [4].

Therefore, based on this definition of vulnerability, there are four criteria: Hazard, Exposure, Sensitivity and Adaptability. These criteria are described below [5-7].

(1) Hazard (H): shows the magnitude, flooding level and the hazards that floods can damage to the study area. This study uses 3 indicators (Table 1);

(2) Exposure (E): is known as direct threats, including characteristics and changing levels of extreme factors in the area. This study uses 6 indicators (Table 1);

(3) Sensitivity (S): is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes. The effect may be direct (e.g., a change in crop yield in response

Table 1 Criteria for assessing vulnerability level to flooding in HCM City.

No.	Criteria	Symbols	Sources
1	HAZARD (H)		
1.1	Flooding area (m^2)	H1	Flooding data
1.2	Flooding depth (m)	H2	Flooding data
1.3	Flooding time (min)	H3	Flooding data
2	EXPOSURE (E)		
2.1	Density	E.1	Statistical yearbook
2.2	Population (people)	E.2	Statistical yearbook
2.3	Current land use	E.3	Land use map
2.4	Number of manufactures/factories	E.4	Statistical yearbook
2.5	Length of flooded road	E.5	Resident questionnaire
2.6	Type of housing	E.6	Resident questionnaire
3	SENSITIVITY (S)		
3.1	Social sensitivity		
	Working-age population	S.xh.1	Statistical yearbook
	Female ratio	S.xh.2	Statistical yearbook
	The poor/total number of households	S.xh.3	Statistical yearbook
3.2	Economic sensitivity		
	Income per capita	S.kt.1	Statistical yearbook
	Livelihood	S.kt.2	Resident questionnaire
	Main income source	S.kt.3	Resident questionnaire
3.3	Environmental sensitivity		
	Rate of households registering for waste collection (%)	S.mt.1	Officer questionnaire
	Rate of households using clean water	S.mt.2	Officer questionnaire
	Current state of air pollution	S.mt.3	Resident questionnaire
	Domestic water quality	S.mt.4	Resident questionnaire
	Potential for disease outbreak	S.mt.5	Resident questionnaire
4	ADAPTABILITY (A)		
4.1	Government		
	Number of staff working in the field of natural disaster prevention	A.cq.1	Officer questionnaire
	Ward health activities	A.cq.2	Officer questionnaire
	Flood adaptation plan/program	A.cq.3	Officer questionnaire
	Effectiveness of the flood protection program/plan	A.cq.4	Officer questionnaire
	Quality of District Public Service activities in the ward	A.cq.5	Officer questionnaire
4.2	Resident		
	Flood resistance	A.cd.1	Resident questionnaire
	Access to news (radio, television, internet)	A.cd.2	Resident questionnaire
	Quality of flood articles	A.cd.3	Resident questionnaire
	Community support/community solidarity	A.cd.4	Resident questionnaire

to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise). This study uses 11 indicators (Table 1);

(4) Adaptability (A): is the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. This study uses 9 indicators (Table 1).

2.2 Steps

Establishing the flood vulnerability criteria includes the steps which are shown as Fig. 2.

2.3 Formulation for Flood Vulnerability

After setting up the factors of criteria fully, the values of each variable have been collected and edited enough.

The values of each variable will be normalized from 0 to 1 [8].

The vulnerability index due to flooding is considered a function of four criteria: hazard, exposure, sensitivity and adaptability [9-11]:

$$FVI = f(H, E, S, A) \quad (1)$$

There are many different formulations in last studies but the formulas were used in this study as Eq. (2):

$$FVI = H \times w_H + E \times w_E + S \times w_S + (1 - A) \times w_A$$

in which, w_H, w_E, w_S, w_A: weight of 4 criteria.

Values of 4 citeria: H, E, S, A are defined from its variables. The formula for calculating these criteria use a weighted plus formula (Eq. (3)):

$$X = \sum_{i=1}^{n} X_i . w_i \quad (3)$$

in which: X—criteria to be determined; X_i—value of the variable i; w_i—weight of the variable i and $\sum_{i=1}^{n} w_i = 1$.

