Journal of Environmental Science and Management 21-2: 39-46 (December 2018) ISSN 0119-1144

Identifying Vulnerability Indicators of Rural and Freshwater and Sanitation Systems Climate Change and its Application in Ho Chi Minh City, Vietnam

ABSTRACT

Rural fresh water and sanitation (RFWS) is one of vulnerable sector in the context of climate change (CC). However, vulnerability to CC of RFWS has not yet been assessed in-depth and hardly considered the integrated approach via index method. This study thus aimed to establish vulnerability indicators to CC of RFWS for a comprehensive assessment. By literature review, factors reflecting exposure, sensitivity, and adaptive capacity to CC of RFWS were sufficiently and systematically determined. Expert consulting method was then applied to complete the indicator set, consisting of 53 indicators. There were 22 variables reflecting the exposure to temperature, precipitation, storm, flood, riverbank landslide, saltwater intrusion, and drought; 12 sensitivity variables related to population, water supply and waste treatment, and environment; and 19 adaptivity variables mainly based on facilities and human capitals. The feasibility of the indicator set was examined in a coastal area in Ho Chi Minh city, Vietnam, where the RFWS is a matter of concern and at high risk of CC impacts. Research findings were expected to be an important basis for assessing and proposing measures to cope with CC of RFWS sector.

Key words: *Climate change, rural fresh water and sanitation, vulnerability, exposure, sensitivity, adaptivity*

Ngoc Tuan Le[1*]

[1] University of Science – Vietnam National University Ho Chi Minh City - 227 Nguyen Van Cu St., Ward 4, District 5, Ho Chi Minh City, Vietnam

* lntuan@hcmus.edu.vn

INTRODUCTION

Rural fresh water and sanitation (RFWS) is a matter of concern due to its role in life especially among those who live in rural areas with limited access to this. It directly affects the health and living conditions of humans, especially the vulnerable sector such as women, children, and elderly people (*Cantrell 2013*; *Naomi et al. 2014*; *Andrea 2002*).

Climate change (CC) is one of the biggest challenges, attracting the attention of communities all over the world. With changes in temperature, precipitation, sea level rise and natural disasters, it seriously affected agriculture, forestry, fishery, and industry sectors, as well as RFWS, increasing risks of environmental pollution and water scarcity. Climate Change exacerbates risks to RFWS field (*Cantrell 2013*; *Naomi et al. 2014*).

In order to implement effective response solutions to CC, it is essential to assess the vulnerability of sectors in the context of CC. There are many methods to evaluate vulnerability to CC and natural disasters in general (*Nguyen and Can 2012*; *WWF 2013*). Among these are the integrated approach based onassessment of exposure (E), sensitivity (S), and adaptive capacity (AC) forwarded by which IPCC is widely applied, especially via index method due to its preeminence (*Le 2017*).

However, there has been lack of interest in assessing vulnerability due to CC of RFWS in general as compared to other sectors (agriculture, aquaculture, public health, livelihood). Thus, no in-depth integrated assessment approach (via index method) has been developed for rural water supply (*Doan 2014*), freshwater resources (*UNEP 2012*), water, sanitation and hygiene (*Naomi et al. 2014*), or saltwater intrusion (*Pham and Nguyen 2012*), and flood (*Nguyen and Can 2012, 2015*). In general, aspects of CC, characteristics of RFWS, as well as external factors related to nature, environment, human and social resources have not been sufficiently and systematically considered. It is difficult to explain the vulnerability of this sector in different areas is due to high E, high S, or weak AC of the system. In addition, because system defects concerning E, S, AC components have not been specifically identified, solutions are usually proposed as generic, ineffective, and wasteful.

This study aims to establish vulnerability indicators to CC of RFWS by considering factors reflecting E, S and AC aspects of this sector, then identifying specific indicators that are systematically arranged, and finally to be adjusted by experts. By using carefully-selected indicators, various aspects of vulnerability can be duly considered and better and sufficiently evaluated. In addition, indicators were arranged at different levels, showing different importance as well as in identify defects and strengths of the system to particularly indicate areas of interest (hotspots). As such research findings were expected as an important basis for a comprehensive vulnerability assessment of RFWS in the context of CC and then planning suitable and effective response strategies.

