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ASSESSING VULNERABILITY TO CLIMATE CHANGE OF RURAL FRESH WATER AND SANITATION – A CASE STUDY IN COASTAL AREA IN HO CHI MINH CITY, VIETNAM

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ABSTRACT

The study aimed to assess the vulnerability due to climate change (CC) of rural fresh water and sanitation (RFWS) – an interest issue because of its important role in life as well as sensitivity to CC effects; a case study in coastal area in Ho Chi Minh city, Vietnam (Can Gio district). By index method, applied for the first time in RFWS field, vulnerability (V) was evaluated through 51 indicators. They include 20, 12, and 19 indicators with their weights refecting exposure level (E), sensitivity (S), and adaptive capacity (AC) of the system, respectively. The results showed the positive trend of AC and S by the time while E has insignificantly changed in the context of CC; subsequently, the V index tends to decrease toward 2025 (at medium-low level). The causes and defective chains of each component of E, S, and AC were then analyzed and identified (5 E indicators, 9 S indicators, and 13 AC indicators). Therefore, the priority to manage should be improving AC, followed by reducing S and E.

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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*). Statistics show about 80% of cases of diseases in Vietnam were caused by water pollution (*BMEM, 2012*). 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 agricultural productions, forestry, fishery, and industry, etc. as well as RFWS, increasing risks of environmental pollution and water scarcity (*WHO, 2009; Leuven, 2011; Doan, 2014*). In other words, CC is able to exacerbate risks to RFWS field (*Cantrell and Brittany, 2013; Naomi et al., 2014*), esecially in estuaries and coastal areas. Under these circumstances, in order to implement effectively coping solutions to CC, it is essential to assess vulnerability of RFWS in the context of CC.

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There are many methods to evaluate vulnerability to CC and natural disasters in general (*Nguyen and Can, 2012; WWF - Vietnam, 2013*), in which, integrated assessment approach (based on assessment of exposure -E, sensitivity -S, and adaptive capacity -AC) by IPCC (2007), World Bank (2010), and WWF -Vietnam (2013) is widely applied due to its preeminence. However, assessing vulnerability due to CC of RFWS in general and using integrated assessment approach in particular have not yet been in-depth carried out. Ho Chi Minh city is the economic hub of Vietnam where Can Gio is a coastal district taking important roles in economic development and environmental protection. There are 32 water supply stations in Can Gio district: 27 water supply stations in the form of socialization and the rest 05 of retail changers serving scattered population. In general, it is difficult and challenging in using clean water in Can Gio, i.e. some water supply satellites have not met water demand of citizen, the time for water supply is still limited, only some stations are fulltime operated, etc. (*HCMC People's Committee, 2012; CanGio District People's Committee, 2016*). Recent studies have shown the risk of serious impacts of CC in Can Gio, especially inundation due to sea level rise (*Nguyen, 2012*). However, so far there has been no in-depth study in the field of RFWS in the context of CC, especially assessing vulnerability of this sector in the local. Thereby, this work aims to assess the vulnerability to CC of RFWS, a case study in Can Gio till 2025, and to identify defective chains as well as aspects of interest to propose suitable management solutions, contributing to minimize risks and ensure sustainable development of the local.

MATERIALS AND METHODS

Professional adjustment: was applied in conjunction with the analytic hierarchy process (AHP) to identify vulnerability indicators and their weights. There were 32 experts from 17 prestigious universities and research institutes participating in the survey.

AHP method: was used to calculate weights of E, S, and AC indicators. Expert opinions were synthesized by geometric average method. Priority weight of each indicator was resulted from the multiplication between its weight and the weight of the group that it belongs to. Professional adjustments consistent when the consistency ratio (CR) is less than 0.1.

Sociological investigation method: The survey of adaptive capacity (awareness, attitudes, and behaviors of communities and local managers about RFWS and CC, management capacity of related sectors, etc.) and sensitivity was performed via questionaires in all wards of the district. Respondents were residential communities (203 households), commune authorities (7 Ward People's Committees), and local managers (35 officers).

Modelling: MIKE NAM and MIKE 11 were used to calculate hydraulic and spreading of salinity on downstream of DongNai River basin to 2025 MIKE 21 was used to calculate hydraulic to 2025 and then to assess inundation situation in investigated area.

