Establishing vulnerability indicators to inundation in the context of the climate change

Le Ngoc Tuan, Le Thi Yen Phi, Nguyen Van Bang

***Abstract*—Flooding is a concern phenomenon, especially in the context of climate change (CC) and sea level rise. This work aimed to establish indicators used to assess vulnerability (V) due to inundation on the basis of considering the exposure (E), sensitivity (S) and adaptive capacity (AC) of a system. By literature review, data analysis, and expert methods, 33 indicators for assessing vulnerability due to inundation were established, including 4 E, 11 S (divided into 4 groups: society, economic, environment, and land use), and 18 AC indicators (divided into 4 groups: human, financial, infrastructure, and society). This work resulted in an important basis for comprehensive evaluation of vulnerability due to inundation in the context of CC and proposing suitable solutions.**

***Index Terms*—climate change, inundation, vulnerability, exposure, sensitivity, adaptive capacity.**

1 INTRODUCTION

Climate change (CC) - especially global warming and sea level rise - is one of the major challenges for humanity in the 21st century. Disasters and severe weather phenomena are increasing in quantity, strength, and scope of impact. They are the top concern of the world, including Viet Nam [1]. Therefore, studies on CC need carrying out to provide necessary information for plans, projects, etc, improving adaptability of the system.

Inundation resulted in negative impacts on human health, environment quality and socio-economic activities (areas of cultivation, industrial zones, urban, traffic road, etc.), leading to serious effects to countries having high population density at low delta and coastal areas as Vietnam. Especially in the context of CC, the increase in the precipitation in the rainy season, and sea level rise, inundation (and tidal inundation in particular) becames more and more serious.

Under these circumstances, in order to implement effectively response solutions to CC, it is essential to the assess vulnerability of flooding in the context of CC. In general, there are 2 main groups to evaluate the vulnerability: absolutized andrelativized assessment which might carry out by model method, stakeholder-based approaching method, and index method (combined with GIS) [2, 3] where the last one had been often used. This index was based on many indicators showing the vulnerability of an area or sector. It could be a preeminent method because of including all of input factors the ability of evaluating the importance of aspects forming the vulnerability. It was also an effective method to quantify the qualitative factors (via index), to compare the vulnerability of considered areas, and to indicate defective links among E, S, and AC aspects [4–7], an important basic for proposing response measures.

Accordingly, this work aimed at establishing vulnerability indicators to inundation in the context of CC, providing basis for comprehensive evaluation of vulnerability as well as planning proper response programs and projects.

2 METHODS

According to [4], vulnerability was the degree to which a system is susceptible to, and unable to cope with, adverse effects. The vulnerability was a function of the character, magnitude, and rate of effects and variation to which a system was exposed, the sensitivity, and adaptive capacity of that system [4–7]. Accordingly, the vulnerability

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was assessed through three sub-indices: the extent of exposure (E), the sensitivity (S) and the adaptive capacity (AC). Oriented research framework was shown in Fig. 1.

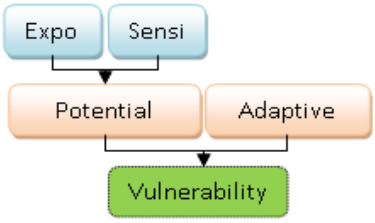

Fig.1. Research framework

Literature review method: Related data and materials, such as CC, flooding, vulnerability assessment method, etc. were gathered, analyzed and synthesized.

Professional adjustment: was applied to analyze, evaluate, and select variablesrelevant to indices of E, S, and AC. Questionnaire was used with the participation of 30 scientists and researchers in the field of CC and inundation.

Data analysis is applied to process the results of consultation

3 RESULTS AND DISCUSSION

Identifying factors reflecting vulnerability to inundation in the context of CC

Factors reflecting the exposure (E)

Factors affecting the level of exposure were those expressing the nature and deciding the severity of the phenomenon [4]. Natural characteristics such as altitude, location, rivers, hydro-meteorological conditions and human life were considered in the simulation process of inundation levels – a basis for evaluation of exposure level.

Inundation are areflects impact risks: the larger inundated area, the higher risk is [9, 10]. Inundation levels also depended on inundated depth and duration [9, 11]: the greater the depth of inundation and the longer the inundated time are, the more threats to the safety and quality of works, living conditions, production and environment woull be. In addition to spatial elements, inundation frequency was also an important factor related to impacts and damages [12, 13].

Factors reflecting the sensitivity (S)

The sensitivity is the degree to which a system is affected detrimentally or beneficially, directly or indirectly [4], commonly considered viafollowing aspects: society [14 - 17], economic [12, 13, 16, 17], environment [9, 11, 12, 16] and land use [11, 13] – presenting natural and social conditions.