MATERIAL AND METHODS

According to *IPCC* (*2007*), vulnerability is the degree to which a system is susceptible and unable to cope with adverse effects. Vulnerability is a function of the character, magnitude, and rate of effects and variation to which a system is exposed, the sensitivity, and adaptive capacity of that system (*IPCC 1995*; *IPCC 2001*; *Pham and Nguyen 2012*; *Tran et al. 2012*). Vulnerability is assessed through E, S, and AC of the system (*IPCC 2007*), as depicted in the oriented research framework of the study (**Figure 1**).

Literature review method: intensive literature review was used to gather data and materials related to CC, RFWS, vulnerability assessment method. Based on literature review, main elements of CC and RFWS sector were sufficiently and systematically identified. Subsequently, factors reflecting E, S, and AC to CC of RFWS sector were determined. It was an important basis to design vulnerability indicators prior to expert consultation.

Expert consultation method: this was applied to improve the scientific and feasibility of designed vulnerability indicators. Questionnaire was individually administered to participating 32 scientists and researchers in the field of CC and RFWS. For each expert, the designed indicator set was taken into consideration:

- Keeping variables: where variables were deemed as appropriate and applicable.
- Replacing variables: Variables were replaced by more appropriate variables or terminologies
- Eliminating variables: Variables were eliminated due to overlapping or being similar to other variables, unnecessary or unclear
- Adding variables: The missing variables were added