The values of weight are calculated by the AHP (analytic hierarchy process) method [12].

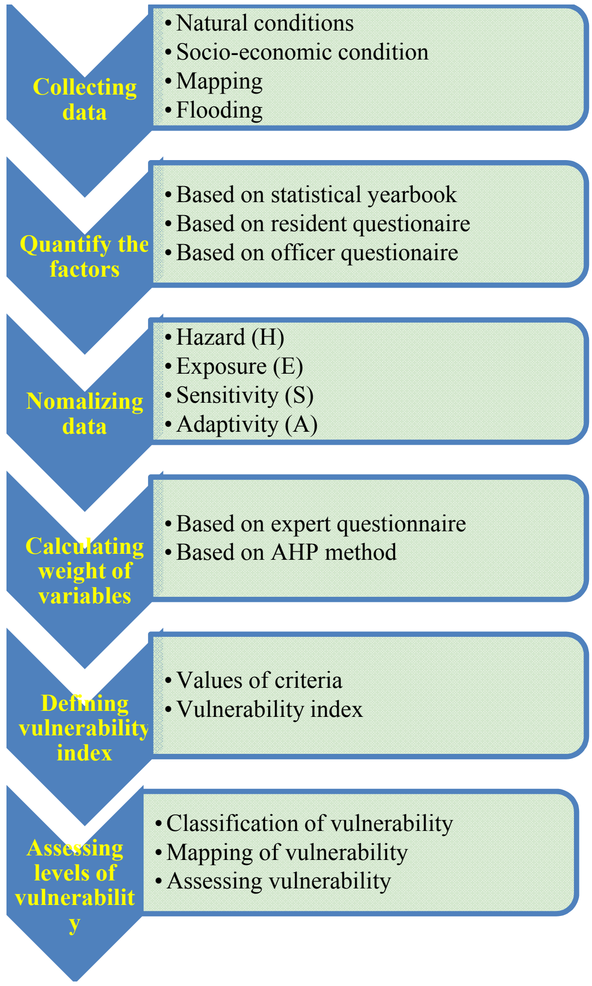

Fig. 2 Steps for assessing flood vulnerability in District 6, HCM City [3, 4].

3. Assessing Flood Vulnerability in District 6, HCM City

3.1. Introduction to District 6, HCM City

District 6 consists of 14 wards, located in the southwest of HCM City. District 6 is shaped like a triangle.

Main fields of District 6 are trade and service. It mainly trade exchange with the provinces in the Southwest region. In addition, most of them are laborers, especially many Chinese-Vietnamese people who are experienced in handicraft business and production. District 6 has a total natural area of 7.14 km^2, accounting for 0.34% of the natural area of the city. The current population of District 6 is 252,811 people, with an average population density of 35,408 people/km^2, of which 53% are women.

Flooded areas in District 6 are Bung Binh Cay-Tan Hoa Dong-Ba Hom (in Tan Hoa-Lo Gom basin). Especially, Cho Lon Bus Station is typical flooded area due to inadequate drainage and encroached canals. The canal sections are narrowed, so the water level of canals is high up in the rain. Moreover, when heavy rain coincides with high tides, the water level in the canal is higher than the height of the road surface causing severe flooding. In addition, since the Bau Cat which is upstream of the Tan Hoa-Lo Gom Canal has been urbanized; it has increased the flow and water level at the Ong Buong bridge, causing flooding in this area. It is worth mentioning that even if there is only rain in the upper of Tan Hoa canal (Tan Binh District), the area is also flooded by the inundation.

3.2 Database of Flood Vulnerability in District 6, HCM City

The data used for the vulnerability assessment for District 6 of HCMC include:

(1) Statistical yearbook for economic and social data of District 6 (District Statistical Office);

(2) Background maps and land use maps (Department of Natural Resources and Environment of HCM City);

(3) Flooding data (Flood Control Center, People's Committee of HCM City);

(4) Resident questionnaire;

(5) Ward/district officer questionnaire;

(6) Expert questionnaire.