Society

Population density reflect the distribution and size of population in the investigated area. The higher the population density was, especially in low and coastal areas, the greater risks (sensitivity levels) of CC in general and inundation in particular would be [9, 11, 16 - 18].

Elderly and children [19] were vulnerable objects in society (limited in health, mobility, and recovery capability, etc.). Regarding gender, women were more vulnerable than men due to basis differences in health and constitution, the unequal in approaching and controlling resources, lack of the role in decision making process, etc. Climate change increasingly challenges the respond capacity of women. The higher the proportion of female-to-male, the greater the sensitivity was. For income [9, 11, 15, 16, 18] the poor had high vulnerability due to lack of opportunities to approach information, residence, food, facility conditions, etc. Accordingly, the higher proportion of poor households -to- total of households, the higher vulnerability of the investigated area would be.

Economic

Economic was one of the most vulnerable aspects due to CC, natural disasters, especially inundation [12, 13, 16, 17]. The vulnerability was considered by the negative effects related main sectors (agriculture, aquaculture, industry, or trade and service).

Agricultural activities were strongly affected by CC, especially inundation because of its dependence on many natural factors such as soil, water, hydrological regime, temperature, humidity, etc. [8, 16, 19]. Aquaculture also

needed staking into account because water sources could be affected (quality and quantity) by CC and inundation [13, 16, 18]. Industry and trade – service also needed considering due to significant impacts of inundation on the infrastructure for industry and transportation (suppling the material).

Environment

In this research, the environmental aspect was considered in the relationship of inundation and wastewater as well as solid waste emission [20]: (i) The rate of collecting and sanitary treating domestic solid waste; (ii) Pollutant load in wastewater (domestic, industrial, agricultural, and aquaculture wastewater); quality of surface water (by WQI index).

Land use

Land use was one of causes increasing the sensitivity in particular and vulnerability to inundation in general [11, 13].

The damage levels of different land groups were clearly different as presented in Table 1 [13]. To cover all aspects, this work generally considers and classified into 4 groups: agricultural land, non-agricultural land, unused land, and coastal land with surface water.

Table 1. Land groups and levels of damage

No.	Land groups	Damage level
1	Bare land, irrigated land and rivers	Trivial
2	Land for afforestation and other industrial and agricultural crops (religion, belief, etc.)	Very low
3	Agricultural land	Low
4	Rural land	Average
5	Urban and business land	High
6	Public and defense/security land	Very high

Factors reflecting the adaptive capacity (AC)

Adaptive capacity (AC) was the level representing the capability to reduce the negative effects of CC or take full advantages from positive effects [4]. The adaptive objects in this work were *authority* and *community*. For adaptive aspects, variables related AC of a system could be resulted from human activities as education, income, health, policy, and technology [4]. Different researches could consider different aspects, but 4 main aspects would be human, financial, infrastructure, and society.

Human capital

Human capital includes knowledge, experience, awareness, human resource and characteristics, etc. The *awareness* of inundation and CC of people and managers were the most important factors deciding the AC [1, 9, 13, 18] because good awareness could lead to good behaviors for proactive adaptation. In addition, to effectively adapt to inundation, it needed the participation of related local managers. Thereby, the more *good managers in the sector of natural disaster prevention, CC, or natural resource*s the higher adaptive capacity to inundation in particular and CC in general would be.

Financial capital

Financial conditions were an important factor demonstrating the adaptability of the community and local government. For community (CDDC), in the event of inundation difficulties, households might have to use available capital to invest in production, business, and alternative sources of income. The dependence on a fixed source of revenue (especially when revenues are inversely related to inundation) were likely to affect the living quality. Thereby, *GDP and the income diversity* of households [16, 17] were key factors of community adaptive capacity. For authorities (CQDP), financial capital could include *budget* for environmental protection activities, adaptation to inundation and response of CC, etc.[21].

Facility capital

This aspect could be considered as the availability of facilities to respond to inundation. *For community*, AC was represented by the following factors: house structure [19], use of national electric network [15], water supply [18], ability to access information [19, 21], etc. *For managers*, the density of traffic road, urban drainage, irrigated system, tidal prevention system, drainage pump, etc. could be taken into consideration.

Social capital

The educational situation partly reflects awareness ability, comprehension level of community about disasters. The medical assistance could partly help households overcome these difficulties, improve adaptive and recovery ability, etc. Thus, society capital reflecting AC could behealth services, education [15, 22], employed workers [21], programs or plans of adaption to inundation and CC.

Completing vulnerability indicators to inundation in the context of CC

On the basis of determining main factors related to inundation in the context of CC combined with expert opinions, indicators for assessing vulnerability were completed (Table 2).