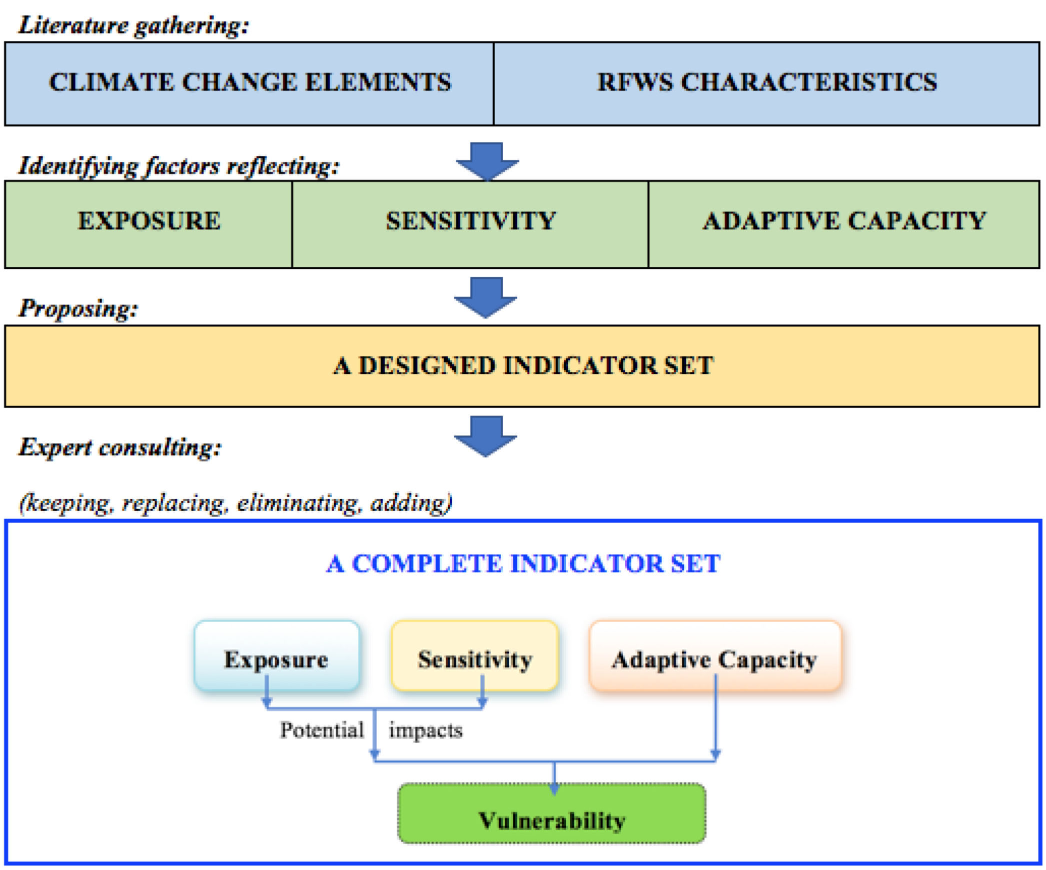

Figure 1. Oriented research framework to identify vulnerability indicators to CC of RFWS.

RESULTS AND DISCUSSION

Identifying factors reflecting the vulnerability to CC of RFWS

Factors reflecting the exposure to CC of RFWS. Factors reflecting the exposure and the severity of the phenomenon (*IPCC 2007*). For RFWS, commonly considered exposure factors are temperature, precipitation, storm, flood, riverbank landslide, saltwater intrusion and drought. The descriptions are as follows:

Temperature. Under CC impacts, the increase in temperature leads to an increase in water evaporation, a reduction of groundwater level, an increase in salinity and water pollution, and consequently, lack of clean water for living and production (*Doan 2014*; *Ha 2014*; *Naomi et al. 2014*; *UNEP 2012*). The important factors are extreme temperature and temperature evolution (*Ha 2014*; *Naomi et al. 2014*; *UNEP 2012*).

Precipitation. Precipitation in dry and rainy seasons are changing due to CC (*Doan 2014*). Decreasing precipitation leads to an increase in groundwater exploitation, while the reduction of water recharge (*Doan 2014*; *Ha 2014*; *UNEP 2012*) and self-purification capacity increase the risks of environmental pollution. Besides, precipitation combined with extreme events are able to significantly affect the environment and socio-economic sectors, including RFWS. Seasonal and annual precipitation evolutions should be taken into consideration (*Naomi et al. 2014*; *Ha 2014*; *UNEP 2012*).

Storm. Storm disperses pollutants into environment, especially in soil and water, affects water supply and drainage infrastructure, thus making it difficult to access the RFWS services. The intensity and frenquency of storm are usually considered and assessed (*Naomi et al. 2014*; *Ha 2014*).

Flood. Increasing inundation in the context of CC spreads out pollutants (from living, breeding, and planting activities) and diseases (such as cholera, dysentery, typhoid), thus seriously affects water quality (*Doan 2014*; *UNEP 2012*) and sanitation. The inundation area (*Doan 2014*) and depth (*Le et al. 2014*) are commonly used in assessing exposure level.

Riverbank landslide. CC is able to significantly change the river flow, enhance risks of landslides, damage structures, water supply pipelines, and sanitation infrastructures along the river and increases sedimentation causing water pollution. The level of exposure depends on the level and speed of erosion (*Le et al. 2014*).

Saltwater intrusion. Similar to other water quality indicators, salinity can harm if thresholds are breached. However, salinity thresholds are relatively complex and depend on the considered factor, such as 1-4 % for rice (*Tanwar 2003*; *Nguyen et al. 2014*), 5-35 % for black tiger shrimp and white shrimp (*MOARD 2014*), 0.25-0.75 % for supply water (*MOC 1999*; *Tran and Nguyen 2011*), thereby affecting the RFWS. Main factors related to saltwater intrusion are maximum salinity (*Doan 2014*), amplitude and duration of salinity (*Le et al. 2014*).

Drought. In this condition, exhausted water resources led to lack of water for household use, planting, breeding activities and maintaining the sanitation. The area and duration of drought are usually considered in relation to the exposure of RFWS (*Naomi et al. 2014*; *Ha 2014*; *UNEP 2012*).