GIS/RS method: in this research, RS was used to assess riverbank landslide speed for calculating E index. Besides, MapInfo 11.0 was applied to mapping the E, S, AC, and V indices to CC in order to visualize calculating results. From calculated results, the Inverse Distance to a Power gridding method and Surfer 10.0 were chosen. Fixed-search radius of 1km was applied. The barrier was not taken into consideration due to the relatively small and uniform investigated area.

Index method: The assessment process by index method is as follows: Identifying indicators (E, S, AC); Determining the weight of each indicator; Collecting and calculating related figures; Standardizing data in the scale of 0-100; Calculating E, S, AC, and V indices; Mapping, analysis and evaluation.
Indices, such as AC, were calculated based on standardized values of sub-indices (AC_i) and their weights (w_{Aci}) by the formula: $\mathbf{AC} = \sum_{i=1}^{n} \boldsymbol{AC_i} * \boldsymbol{W_{ACi}}$ where n: number of component indicators; AC_i: standardized value of the i indicator; W_{Aci}: priority weights of the i indicator; AC: the synthetic adaptive capacity. The same approach was used to calculate E and S indices. For V index, the following formula was used: V = (E + S + AC – 100)/3 (WB, 2010; WWF, 2013). The levels of E, S, AC, and V to CC were evaluated according to the scale presented in *Table 1*.

Table 1. Assessment scale

Value	0-25	25-50	50-75	75-100
Level	Low	Medium-low	Medium-high	High

RESULTS AND DISCUSSIONS

Indicators and weights

Indicators: By professional adjustment and AHP methods as mentioned, indicators for evaluating V to CC of RFWS and their weights were presented in Table 2.

E level to climate change of RFWS

Results in Figure a showed that E index to CC of RFWS in Can Gio district was almost at medium-low level (33 – 53). There was no significant difference among considered points of time. Average E index of the district would be 38.1, 38.5, and 38.8 corresponding to the present time, 2020, and 2025, and tend to gradually increase from the inland to the riverside and coastal areas. Areas with the highest E indices were Thanh An commune, Long Tau riverside, and Phu Loi isles with risks of inundation, landslides, and saltwater intrusion; followed by the north of Tam Thon Hiep commune and Binh Khanh commune due to storms, temperature, and precipitation. Some areas had lower E levels (mainly affected by landslides and inundation) but high population density as well as many infrastructures, etc., so they should be more vulnerable, such as Nha Be riverside (Binh Khanh commune), outfall of Dong Dinh river, Tac Suot wharf (in Mieu Nhi, Mieu Ba, Can Thanh town), and Soai Rap riverside (Ly Nhon commune), etc.

S level to climate change of RFWS

At the present time, an average S index of RFWS in Can Gio was 40.73 (medium-low level). Binh Khanh and Thanh An communes have the highest and lowest S indices corresponding to 58.27 and 28.86, respectively (Fig. b). In the period of 2020-2025, the average S index of the district tend to decrease (35.3 and 33.87 in 2020 and 2025, respectively); ranging from low to medium-low among the communes. Overall, in the period of 2014-2025, the RFWS in Binh Khanh (58.27 to 45.22) and An Thoi Dong (48.35 to 41.21) communes would be capable of having more impacts in the context of CC. It is therefore necessary to pay attention and plan measures to limit damages caused by CC.

AC to climate change of RFWS

Figure c showed the AC indices of RFWS in Can Gio at the present time, 2020 and 2025 tend to increase (from medium-low to medium-high) corresponding to 48, 55.8, and 64.8. It could be explained by the increase in programs and plans to develop RFWS infrastructures, enhancement of local and household environment quality as well as improvement of living standard, etc. At the present time, only Binh Khanh commune and Can Thanh town had AC indices at medium-high level (57.2 and 54.7, respectively). The others had AC indices at medium-low level and the lowest value was in An Thoi Dong commune. In 2020, similar to the current status, the first and the final order would be Binh Khanh and An Thoi Dong, corresponding to 65.4 and 53.9. By 2025, AC indices in Binh Khanh commune and Can Thanh town tend to increase to high level (77.2 - 79.6) while those of the others would be at medium-high level (59.8 - 65.6). Overall, the adaptive capacity to climate change of RFWS tends to increase. However, there are still defective chains in each aspect, i.e. infrastructures of RFWS and human (will be mentioned in the next section), needing suitable adjustments to improve AC, and then to decrease V.