Table 2. Vulnerability indicators to inundation in the context of CC

Aspects	Indicator groups	Objects	Component variables	Note
Exposure (E)			Inundation area (m^2)	+
			Inundation depth (cm)	+
			Inundation duration (minutes)	+
			Number of inundations/year	+
Sensitivity (S)	**Society**		Population density (people/km^2)	+
			The proportion of elderly and children / total population	+
			The proportion of women / men	+
			The proportion of households in poverty / total households	+
	Economic		The proportion of agriculture production value / total production value of economic sectors	+
			The proportion of freshwater aquaculture sector/total production value of economic sectors	+
			The proportion of industrial sector/total production value of economic sectors	+
			The proportion of trade-service sector/ total production value of economic sectors	+
	Environment		The proportion of solid waste collection and treatment	-
			Water quality index (WQI)	-
	Land use		Main land groups, such as: agriculture, non-agriculture, no-use land, coastal land	*
Adaptive capacity (AC)	**Human**	**CDDC**	Awareness of communities of flooding and CC	+
		CQDP	Awareness of managers of flooding and CC	+
			The number of staff taking charge Disaster prevention/CC of or environmental resources	+
	Financial	**CDDC**	Gross Domestic Product (GDP)	+
			Diversity degree of livelihoods	+
		CQDP	The budget for environmental protection (against inundation, disaster prevention and coping with CC)	+
	Infrastructure	**CDDC**	The proportion of households using national electricity network	+
			The proportion of population (or households) using concentrated water supply	+
			Housing structure	+
			Ability to access information (radio, TV)	+
		CQDP	Traffic road density	+
			Urban sewer density	+
			Irrigation system density	+
			Sewer system, tide embankments, drainage pumps	+
	Society		Education index (or The proportion of teachers / pupils)	+
			The proportion of employed workers	+
			The proportion of health workers / population	+
			Programs / plans to adapt to flooding and CC	+

+/ - : positive and negative relationship with the evaluated aspects

** Different land groups have different sensitivity levels*

Results showed experts unanimously agreed with vulnerability indicators due to inundation. In which, indicator of pollutant load in wastewater (belongs to S group) was removed. Indicators for precipitation, surface flows, sea level rise, terrain elevation, canal system, etc. were proposed to integrate into inundation simulations. Thus, indicators for evaluating vulnerability to inundation were completed with 33 variables, including 4 E- variables, 11 S- variables (divided into 4 groups: society, economic, environment, and land use), and 18 AC- variables (divided into 4 groups: human, financial, infrastructure, and society).

These indicators were applied to assess vulnerability to inundation in different scales: wards, districts, cities, and provinces (case studies in Bienhoa city and Dongnai province [23], district 6, Binhthanh district –Ho Chi Minh city [24]).

4 CONCLUSION

By analyzing aspects related to exposure, sensitivity, and adaptive capacity to inundation, this work proposed indicators for assessing vulnerability to inundation in the context of CC including 33 component variables: 04, 11, 18 variables represent the exposure, sensitivity (reflecting society, economic, environment, and land use conditions), and adaptive capacity (human, financial, infrastructure, and society), respectively. Based on these indicators, the detailed and comprehensive evaluation of vulnerability to inundation should be performed, providing the basis for planning proper response solutions, contributing to ensurement of a sustainable development.

REFERENCES

[1]. Worldbank, Economics of adaptation to climate change in Vietnam's aquaculture sector, 2010.

[2]. T.S. Nguyen, T.V. Can, The methods of assessing vulnerability - Theory and Practice - Part 1: Applicability in assessing vulnerability to floods in Central of Vietnam. *Journal of Science - Vietnam National University - Hanoi: Natural Sciences and Technology* 28, 3S, 115–122, 2012.

[3]. N.T. Le, A review of vulnerability assessment due to climate change. *Science and Technology Development Journal*, vol 1, no T2-2017, pp. 5–20, 2017.

[4]. Intergovernmental Panel on Climate Change –IPCC, IPCC WGII – Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II tothe Third Assessment Report of the IPCC. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 869–883, 2007.

[5]. Q.D. Tran, H.T. Nguyen, L. Kanchit, Simulating salinization in Mekong Delta under the impact of sea level rise and the decline in the upstream flow, *Journal of Science – Can Tho University*, 21b, 141–150, 2012.

[6]. IPCC WGII – Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. The Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, New York, USA, 527– 528, 1995.

[7]. IPCC WGII – Climate Change: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 365–388, 2001.

[8]. T.D. Tran, T.H.T. Vu, Review of Economics of Climate Change, International Science Conference Economics of climate change and policy implications for Vietnam, Ha Noi, 2013.

