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IDENTIFYING VULNERABILITY INDICATORS TO CLIMATE CHANGE OF RURAL FRESH WATER AND SANITATION

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ABSTRACT

Rural fresh water and sanitation (RFWS) is one of important issues, especially in the context of climate change (CC). This work aims to establish vulnerability indicators to CC of RFWS via exposure, sensitivity, and adaptive capacity indicators. By literature review and expert methods, 53 indicators were established, including 22 variables reflecting exposure level (divided into 07 groups related to temperature, precipitation, saltwater intrusion, storm, flood, riverbank landslide, and drought), 12 variables of sensitivity (divided into 03 groups of population, water supply and waste treatment, and environment characteristics), and finally 19 variables of the adaptive capacity (facilities and human). Research results are expected as an important basis for a comprehensive vulnerability assessment of RFWS in the context of CC and for proposing management solutions.

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INTRODUCTION

Rural fresh water and sanitation (RFWS) is a matter concern due to its role in life, especially in rural area with limitations of accessing conditions, directly relating to heath and habitat *(Cantrell and Brittany 2013; Naomi et al. 2014; Andrea 2002).* Climate change (CC) is one of the biggest challenges, attracting the attention of community in over the world, including Vietnam. CC with changes in temperature, precipitation, sea level rise, and natural disasters etc. has seriously impacted production of agriculture, forestry, fishery, and industry, etc. as well as RFWS, increasing risks of environmental pollution and water scarcity. In other words, CC is able to exacerbate risks to RFWS field *(Cantrell and Brittany 2013; Naomi et al. 2014)*. Under these circumstances, in order to implement effectively response solutions to CC, it is essential to assess vulnerability of RFWS 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)*, in which, integrated assessment approach (based on assessment of exposure, sensitivity, and adaptive capacity) by IPCC, World Bank, and WWF is widely applied due to its preeminence. However, assessments vulnerability due to CC of RFWS in general and using integrated assessment approach in particular (by IPCC) have not yet been in-depth. Thereby, this work aims to establish vulnerability indicators to CC of RFWS via exposure, sensitivity, and adaptive capacity indicators. Research results are expected as an important basis for a comprehensive vulnerability assessment of RFWS in the context of CC and for proposing management solutions.

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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, Nguyen and Kanchit 2012)*. Accordingly, the vulnerability is assessed through three sub-indices: the extent of exposure (E), sensitivity (S) and adaptive capacity (AC) *(IPCC 2007)*. Oriented research framework was shown in Figure a.

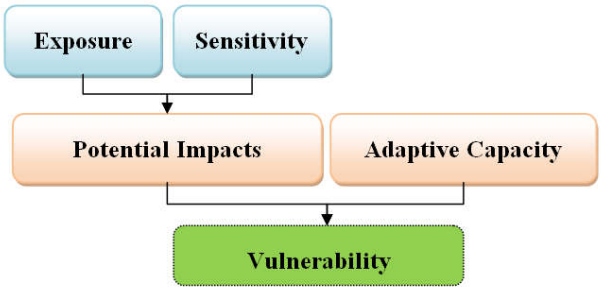

Figure a. Oriented research framework

Literature review method

Reltated data and materials, such as CC, RFWS, vulnerability assessment method, etc. were gathered from research institutes, universities, journals, etc. and then synthesized and analyzed to refine the statistics, the surveyed data, research results, published scientific information to serve this work.

Professional Adjustment: was applied to analyze, evaluate, and select variables relevant to indices of E, S, and AC. Questionnaire was used with the participation of 32 experts who are scientists and researchers in the field of environment, CC, and RFWS. Their work was as follows:

- **Keeping variables:** Variables are considered appropriate and applicable.
- **Replacing variables:** Variables are replaced by more appropriate variables or terminologies.
- **Eliminating variables:** Variables are eliminated due to overlapping with or similar to other variables, unnecessary or unclear.
- **Adding variables:** The missing sub-indices in the preliminary variables are added.

Data analysis: was applied to process the results of consultation with the MS Excel software.

RESULTS AND DISCUSSION

Identification of the factors affecting the vulnerability to CC of RFWS

Factors affecting the exposure (E) to RFWS

Factors affecting the level of exposure are those expressing the nature and deciding the severity of the phenomenon *(IPCC 2007)*. For RFWS, factors presenting exposure levels commonly considered include temperature, precipitation, saltwater intrusion, flood, storm, river erosion and drought, as follows:

Temperature: Under the impact of CC, the increase in temperature leads to an increase in water evaporation, a reduction of groundwater level, an increase in salinity and water pollutant concentrations etc. and consequently a lack of clean water for living and production *(Doan 2014; Ha 2014; Naomi et al. 2014; UNEP 2012)*. The important factors are *temperature are extreme (max, min) and average temperature changes (Ha 2014; Naomi et al. 2014; UNEP 2012)*.