Table 2. Vulnerability indicators to CC of RFWS and their weights

GROUP	INDIVIDUAL INDICATOR		CODE	WEIGHT
Exposure indicators (E)				
Teperature -E.nd	Min temperature evolution		E.nd.1	0.026
	Max temperature evolution		E.nd.2	0.053
	Average temperature evolution		E.nd.3	0.024
	Annual amplitude of average temperature		E.nd.4	0.022
	The number of hot days (over 35^{o}C) per year		E.nd.5	0.040
Precipitation -E.lm	Annual precipitation evolution		E.lm.1	0.034
	Rainy seasion precipitation evolution		E.lm.2	0.034
	Dry seasion precipitation evolution		E.lm.3	0.037
	The number of heavy rainy days (> 50 mm/day) per year		E.lm.4	0.036
Wind -E.g	Max wind speed		E.g.1	0.129
Saltwater intrusion -E.xnm	Max salinity		E.xnm.1	0.051
	Duration of salinity above 18‰		E.xnm.2	0.034
	Duration of salinity above 30‰		E.xnm.3	0.058
	Salinity amplitude of the saltiest month		E.xnm.4	0.028
Inundation -E.ng	Inundation area		E.ng.1	0.057
	Inundation depth		E.ng.2	0.029
	Inundation duration		E.ng.3	0.037
	The number of inundation per year		E.ng.4	0.037
Riverbank landslide -E.sl	Landslide speed		E.sl	0.103
Drought -E.hh	Drought index		E.hh	0.131
Sensitivity indicators (S)				
Population	Population density		S.ds.1	0.130
S.ds	Vulnerable objects	The proportion of women / men	S.ds.2	0.051
		The proportion of elderly and children / total population	S.ds.3	0.082
		The proportion of households in poverty / total households	S.ds.4	0.079
Water supply and waste treatment S.sdn	Water supply	The proportion of people using clean water according to the national technical regulations (%)	S.sdn.1	0.103
		The number of water supply points	S.sdn.2	0.043
		Length of water pipes	S.sdn.3	0.072
		The proportion of water supply lost	S.sdn.4	0.040
	Waste treatment	The number of lanfills	S.sdn.5	0.054
		The number of wastewater treatment works/plants	S.sdn.6	0.048
Environment S.mt	The proportion of tree cover area/total area (%)		S.mt.1	0.174
	Surface water quality (WQI)		S.mt.2	0.123
Adaptive capacity indicators (AC)				
Infrastructure of RFWS AC.ht	Water supply	The proportion of water supply capacity/water demand	AC.ht.1	0.102
		Water pipe density	AC.ht.2	0.146
	Drainage	Drainage pipe density	AC.ht.3	0.124
	Waste treatment	The proportion of household solid waste collected and landfilled	AC.ht.4	0.046
		The proportion of houses having sanitary latrines (%)	AC.ht.5	0.073
		The proportion of houses having hygienic cattle sheds (%)	AC.ht.6	0.059
Human AC.cn	Local govermnet	The number of staff taking charge of environmental resources (CC and RFWS)	AC.cn.1	0.032
		Awareness of managers of CC and RFWS	AC.cn.2	0.045
		Development plan of infrastructure of RFWS	AC.cn.3	0.039
		The budget for coping with CC, disasters, and RFWS field	AC.cn.4	0.046
	Communities	Awareness of communities of CC and RFWS	AC.cn.5	0.075
		Per capita income	AC.cn.6	0.037
		Ability to access information when occurring incidents (internet, TV, cellphone etc.)	AC.cn.7	0.038
		Ability of clean water storage (volume, time of use, etc.)	AC.cn.8	0.030
	Society	The proportion of zone area of cultural activities and sport / population	AC.cn.9	0.014
		The proportion of health workers / population	AC.cn.10	0.023
		Education index	AC.cn.11	0.018
		The roportion of employed workers	AC.cn.12	0.032
		Trafic roads according to new rural standards	AC.cn.13	0.021

V due to climate change of RFWS

As mentioned, V index was calculated on the basis of E, S and AC indices. Results showed that, during the period 2014 - 2025, V index tends to decrease, being consistent with the little change in E index, improvement of AC by the time, and decrease in S (*Fig. a-c*).