Factors reflecting the sensitivity to CC of RFWS. Sensitivity is the degree to which a system is affected detrimentally or beneficially, directly or indirectly (*IPCC 2007*). This work considered an indicator set and guidelines for implementation of monitoring and evaluating the rural water supply and sanitation and the national set of criteria on new rural development of Ministry of Agriculture and Rural Development (*Nguyen et al. 2014*; *MOARD 2014*) to determine main factors of RFWS- as a basis for sensitivity analysis in the context of CC. Thereby, sensitivity factors include:

Population. Sensitivity of studied sector and/or area depending on the native community. Population characteristics can be reflected via population density (*MOARD 2014*) and vulnerable sectors (women, children, poverty, and elderly people) (*Ha 2014*; *UNEP 2014*; *Nguyen and Can 2015*) which also reflect sensitivity of the system by pressurizing water resources and living conditions.

Water supply and waste treatment. CC seriously affects infrastructures of RFWS, both water supply and waste disposal. It indirectly affects the ability of clean water access and sanitation conditions. Factors considered to assess sensitivity are infrastructure of water supply (*European Commission 2009*), waste treatment and the proportion of people using qualified water (*Leuven 2011*).

Environment. This aspect reflects the sensitivity to CC of RFWS sector in different areas via surface water quality (*Leuven 2011*) and tree cover area (*European Commission 2009*).

Factors reflecting the adaptive capacity to CC of RFWS. Adaptive capacity of a system can be based on human, natural, financial, manufactured, and social capitals. Some common AC indicators are infrastructure (*European Commission 2009*), management capacity (*Naomi et al. 2014*; *UNEP 2012*), budgets of government (*Nguyen and Can 2012*); awareness (*Ha 2014*), per capita income (*Nguyen and Can 2015*), response experience (*Nguyen and Can 2015*) and ability to access information of communities (*Nguyen and Can 2015*). Thereby, AC indicators were devided into two main groups:

Infrastructure of RFWS: The considered aspects are infrastructure of water supply (*European Commission 2009*) (network, capacity), drainage, and waste treatment (*Leuven 2011*) (solid waste collected and landfilled; households having sanitary latrines; households having hygienic cattle sheds).

Human:

Local government: It is responsible for monitoring the change in RFWS, desseminating the necessary information of water demand and supply, assisting community to cope with and to overcome related consequences resulted from CC. The AC factors of local government could be the number of staff taking charge of environmental resources, awareness of CC and RFWS of officers (*Naomi et al. 2014*; *UNEP 2012*), development plan of RFWS infrastructure, and budgets for coping with CC and disasters (*Nguyen and Can 2012*).

Community: Community is a main object to be influenced. Its adaptability is thus a particularly important factor in assessing the vulnerability and reflected by awareness of CC and RFWS of community (*Ha 2014*), per capita income (*Nguyen and Can 2015*), ability to access information under incident circumstances (*Nguyen and Can 2015*) and ability of clean water storage (*Leuven 2011*).

Society: The AC social factors can be health, education, culture and employment (*Nguyen and Can 2015*).

Completing the vulnerability indicators to CC of RFWS

Based on evaluating and determining factors reflecting vulnerability to CC of RFWS, an indicator set of 50 variables was basically designed (called as a designed set), including 16, 14, and 20 variables of exposure, sensitivity, and adaptability, respectively. This designed set was then taken into consultation of experts to improve the scientific and feasibility of indicators to be the complete set.

Overall, the designed indicator set was relatively consensus with experts's opinions where 37, 2, 16, and 13 variables were unchanged, edited, complemented, and eliminated, respectively (**Table 1**).