Precipitation: CC decreases and increases precipitation in dry seasons and rainy seasons, respectively *(Doan 2014)*. Decreasing precipitation leads to an increase in groundwater exploitation while a reduction of water recharge *(Doan 2014; Ha 2014; UNEP 2012)* and self-purification capacity as well as increase in risks of environmental pollution. Besides, rain combined with extreme environmental factors are able to significantly influence to the environment and socio-economic sector including RFWS. The important factors reflecting the exposure level for precipitation are *seasonal and annual precipitation change (Naomi et al. 2014; Ha 2014; UNEP 2012)*.

Saltwater intrusion: Saltwater intrusion significantly reduces water quality. Similar to other indicators of water quality, salinity will harm when crossing the threshold, however, salt threshold values are relatively complex and depend on the considered object, e.g. 1-4 ‰ for rice *(Tanwar 2003; Nguyen et al. 2014)*, 5-35 ‰ for black tiger shrimp and white shrimp *(MOARD 2014),* 0.75 ‰ for supply water *(MOC 1999; Tran and Nguyen 2011),* etc. thereby certain affect to RFWS. The main factors reflecting the exposure level for saltwater intrusion are *maximum salinity (Doan 2014), amplitude of salinity, and salty duration (Le et al. 2014)*, ect.

Riverbank landslide: CC is able to change strongly river flow, enhance risks of landslides, damage works, water supply pipelines, sanitation infrastructure along the river, and increase sedimentation causing water pollution, ect. The level of exposure depends on the *level and risks of erosion (Le, Hoang and Vo 2012)*.

Inundation: Increasing inundation in the context of CC spreads out pollutants from living, breeding, and cropping activities, etc. and then is able to seriously impact water quality (surface water, groundwater) *(Doan 2014; UNEP 2012)* as well as sanitation. Moreover, inundation also increases risks of spreading diseases such as cholera, dysentery, typhoid, etc. *The inundation area (Doan 2014) and depth (Le et al. 2014)* are common factors used in assessing exposure level.

Storm: Storms disperse pollutants into environment, especially in soil and water, consequently cause local pollution, affect infrastructure of water supply and drainage as well as the community ability of access to RFWS services. *The intensity and frenquency of storms (Naomi et al. 2014; Ha 2014)* are usually considered and assessed.

Drought: In drought condition, exhausted water resource leads to lack of water for living, producting, cropping, and breeding activities as well as maintaining sanitation. *The area and duration of drought* are able to strongly affect RFWS *(Naomi et al. 2014; Ha 2014; UNEP 2012)*.

Factors affecting the sensitivity (S) to RFWS

Sensitivity is the degree to which a system is affected detrimentally or beneficially, directly or indirectly *(IPCC 2007)*. Thus, factors representing the sensitivity are those reflect the nature and decide the affected ability of the subject. This work considered *Indicator set and guideline for implementation of rural water supply and sanitation monitoring and evaluation* and *The national criteria on new rural* of Ministry of Agriculture and Rural Development *(Nguyen et al. 2014; MOARD 2014)*. They helped to determine main factors of RFWS - as a basis of sensitivity

analysis in the context of CC. Thereby, the factors reflecting sensitivity include:

Population: Sensitivity levels of objects and studied areas depend on native communities. Population characteristics can be reflected via *population density (MOARD 2014)*, *vulnerable objects (proportion of sexual, poverty, elderly and children, ect.) (Ha 2014; UNEP 2014; Nguyen and Can 2015)*. These factors reflect sensitivity level via the ability to pressurize water resources and habitat.

Water supply and waste treatment: CC seriously affect infrastructure of RFWS, including infrastructure of water supply and waste disposal, affect indirectly the ability of using clean water and sanitation conditions. The factors considered to assess sensitivity are *infrastructure of water supply (European Commission 2009) and waste treatment as well as the proportion of people using qualified water (Leuven 2011), etc.*

Factors affecting the adaptive capacity (AC) to RFWS

Adaptive capacity of a system can be formed on basis of human activities such as education, income, heath, institutions and technology. Some indicators of AC commonly assessed are: *infrastructure (European Commission 2009)*, *management capacity (Naomi et al. 2014; UNEP 2012)*, *the budget (Nguyen and Can 2012)*, ect of the government; *awareness (Ha 2014)*, *per capita income (Nguyen and Can 2015)*, *response experience (Nguyen and Can 2015)*, *the ability to receive information (Nguyen and Can 2015)*, ect. of communities. Thereby, indicators of AC in this work are devided into 02 groups:

Infrastructure of RFWS: The considered aspects are *infrastructure of water supply (European Commission 2009)* (water supplying network, capacity, ect.), *drainage* (drainage network), and *waste treatment (Leuven 2011)* (the proportion of household solid waste collected and landfilled; the

Table 1. The survey results of vulnerability indicators

Sub-indices	The number of					
	Kept variables	*Edited variables*	*Eliminated variables*	*Added variables*	*Initial variables*	*Completed variables*
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*

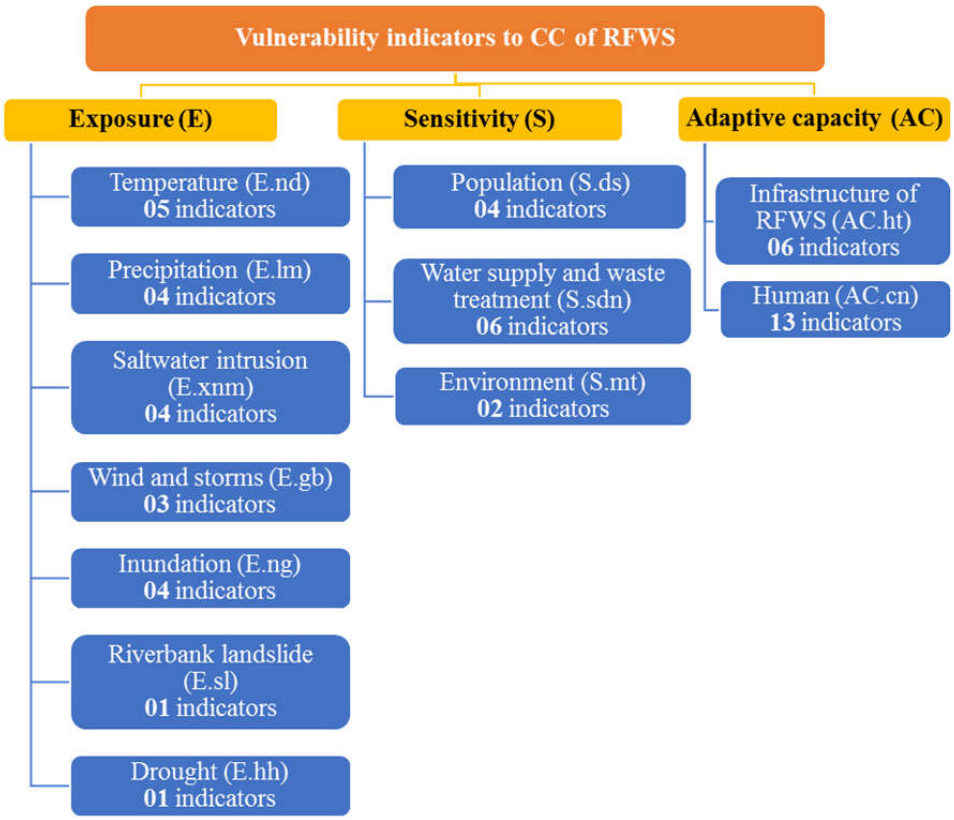

Figure b. **Diagram of vulnerability indicators to CC of RFWS**

Environment: Environmental factors have a certain significance in reflecting the sensitivity of the RFWS sector in the context of CC among different areas via following indicators: *surface water quality (Leuven 2011), tree cover area (European Commission 2009), ect.*

proportion of houses having sanitary latrines; the proportion of houses having hygienic cattle sheds, etc).

Human

- ***Local government:*** The local government is responsible for monitoring the change in RFWS,

announcing to the people the necessary information of water demand and supply, assisting the people to cope with and overcome consequences resulted from CC in the relationship with RFWS sector. The factors reflecting AC of local government could be *the number of staff taking charge of environmental resources, Awareness of managers of CC and RFWS* (*Naomi et al. 2014; UNEP 2012), Development plan of infrastructure of RFWS, The budget for coping with CC, disasters, and RFWS field (Nguyen and Can 2012), etc.*

- ***Communities:*** Community is a main object influenced, thus the adaptability of local community is a particularly important factor in assessing the vulnerability. The variables shown the adaptability to CC of residential community could be *awareness of communities of CC and RFWS (Ha 2014), per capita income (Nguyen and Can 2015), ability to access information when occurring incidents (Nguyen and Can 2015), ability of clean water storage (Leuven 2011)*, etc.
- ***Society:*** The social factors reflecting AC include *health, education, culture, employment, etc (Nguyen and Can 2015)*.