At the present time

V indices to CC of RFWS in Can Gio district were all at medium-low level. The highest value was in An Thoi Dong commune (47), followed by Binh Khanh, Tam Thon Hiep, Long Hoa, Ly Nhon, Thanh An communes (41 - 46), and the lowest one was in Can Thanh town (39) (*Fig. d*).

The high V index of An Thoi Dong communecould be resulted from the sanitation group of the system which both AC decrease and S increase:

- Infrastructure: drainage systems were limited, usability and ability to cope with incidents had not yet met the demand, e.g. water pipelines were mainly located in a few areas;
- Waste treatment: local and household environment quality (related to solid waste management, hygienic breeding facilities, and hygienic latrines, etc.) had not yet been ensured, leading to an increase in environmental pollution;
- Human: CC response programs for RFWS in the local had not been actively developed and implemented yet. Besides, ability to access information or other social services should be improved, etc.

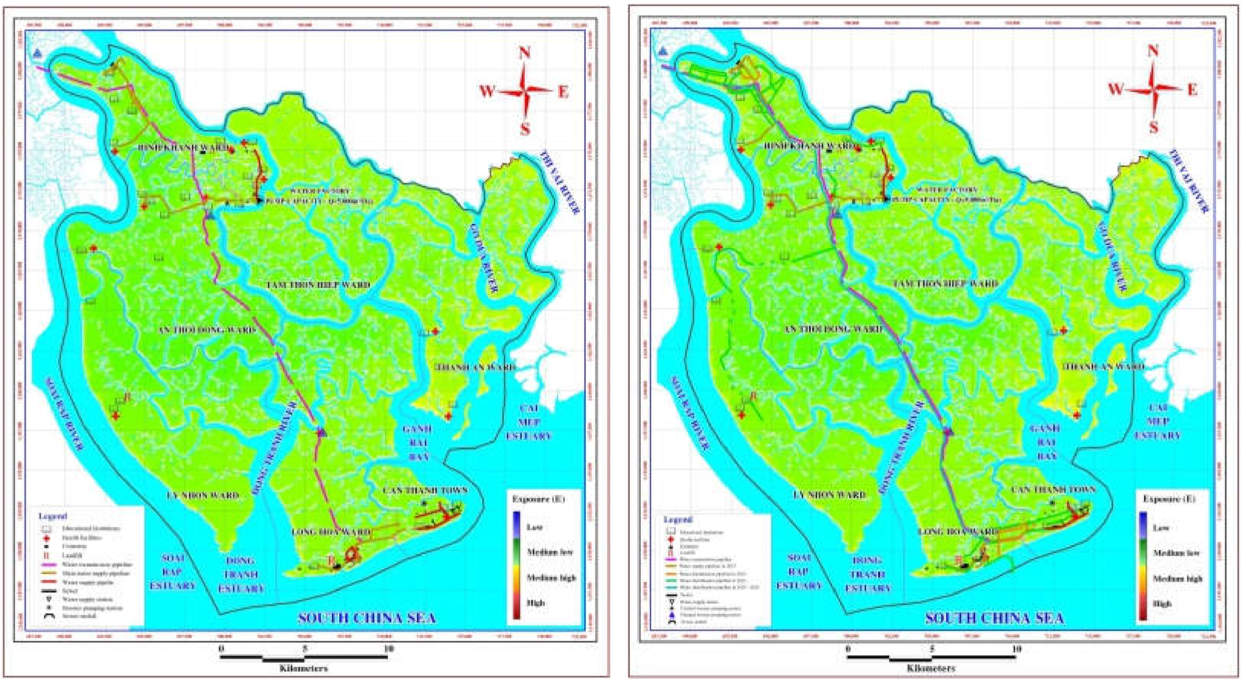

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Figure a: Map of E level of RFWS in the context of CC: (1) the present time, (2) 2025