Specific data sources of each variable and factor are shown in Table 1.

3.3 Results

(1) Hazard (H)

The results of flood hazard (H) for each ward are shown in Table 2:

(2) Exposure (E)

The results of flood exposure (E) for each ward are shown in Table 3:

(3) Sensitivity (S)

+ Social sensitivity (S_{so})

The results of social sensitivity (S_{so}) for each ward are shown in Table 4:

Table 2 Results of flood hazard (H).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
H1	0.10	0.60	0.60	0.00	0.00	0.00	0.78	0.00
H2	0.60	0.20	0.18	0.00	0.00	0.00	0.19	0.00
H3	0.30	0.25	0.19	0.00	0.00	0.00	0.22	0.00
H		0.26	0.22	0.00	0.00	0.00	0.26	0.00

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
H1	0.10	0.00	0.00	0.69	0.00	0.00	0.51	0.55
H2	0.60	0.00	0.00	0.15	0.00	0.00	0.10	0.24
H3	0.30	0.00	0.00	0.08	0.00	0.00	0.17	0.36
H		0.00	0.00	0.18	0.00	0.00	0.16	0.31

w_i = weight; P1 = ward 1.

Table 3 Results of flood exposure (E).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
E.1	0.18	0.50	0.46	0.51	0.72	0.76	0.59	0.36
E.2	0.19	0.35	0.27	0.29	0.37	0.42	0.45	0.42
E.3	0.36	0.71	0.71	0.71	0.66	0.67	0.69	0.74
E.4	0.17	0.07	0.80	0.06	0.29	0.07	0.27	0.06
E.5	0.05	0.11	0.21	0.00	0.00	0.00	0.19	0.00
E.6	0.05	0.40	0.46	0.52	0.40	0.44	0.42	0.48
E		0.45	0.56	0.44	0.51	0.49	0.52	0.44

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
E.1	0.18	0.70	0.55	0.17	0.33	0.45	0.36	0.62
E.2	0.19	0.70	0.36	0.65	0.75	0.80	0.75	0.65
E.3	0.36	0.66	0.69	0.70	0.70	0.69	0.72	0.67
E.4	0.17	0.08	0.10	0.25	0.23	0.30	0.40	0.10
E.5	0.05	0.70	0.55	0.17	0.33	0.45	0.36	0.62
E.6	0.05	0.70	0.36	0.65	0.75	0.80	0.75	0.65
E		0.54	0.46	0.49	0.52	0.55	0.59	0.53

w_i = weight; P1 = ward 1.

Table 4 Results of flood social sensitivity (S_{so}).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
S_{so} 1	0.59	0.38	0.30	0.29	0.39	0.47	0.42	0.38
S_{so} 2	0.29	0.53	0.54	0.52	0.52	0.51	0.53	0.52
S_{so} 3	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{so}		0.38	0.33	0.33	0.38	0.42	0.40	0.38

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
S_{so} 1	0.59	0.76	0.38	0.64	0.74	0.80	0.72	0.69
S_{so} 2	0.29	0.53	0.52	0.52	0.53	0.52	0.52	0.53
S_{so} 3	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{so}		0.60	0.38	0.53	0.59	0.62	0.58	0.56

w_i = weight; P1 = ward 1.

+ Economical sensitivity (S_{ec})

The results of economical sensitivity (S_{ec}) for each ward are shown in Table 5.

The results of environmental sensitivity (S_{en}) for each ward are shown in Table 6.

The results of sensitivity (S) for each ward are shown in Table 7.

(4) Ad**a**ptability (A)

+ Government aspect (A_{Go}):

The results of Government aspect (A_{Go}) of Adaptability for each ward are shown in Table 8.