After gathering experts's opinions, vulnerability indicators to CC of RFWS in general had been completed and sufficiently reflected concerning aspects (**Figure 2** and **Table 2**). The feasibility of the completed indicator set was examined in a coastal area in Ho Chi Minh city

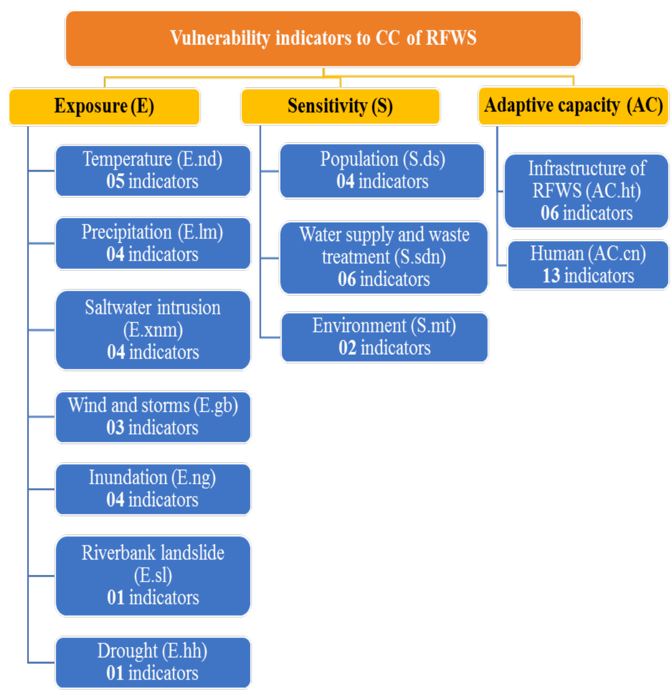

Figure 2. Diagram of vulnerability indicators to CC of RFWS.

Table 1. Expert consulting results of vulnerability indicators.

	The number of variables					
	Kept	Edited	Eliminated	Added	Designed	Completed
E	13	1	3	9	16	22
S	9	1	4	2	14	12
AC	15	0	6	5	20	19
Total	37	2	13	16	50	53

where the RFWS is a matter of concern and at high risk of CC impacts (*Nguyen 2012*) (**Figure 3**). A decrease in V index by the time due to insignificant change of E index while positive changes of S and AC in relation to infrastructures and socio-economic development plans. The defects of system were indicated, including 5, 9, and 13 indicators of E, S, and AC aspects, respectively. The solutions and their priority orders were then proposed (increasing AC, followed by mitigating S and E) to mitigate the CC vulnerability of RFWS and contribute to the local sustainable development.