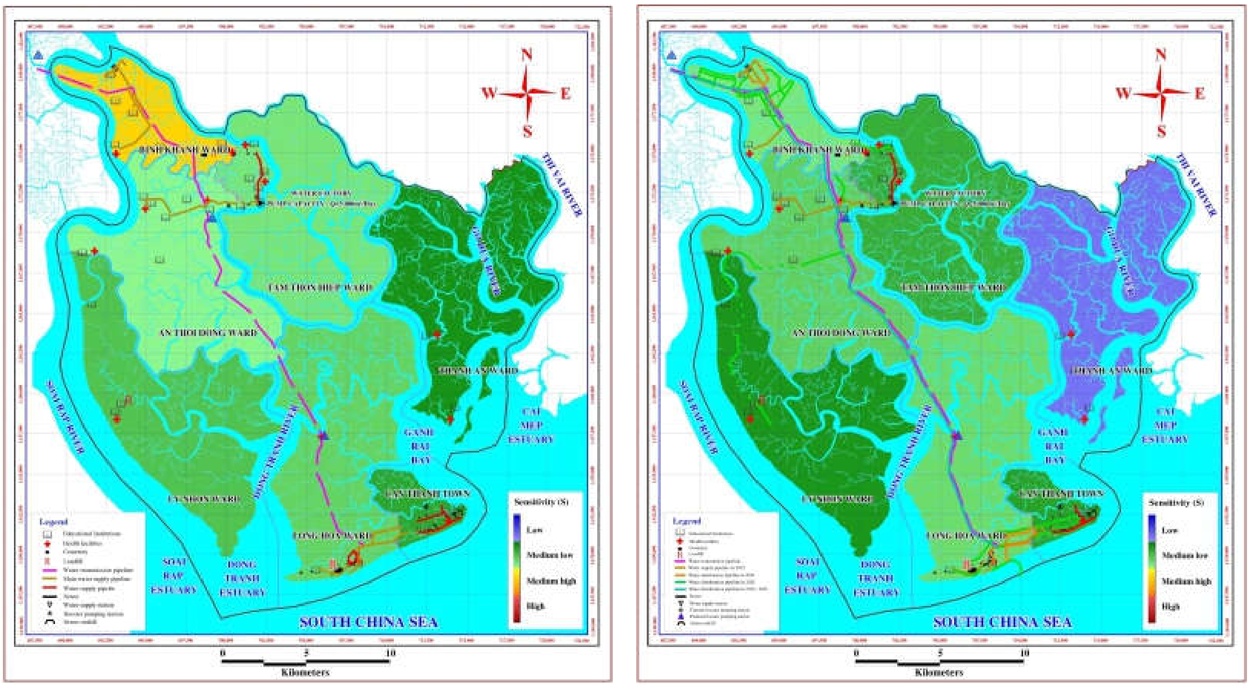

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Figure b. Map of S level of RFWS in the context of CC: (1) the present time, (2) 2025

The period of 2020 – 2025

In 2020, V indices of communes would be at medium-low level. The average V index of the district would be 39.6, decreasing 5.3 compared to that at the present time. In particular, V index in An Thoi Dong commune would be still the most interesting (42) (*Fig. e*). *By 2025,* the average V index of the district would decline by 3.5 compared to that in 2020 (or 8.8 compared to that at the present time). However, the orders of V indices of communes would be change compared to those of the previous periods. Accordingly, V index in Long Hoa commune would be the highest (39.6), followed by that in An Thoi Dong, Tam Thon Hiep, Binh Khanh, Ly Nhon, Thanh An communes (34 - 37.5), and finally in Can Thanh town (31.2). It could be explained as follows:

- AC indices unevenly increase among localities, depended on orientations of socio-economic development, in which planning water supply and drainage works is the most interesting;
- S indices tend to decline in the period of 2020 - 2025 (about 1.4 for the whole district). Notably, S indices in Long Hoa commune and Can Thanh town increase about 4.8 and 3.7, respectively.