The results of resident aspect (A_{re}) of Adaptability for each ward are shown in Table 9.

The results of adaptability (A) for each ward are shown in Table 10.

(5) FVI (Flood Vulnerability Index)

From the results of H (Table 2), E (Table 3), S (Table 7) and A (Table 10), the formula (Eq. (3)) is used to calculate the vulnerability index due to flooding in District 6 of HCM City as shown in Table 11 and Fig. 3.

The results of the flood vulnerability index in District 6 of HCMC show that:

According to hazard criteria and results of data collected from the Flood Control Center in District 6, there are inundated wards of 1, 2, 6, 10, 13, 14 with lowest depth in ward 13 of 0.1 m and the remaining wards reach the threshold of 0.2 m. Ward 14 has a longest flooded time with 128 minutes and Ward 10 has the shortest flooded time with 30 minutes, The flooded time of remaining wards ranges from 60 minutes to 90 minutes. Flooded wards will be damaged more than others wards.

According to the values of the exposure in District 6, these wards, such as 2, 4, 6, 8, 11, 12, 13, 14 have a value of exposure over 0.5, in which, Ward 11, 13 and 14 are the most vulnerable areas because the number of business establishments as well as population is higher than that of other Wards. Particularly, Ward 14 has the largest population with 28,777 people and Ward 11 and Ward 13 with a population of nearly 27,000 people. Generally, wards with large populations, large factory facilities and frequently flooded roads have higher exposure levels.

Table 5 Results of flood economical sensitivity (S_{ec}).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
S_{ec} 1	0.59	1.00	0.89	0.83	0.86	0.87	0.79	0.83
S_{ec} 2	0.29	0.42	0.58	0.50	0.60	0.42	0.58	0.44
S_{ec} 3	0.11	0.34	0.36	0.38	0.36	0.38	0.44	0.36
Ss		*0.75*	*0.73*	*0.68*	*0.72*	*0.68*	*0.68*	*0.65*

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
S_{ec} 1	0.59	0.83	0.85	0.86	0.88	0.91	0.82	0.75
S_{ec} 2	0.29	0.52	0.50	0.48	0.40	0.40	0.50	0.56
S_{ec} 3	0.11	0.34	0.38	0.36	0.32	0.34	0.40	0.38
S_{ec}		0.68	0.69	0.69	0.67	0.69	0.67	0.65

w_i = weight; P1 = ward 1.

+ Environmental sensitivity (S_{en}):

Table 6 Results of flood environmental sensitivity (S_{en}).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
S_{en} 1	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{en} 2	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{en} 3	0.23	0.42	0.42	0.46	0.48	0.42	0.42	0.50
S_{en} 4	0.22	0.22	0.22	0.22	0.20	0.20	0.22	0.20
S_{en} 5	0.33	0.22	0.22	0.22	0.20	0.20	0.22	0.20
S_{en}		0.22	0.22	0.23	0.22	0.21	0.22	0.23

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
S_{en} 1	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{en} 2	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{en} 3	0.23	0.52	0.48	0.54	0.44	0.42	0.54	0.52
S_{en} 4	0.22	0.22	0.22	0.22	0.26	0.24	0.22	0.20
S_{en} 5	0.33	0.22	0.22	0.22	0.26	0.24	0.22	0.20
S_{en}		0.24	0.23	0.25	0.24	0.23	0.25	0.23

w_i = weight; P1 = ward 1.

+ Sensitivity (S):

Table 7 Results of flood sensitivity (S).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
S_{so}	0.62	0.38	0.33	0.33	0.38	0.42	0.40	0.38
S_{ec}	0.26	0.75	0.73	0.68	0.72	0.68	0.68	0.65
S_{en}	0.12	0.22	0.22	0.23	0.22	0.21	0.22	0.23
S		0.45	0.42	0.40	0.45	0.46	0.45	0.43

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
S_{so}	0.62	0.38	0.53	0.59	0.62	0.58	0.56	0.60
S_{ec}	0.26	0.68	0.69	0.69	0.67	0.69	0.67	0.65
S_{en}	0.12	0.24	0.23	0.25	0.24	0.23	0.25	0.23
S		0.58	0.44	0.54	0.57	0.59	0.56	0.54

w_i = weight; P1 = ward 1.