Table 2. Vulnerability indicators to CC of RFWS

Indicator group	*Individual indicator*		*Code*
Exposure indicators (E)			
Teperature	Min temperature evolution		E.nd.1
E.nd	Max temperature evolution		E.nd.2
	Average 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	Annual precipitation evolution		E.lm.1
E.lm	Rainy seasion precipitation evolution		E.lm.2
	Dry seasion precipitation evolution		E.lm.3
	The number of heavy rainy days (> 50 mm day^{-1}) per year		E.lm.4
Saltwater intrusion	Max salinity		E.xnm.1
E.xnm	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	Max wind speed		E.gb.1
E.gb	The number of thunderstorms and tornadoes per year		E.gb.2
	The number of storms and tropical depressions per year		E,gb.3
Inundation	Inundation area		E.ng.1
E.ng	Inundation depth		E.ng.2
	Inundation duration		E.ng.3
	The number of inundation per year		E.ng.4
Riverbank landslide E.sl	Landslide speed		E.sl
Drought E.hh	Drought index		E.hh
Sensitivity indicators (S)			
Population	Population density		S.ds.1
S.ds	Vulnerable	The proportion of females/males	S.ds.2
	objects	The proportion of elderly and children / total population	S.ds.3
		The proportion of households in poverty / total households	S.ds.4
Water supply and waste treatment	Water supply	The proportion of people using clean water according to the national technical regulations (%)	S.sdn.1
S.sdn		The number of water supply points	S.sdn.2
		Length of water pipes	S.sdn.3
		The proportion of water supply lost	S.sdn.4
	Waste treatment	The number of lanfills	S.sdn.5
		The number of wastewater treatment works/plants	S.sdn.6
Environment	The proportion of tree cover area/total area (%)		S.mt.1
S.mt	Surface water quality (WQI)		S.mt.2
Adaptive capacity indicators (AC)			
Infrastructure of RFWS	Water supply	The proportion of water supply capacity/water demand	AC.ht.1
AC.ht		Water pipe density	AC.ht.2
	Drainage	Drainage pipe density	AC.ht.3
	Waste treatment	The proportion of household solid waste collected and landfilled	AC.ht.4
		The proportion of houses having sanitary latrines (%)	AC.ht.5
		The proportion of houses having hygienic cattle sheds (%)	AC.ht.6
Human	Local govermnet	The number of staff taking charge of environmental resources (CC and RFWS)	AC.cn.1
AC.cn		Awareness of managers of CC and RFWS	AC.cn.2
		Development plan of infrastructure of RFWS	AC.cn.3
		The budget for coping with CC, disasters, and RFWS field	AC.cn.4
	Communities	Awareness of communities of CC and RFWS	AC.cn.5
		Per capita income	AC.cn.6
		Ability to access information when occurring incidents (internet, TV, cellphone etc.)	AC.cn.7
		Ability of clean water storage (volume, time of use, etc.)	AC.cn.8
	Society	The proportion of zone area of cultural activities and sport / population	AC.cn.9
		The proportion of health workers / population	AC.cn.10
		Education index	AC.cn.11
		The roportion of employed workers	AC.cn.12
		Trafic roads according to new rural standards	AC.cn.13

Completing the indices to assess vulnerability to CC of RFWS

Based on the analysis and evaluation of the factors affecting the level of vulnerability to CC of RFWS, this work proposed an inception indicators that consists of 50 component variables: 16 variables of exposure; 14 variables of sensitivity; and 20 variables of adaptability. This result is a basis for forming the survey sample, and then consultation of experts was performed in order to improve and perfect the indicators.
Survey results were analysed and presented in *Table I*. Overall, the preliminary indicators were received relatively high consensus of experts with 37 variables unchanged, 2 variables edited, 16 variables complemented, and 13 variables eliminated. After synthesizing experts's opinions, the vulnerability indicators to CC of RFWS in general had been completed and fully reflected related elements, presented in *Figure b* and *Table II*. It should be noted that the ability to gather data (data availability, gathering and calculating conditions, etc.) greatly decides the feasibility of the method and reliability of results.

Conclusion and Recommendations

Based on the analysis of the aspects related to the degree of exposure, sensitivity, and adaptive capacity to CC of RFWS, interviewing 32 experts, this work proposes vulnerability indicators to CC of RFWS including 53 component variables. In which, 22 variables represent the exposure divided into 7 groups (temperature, precipitation, saltwater intrusion, storm, flood, riverbank landslide, and drought); 18 variables reflect the sensitivity divided into 3 groups (population, water supply and waste treatment, and environment characteristics); and 20 variables show adaptive capacity divided into two main groups (facilities and human). Research results are expected as an important basis for a comprehensive vulnerability assessment of RFWS in the context of climate change and for proposing management solutions.

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