Generally, in 2025, AC indices are expected to improve following plans and orientations of socio-economic development, especially in the field of RFWS. On the other hand, S indices of the system would decrease while E level would not significantly increase as mentioned.

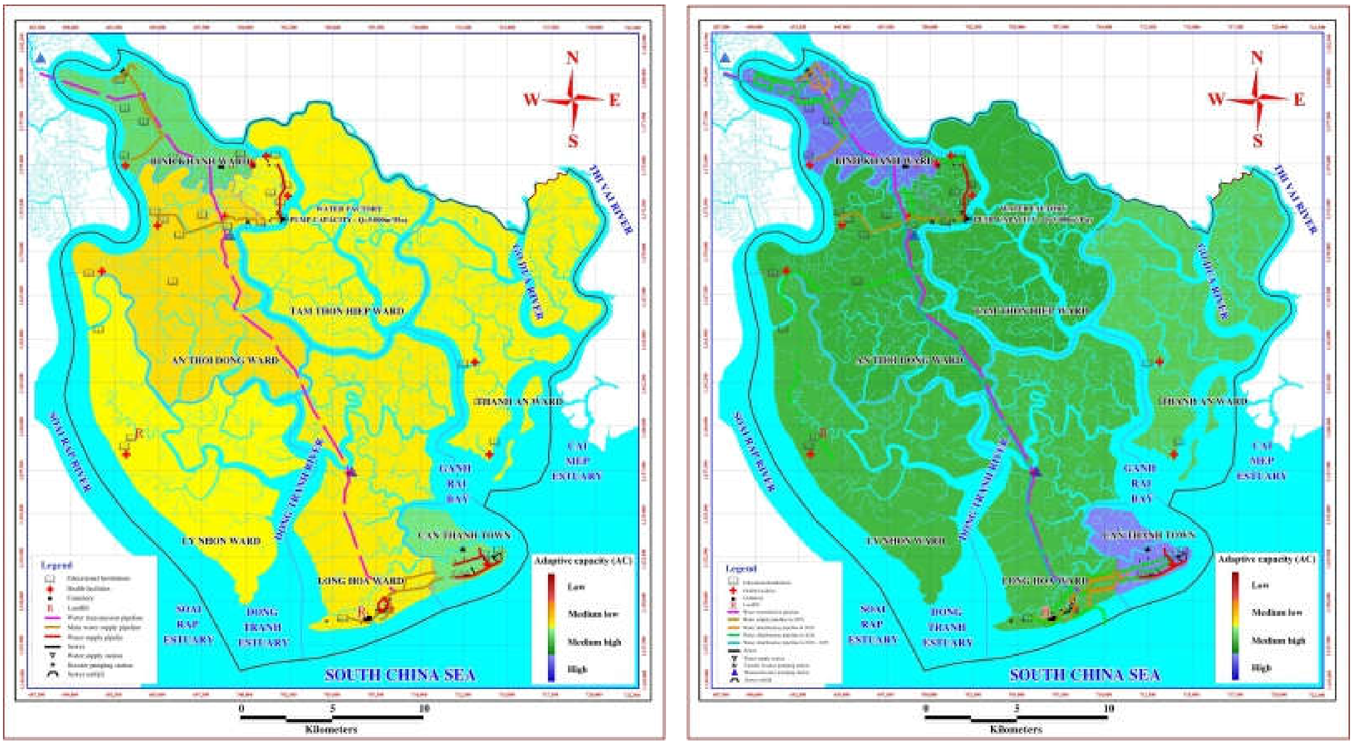

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Figure c: Map of AC level of RFWS in the context of CC: (a) the present time, (b) 2025