Table 8 Results of flood adaptability—government aspect (A_{Go}).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
A_{Go} 1	0.18	0.40	0.40	0.40	0.40	0.40	0.40	0.40
A_{Go} 2	0.18	0.20	0.20	0.20	0.20	0.20	0.20	0.20
A_{Go} 3	0.31	0.40	0.40	0.20	0.20	0.20	0.40	0.20
A_{Go} 4	0.33	0.40	0.40	0.50	0.46	0.38	0.42	0.48
A_{Go} 5	0.06	0.20	0.20	0.20	0.20	0.20	0.20	0.20
A_{Go}		0.38	0.38	0.35	0.33	0.31	0.38	0.34

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
A_{Go} 1	0.18	0.40	0.40	0.40	0.40	0.40	0.40	0.40
A_{Go} 2	0.18	0.20	0.20	0.20	0.20	0.20	0.20	0.20
A_{Go} 3	0.31	0.20	0.20	0.80	0.20	0.20	0.40	0.40
A_{Go} 4	0.33	0.52	0.50	0.50	0.44	0.42	0.44	0.52
A_{Go} 5	0.06	0.20	0.20	0.20	0.20	0.20	0.20	0.20
A_{Go}		0.35	0.35	0.53	0.33	0.32	0.39	0.42

w_i = weight; P1 = ward 1.

+ Resident aspect (A_{re}):

Table 9 Results of flood adaptability—resident aspect (A_{re}).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
A_{Re} 1	0.45	0.54	0.50	0.50	0.48	0.48	0.54	0.52
A_{Re} 2	0.28	0.72	0.70	0.74	0.78	0.76	0.74	0.78
A_{Re} 3	0.19	0.72	0.70	0.74	0.78	0.76	0.74	0.78
A_{Re} 4	0.08	0.60	0.60	0.60	0.60	0.60	0.60	0.60
A_{Re}		0.63	0.60	0.62	0.63	0.62	0.64	0.65

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
A_{Re} 1	0.45	0.66	0.62	0.44	0.44	0.48	0.44	0.40
A_{Re} 2	0.28	0.78	0.74	0.76	0.74	0.76	0.74	0.70
A_{Re} 3	0.19	0.78	0.74	0.76	0.74	0.76	0.74	0.70
A_{Re} 4	0.08	0.60	0.60	0.60	0.60	0.60	0.60	0.60
A_{Re}		0.71	0.67	0.60	0.59	0.62	0.59	0.56

w_i = e = weight; P1 = ward 1.

+ Adaptability (A):

Table 10 Results of flood Adaptability (A).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
A_{Go}	0.50	0.38	0.38	0.35	0.33	0.31	0.38	0.34
A_{Re}	0.50	0.63	0.60	0.62	0.63	0.62	0.64	0.65
A		0.50	0.49	0.48	0.48	0.46	0.51	0.49

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
A_{Go}	0.50	0.35	0.35	0.53	0.33	0.32	0.39	0.42
A_{Re}	0.50	0.71	0.67	0.60	0.59	0.62	0.59	0.56
A		0.53	0.51	0.57	0.46	0.47	0.49	0.49

w_i = weight; P1 = ward 1.

Table 11 Results of FVI (Flood Vulnerability Index).