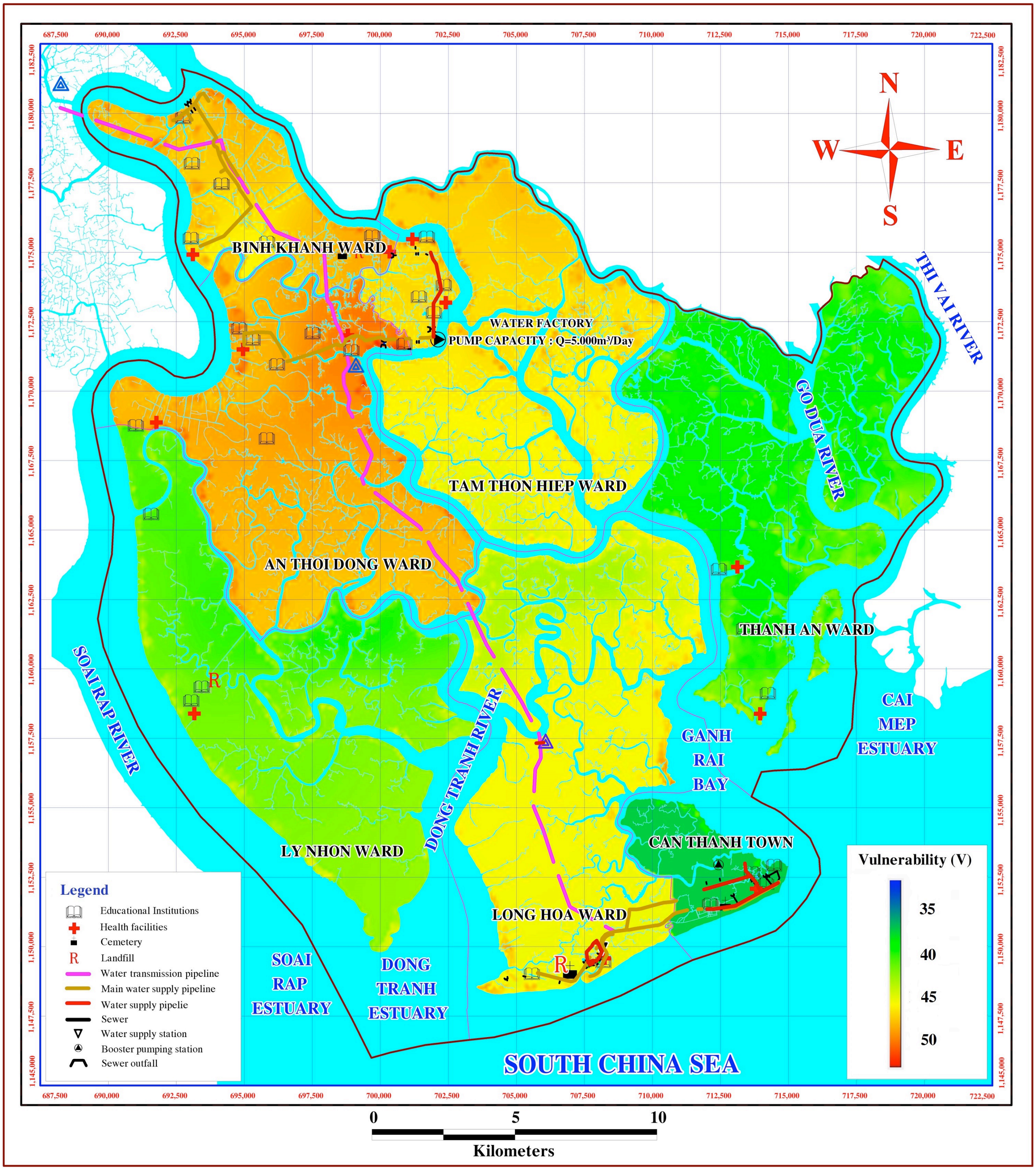

Figure 3. CC vulnerability index of RFWS in a coastal area in Ho Chi Minh city.

Table 2. Vulnerability indicators to CC of RFWS.

Indicator group	Individual indicator		Code
Exposure indicators (E)			
Temperature E.nd	Min temperature evolution		E.nd.1
	Average temperature evolution		E.nd.2
	Max temperature evolution		E.nd.3
	Annual amplitude of average temperature		E.nd.4
	The number of hot days (over 35^{o}C) per year		E.nd.5
Precipitation E.lm	Annual precipitation evolution		E.lm.1
	Rainy season precipitation evolution		E.lm.2
	Dry season precipitation evolution		E.lm.3
	The number of heavy rainy days (> 50 mm day^{-1}) yr^{-1}		E.lm.4
Saltwater intrusion E.xnm	Max salinity		E.xnm.1
	Duration of salinity above 1% (changeable)		E.xnm.2
	Duration of salinity above 4% (changeable)		E.xnm.3
	Salinity amplitude of the saltiest month		E.xnm.4
Wind and storms E.gb	Max wind speed		E.gb.1
	The number of thunderstorms and tornadoes yr^{-1}		E.gb.2
	The number of storms and tropical depressions yr^{-1}		E,gb.3
Inundation E.ng	Inundation area		E.ng.1
	Inundation depth		E.ng.2
	Inundation duration		E.ng.3
	The number of inundation times per year		E.ng.4
Riverbank landslide E.sl	Landslide speed		E.sl
Drought E.hh	Drought index		E.hh
Sensitivity indicators (S)			
Population S.ds	Population density		S.sdn.1
	Vulnerable objects	The proportion of females to males	S.ds.2
		The proportion of children and elderly people to total population	S.ds.3
		The proportion of households in poverty to total households	S.ds.4
Water supply and waste treatment S.sdn	Water supply	The proportion of people using clean water (according to the national technical regulations) to total population	S.sdn.1
		The number of water supply positions	S.sdn.2
		Length of water pipes	S.sdn.3
		The proportion of water lost to total water supply	S.sdn.4
	Waste treatment	The number of landfills	S.sdn.5
		The number of wastewater treatment plants	S.sdn.6
Environment S.mt	The proportion of tree cover area to total area		S.mt.1
	Surface water quality (WQI)		S.mt.2