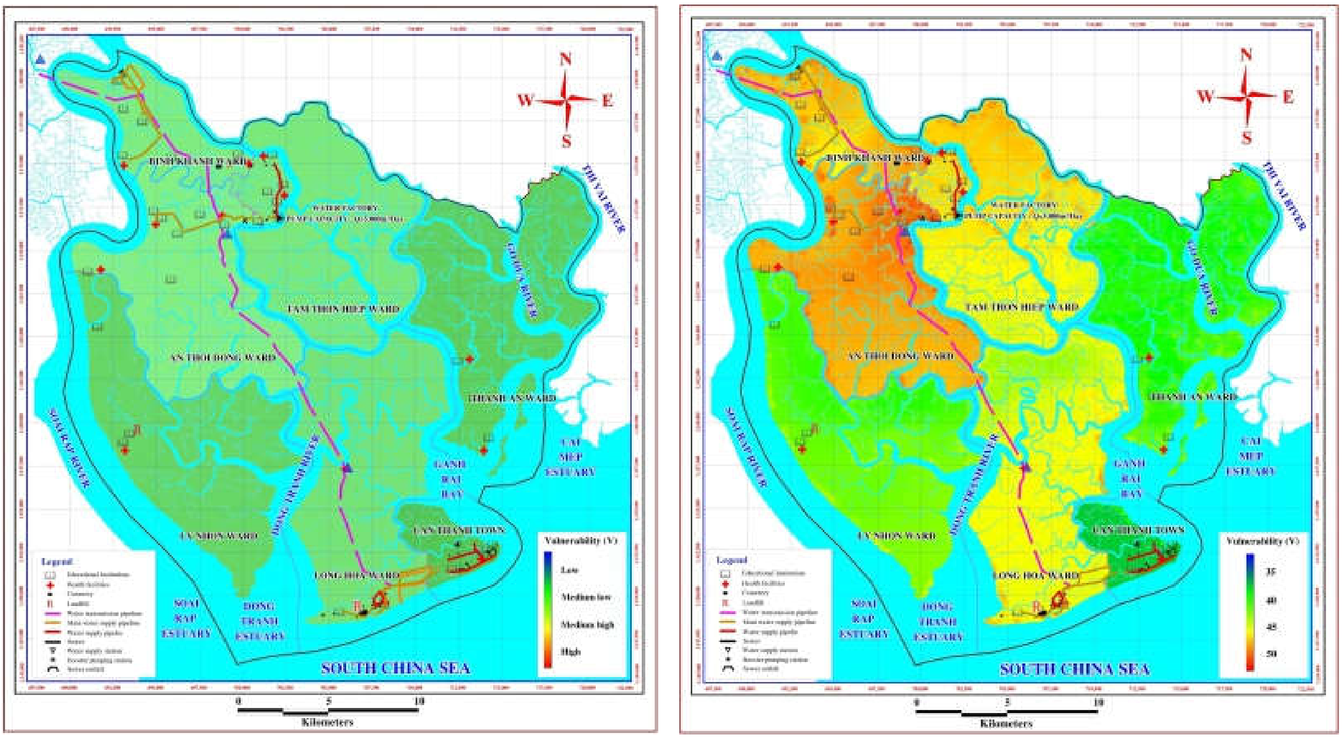

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Figure d. Map of V index to CC of RFWS at the present time: (1) According to vulnerability rating scale (0-100), (2) detailed vulnerability (35 - 50)

Accordingly, the vulnerability level of the RFWS tends to decline. It could be implied that developing and implementing strategies on improving AC of RFWS is necessary for the coming up period.

Identify adaptive demands

Based on V index, roles of each component (E, S, AC) in relation to V index were considered and assessed. Subsequently, defective chains (adaptive demands as well) of each aspect were analysed and identified. The results showed that:

- Solutions to mitigate the vulnerability should be focused on increasing adaptive capacity and mitigating the sensitivity to CC of RFWS;