Variable	w_i	P1	P2	P3	P4	P5	P6	P7
H	0.50	0.26	0.22	0.00	0.00	0.00	0.26	0.00
E	0.23	0.45	0.56	0.44	0.51	0.49	0.52	0.44
S	0.19	0.45	0.42	0.40	0.45	0.46	0.45	0.43
A	0.08	0.50	0.49	0.48	0.48	0.46	0.51	0.49
VFI		0.36	0.36	0.22	0.24	0.24	0.37	0.22

Variable	w_i	P8	P9	P10	P11	P12	P13	P14
H	0.50	0.00	0.00	0.18	0.00	0.00	0.16	0.31
E	0.23	0.54	0.46	0.49	0.52	0.55	0.59	0.53
S	0.19	0.58	0.44	0.54	0.57	0.59	0.56	0.54
A	0.08	0.53	0.51	0.57	0.46	0.47	0.49	0.49
VFI		0.28	0.23	0.35	0.26	0.28	0.36	0.42

w_i = weight; P1 = ward 1.

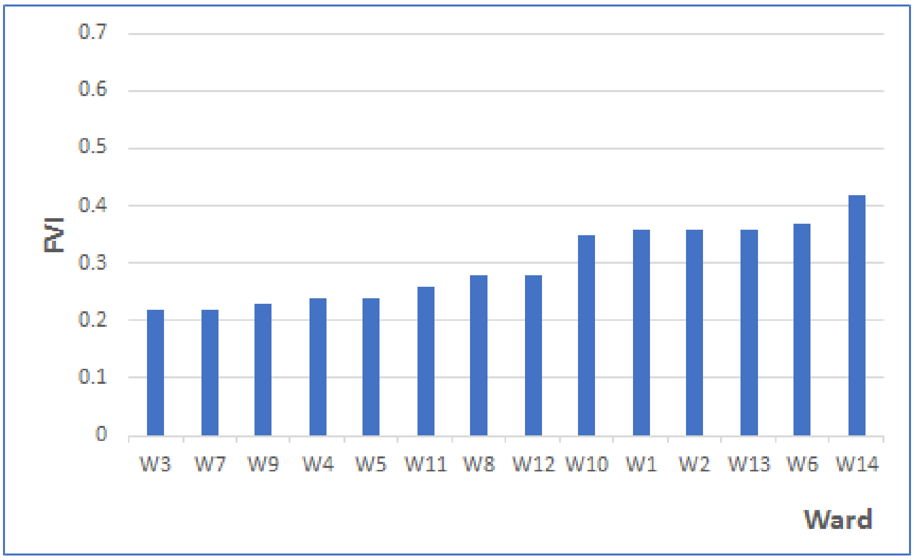

Fig. 3 Chart of FVI in District 6, HCM City.

Based on the values of the sensitivity in District 6, the wards which have the sensitivity greater than 0.5 are wards of 8, 10, 11, 12, 13 and 14. According to data collected from the statistical yearbook, the number of people in the working age of wards 11, 12, 13 and 14 is higher than that of other wards.

As for the adaptability, the higher adaptive capacity of wards is, the lower damage is. According to the calculated values, wards of 2, 3, 4, 5, 11, 12, 13 and 14 have low adaptability, so the damage will be higher than other wards.

The highest FVI (Flood Vulnerability Index) reached 0.452. The smallest value was 0.288 and the mean value was 0.390.

In general, in District 6, there were 4 wards with high vulnerability, including wards of 2, 6, 13 and 14 and the remaining wards had average vulnerability.

4. Conclusion

Based on the natural conditions, socio-economic characteristics and impact level of urban flooding in HCM City (Vietnam), the study identified a set of criteria for assessing vulnerability to urban flooding on socio-economic and environmental aspects.

The set of criteria includes the hazard (H), exposure (E), sensitivity (S) and adaptability (A). There are 29 variables belonging to 4 criteria. The variables and criteria are basically suitable for urban flooding as HCMC.

Results for District 6 which is the typical flood level in HCMC show that there are 4 wards with high vulnerability, the vulnerability index is greater than 0.4, including wards of 2, 6, 13 and 14 and the remaining wards have average vulnerability.

Based on the assessment of the flood vulnerability, measures will be proposed for each indicator or criterion to minimize this risk. The proposed results will be presented in further studies.

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