Table 2. Vulnerability indicators to CC of RFWS. (cont.)

Indicator group	Individual indicator		Code
Adaptive capacity indicators (AC)			
Infrastructure of RFWS AC.ht	Water supply	The proportion of water supply to water demand	AC.ht.1
		Water pipe density	AC.ht.2
	Drainage	Drainage pipe density	AC.ht.3
	Waste treatment	The proportion of municipal solid waste collected and landfilled to total generated solid waste	AC.ht.4
		The proportion of households having sanitary latrines to total households	AC.ht.5
		The proportion of households having hygienic cattle sheds to total households having breeding activities	AC.ht.6
Human AC.cn	Local goverment	The number of staff taking charge of environmental resources (CC and RFWS)	AC.cn.1
		Awareness of CC and RFWS of staffs	AC.cn.2
		Development plans of RFWS infrastructure	AC.cn.3
		Budgets for coping with CC and disasters	AC.cn.4
	Community	Awareness of CC and RFWS of community	AC.cn.5
		Per capita income	AC.cn.6
		Ability to access information under incident circumstances (internet, TV, cellphone)	AC.cn.7
		Ability of clean water storage (volume, time of usage)	AC.cn.8
	Society	The proportion of area for cultural and sport activities to total population	AC.cn.9
		The proportion of health workers to total population	AC.cn.10
		Education index	AC.cn.11
		The proportion of employed workers to total population (or population of working age)	AC.cn.12
		The proportion of traffic road length according to new rural standards to total traffic road length	AC.cn.13

CONCLUSION AND RECOMMENDATIONS

Since there was no tool yet for comprehensive and systematic assessment of the CC vulnerability of RFWS sector, the study aimed to develop a set of indicators as a basis for evaluating. After conducting intensive literature review, 50 indicators were chosen and systematically arranged, covering the exposure, sensitivity, and adaptive capacity to CC of RFWS. These indicators were then consulted 32 experts. The findings were a set of 53 indicators, including 22 variables reflecting the exposure to temperature, precipitation, storm, flood, riverbank landslide, saltwater intrusion, and drought; 12 sensitivity variables related to population, water supply and waste treatment, and environment; and 19 adaptivity variables mainly based on facilities and human capitals. The feasibility of the completed indicator set was examined in a coastal area in Ho Chi Minh city, Vietnam, where the RFWS is a matter of concern and at high risk of CC impacts. This study noticed that data gathering abilily (availability, calculating ability) greatly decides the feasibility of the method and reliability of results. It is therefore recommended that these indicators could be replaced by similar ones as long as natural, manufactured, social, financial, and human capitals must be carefully taken into consideration.

REFERENCES

Andrea C. T. 2002. A Water Supply and Sanitation Study of the Village of Gouansolo in Mali, West Africa. Michigan Technological University. 101 pp.

Cantrell B. L. 2013. An Evaluation of a Water, Sanitation, and Hygiene Program in Rural Communities Outside of Portau-Prince, Haiti. Georgia State University. 71 pp.

Doan T. H. 2014. "Assessing vulnerability due to climate change to rural water supply in Mekong Delta." *Journal of Water resouces and Environmental Engineering* 46: 34 – 40.

European Commission. 2009. The Climate change challenge for European regions. (http://ec.europa.eu/regional_policy/sources/docoffic/working/regions2020/pdf/regions2020_climat.pdf, accessed on 29 Sep 2016).