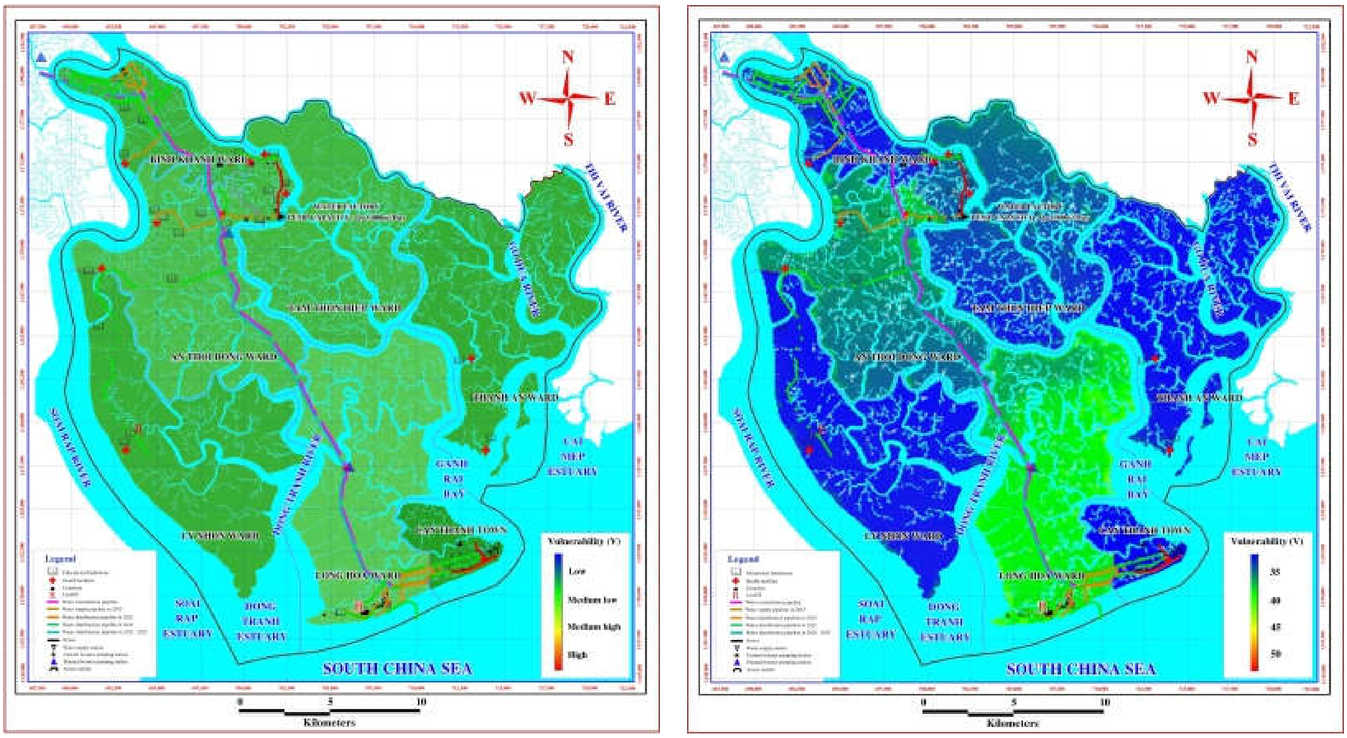

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Figure e. Map of V index to CC of RFWS in 2025: (1) According to vulnerability rating scale (0-100), (b) detailed vulnerability (35 - 50)

- Adaptive demands in each locality are different: (i) E and AC are interested in Thanh An; (ii) S and AC are interested in Long Hoa, Tam Thon Hiep, Binh Khanh, and An Thoi Dong; (iii) AC is a weak aspect in Ly Nhon.
- Defective chains were identified and then prioritized to adapt: 5 E indicators (E.lm, E.xnm > E.hh, E.g > E.nd), 9 S indicators (S.ds.3, S.sdn.4, S.mt.1, S.mt.2 > S.ds.4, S.sdn.3, S.sdn.5 > S.ds.2, S.sdn.2), and 13 AC indicators (AC.ht.3, AC.cn.3, AC.cn.6, AC.cn.9, AC.cn.10, AC.cn.11, AC.cn.13 > AC.cn.7, AC.cn.8, AC.cn.1, AC.cn.4, AC.ht.2 > AC.cn.5).

Conclusion

Vulnerability to CC of RFWS was synthetically calculated based on 3 components: E, S, AC; a case study in a coastal area in Ho Chi Minh city of Vietnam. V index declines by the time due to insignificant change of E index while S and AC positively change in relation to the plans of socio-economic and infrastructure development. The priority of solutions was then proposed: increasing AC, followed by mitigating S and E. In every aspect (E, S, AC), defective chains were also identified (5 E indicators, 9 S indicators, and 13 AC indicators) - providing the basis for planning priority management solutions, improving the effectiveness of RFWS in particular, and contributing to sustainable development of the local in general.

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