[9]. T.S. Nguyen, T.V. Can, Method for calculating weight to determine flood vulnerability index in Vu Gia - Thu Bon river basin. *Journal of Science - Vietnam National University – Hanoi*, 31, 1S, 93–102, 2015.

[10]. X.H. Nguyen, V.T. Phan, Assessment of climate change impact on flood in Nhat Le river basin, Vietnam. *Journal of Science - Vietnam National University - Hanoi: Natural Sciences and Technology*, 31, 3S, 125–138, 2015.

[11]. T.S. Nguyen, T.V. Can, Calculating Flood Vulnerability Index using Analysis Hierarchy Process (AHP) – Case study in some communes of Quang Nam Province, Downstream Thu Bon River Basin. *Scientific and Technical Hydro - Meteorological Journal*, 643, 10–18, 2014.

[12]. J. Schanze, E. Zeman, J. Marsalek (Eds.) Flood Risk Management – Hazards, Vulnerability and Mitigation Measures. NATO Science Series, Springer Publisher, 2005.

[13]. D.D. Dang, T.S. Nguyen, Mapping flood vulnerability of Nhue Day river basin in Hanoi. *Journal of Science - Vietnam National University - Hanoi: Natural Sciences and Technology*, 29, 1S, 56 – 63, 2013.

[14]. P. O'brien, D. Mileti, Citizen Paticipation in Emergency Response Following the Loma Prieta Earthquake. *International Journal of Mass Emergencies and Disasters*, 10, 71–89, 1992.

[15]. A.A. Yusuf, H. Francisco, Climate Change Vulnerability Mapping for Southeast Asia. International Development Research Centre – Centre de Recherches pour le Développement international (IDRC – CRDI), 2009.

[16]. P. Mackay, M. Russell, Socialist Republic of Vietnam: Climate Change Impact and Adaptation Study in the Mekong Delta, Project Report. Hanoi: Asian Development Bank (ADB), 2011.

[17]. E.K. Antwi, Community vulnerability assessment index for flood prone savannah agro-ecological zone: A case study of Wa West District, Ghana. *Weather and Climate Extremes* 10, 56–69, 2015.

[18]. T. Bao et al. Vulnerability assessment due to natural disasters to Tan Thanh district, Ba Ria Vung Tau. *Sub-Insititute of HydroMeteorology and Climate change*, 2015.

[19]. The Development Bank of Latin America (CorporaciónAndina de Fomento) – CAF. Vulnerability Index to climate change in the Latin American and Caribbean Region, 2014.

[20]. Associated Programme on Flood Management –APFM, Integrated Flood Management Tools Series - Management Of Flash Floods. Global Water Partthership and Wỏld Meteorological Organization, 2012.

[21]. Swanson, Theory Framework for Applied Disciplines: Boundaries, Contributing, Core, Useful, Novel, and Irrelevant Components. The University of Texas at Tyler, 2007.

[22]. F. Ellis, Rural Livelihoods and Diversity in Developing Countries. Oxford University Press, 2000.

[23]. L.N. Tuan, N.K. Phung, Study on inundation possibility in Dongnai province in the context of climate change. Dongnai Department of Science and Technology, 2017.

[24]. L.N. Tuan, Establishing climate change scenarios in Hochiminh city following new methodologies of IPCC and MONRE. Department of Science and Technology Hochiminh city, 2017.

Xây dựng bộ chỉ thị đánh giá tính dễ bị tổn thương do ngập trong bối cảnh biến đổi khí hậu

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***Tóm tắt*—Ngập là một hiện tượng đáng quan tâm, đặc biệt là trong bối cảnh biến đổi khí hậu (BĐKH) và nước biển dâng (NBD). Nghiên cứu nhằm mục tiêu xây dựng bộ chỉ thị đánh giá tính dễ bị tổn thương (V) do ngập trên cơ sở xem xét mức độ phơi nhiễm (E), mức độ nhạy cảm (S) và khả năng thích ứng (AC) của hệ thống. Bằng phương pháp phân tích, tổng hợp tài liệu kết hợp tham vấn chuyên gia, bộ chỉ thị được xây dựng với 33 chỉ thị, gồm 4 chỉ thị E, 11 chỉ thị S (chia thành 4 nhóm: xã hội, kinh tế, môi trường, sử dụng đất) và 18 chỉ thị AC (chia thành 4 nhóm: con người, tài chính, cơ sở vật chất và xã hội). Kết quả nghiên cứu là cơ sở quan trọng cho việc đánh giá toàn diện tính dễ bị tổn thương do ngập trong bối cảnh BĐKH và đề xuất giải pháp quản lý hiệu quả.**

***Từ khóa*—biến đổi khí hậu, ngập lụt, tính dễ bị tổn thương, mức độ phơi nhiễm, mức độ nhạy cảm, khả năng thích ứng**