Ha H. D. 2014. Assessing vulnerability due to climate change impact to agricultural production applied for a number of provinces in the Red River delta. Vietnam Institute for Water Resources Research.

IPCC WGII. 1995. 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: pp 527–528.

IPCC WGII. 2001. Climate Change 2001: 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: pp 365 – 388.

IPCC WGII. 2007. Climate Change 2007: 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: pp 869 – 883.

Leuven L. J. V. 2011. "Chapter 2: Water/Wastewater Infrastructure Security: Threats and Vulnerabilities." In: Handbook of Water and Wastewater Systems Protection. (ed. Clark, Robert, Hakim, Simon, Ostfeld, Avi (Eds.)). Springer. pp. 27-46.

Le A. T., Hoang T. T., Vo V. N. 2012. The impacts of Climate Change to livehoods of people in Mekong delta. Climate Change Institute.

Le A. T., Hoang T. T., Vo V. N. 2014. "The impacts of Climate Change to livehoods of people in Mekong Delta". Paper presented at the 6th Forum of Nature and Culture Conservation for the Sustainable Development in the Mekong Delta., Long An, Vietnam. June 2014.

Le N. T. 2017. "Assessing the vulnerability to climate change – A review." *Science & Technology Development Journal,* 20 (T2-2017): 5-20

Naomi O., Ian R., Roger C., Richard C. and Julian D. 2014. Adaptation to Climate Change in Water, Sanitation and Hygiene. Assessing risks and appraising options in Africa. Overseas Development Institute (ODI). 83 pp.

Nguyen K. P. 2012. Climate change and its impacts in Ho Chi Minh city. Vietnam National University – Ho Chi Minh City Publisher.

Nguyen T.S and Can T.V. 2012. "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.

Nguyen T.S and Can T.V. 2015. "Construction of weighted method for determining vulnerability index to flood in Vu Gia - Thu Bon river basin." *Journal of Science, Vietnam National University, Hanoi: Natural Sciences and Technology* 31(1S): 93-102.

Nguyen V.B, Cao N.N.K, Le V.B, Nguyen Q.K and Ngo N.H. 2014. "Effect of KNO3, brassinosteroid and CaO on growth of rice under saline irrigated conditions." *Journal of Science, Can Tho University, Thematic: Agriculture* 3: 15 - 22.

Pham T.T and Nguyen T.H. 2012. "Impact of climate change: Sea level rise to saltwater intrusion in the North delta coastal strip." *Journal of Water resouces and Environmental Engineering* 37: 35-39.

Tanwar. 2003. Saline water management for irrigation (3rd Revised Draft). International Commission on Irrigation and Drainage (ICID) New Delhi, India. 123 pp.

The Ministry of Construction (MOC). 1999. TCXD 233:1999: The parameters using for selection of the surface and groundwater resource in the water supply system.

The Ministry of Agriculture and Rural Development (MOARD). 2014. Circular 22/2014/TT-BNN, dated 29.07.2014.

Tran D.H and Nguyen Q.H. 2011. "Assessing water quality in estuaries and coastal areas to orientate suitable treatment technologies for water supply purposes." *Journal of Science and Technology in Civil Engineering* 10: 89-98.

Tran Q.D., Nguyen H.T. and Kanchit L. 2012. "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* 21(b): 141-150.

UNEP. 2012. Vulnerability Assessment of Freshwater Resources to Climate change: Implications for Shared Water Resources in the West Asia region. 153 pp. (http://www.unep.org/dewa/Portals/67/pdf/Freshwater_vunerability_Report_LR.pdf, accessed on 29 Sep 2016).

WWF. Vietnam 2013. Climate Change Vulnerability Assessment of Ecosystems in Vietnam. The Ministry of Resources and Environment, Sida.

ACKNOWLEDGMENT

This research is funded by Vietnam National University Ho Chi Minh City (VNU-HCM) under grant number C2016-18-15.