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Livelihood Vulnerability Index to Climate Change in the Mekong River Delta in Vietnam: A Case Study in Three Provinces

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Abstract

The Livelihood Vulnerability Index - the Intergovernmental Panel on Climate Change (LVI-IPCC) is applied to assess livelihood vulnerability in the Mekong River Delta (MRD). There are seven major components in measuring the livelihood vulnerability, including the livelihood strategy, demographic profile, social network, food, water status, health, natural disasters and climate change. Results indicated that climate change have had a huge impact on agricultural production in the MRD. Moreover, the floodplains along the Mekong River are more vulnerable than others (LVI-IPCCAn Phu: -0.03; LVI-IPCCTri Ton: -0.038), due to higher vulnerability in terms of exposure and sensitivity factors. An Phu district was more vulnerable in terms of health and water status. Moreover, households in Duyen Hai and Tra Cu districts with long coastline and coastal production areas, were most affected by saline intrusion. People were more vulnerable in terms of livelihood strategies and social networks, leading to less adaptive capacity.

Keywords: *Vulnerability, LVI-IPCC, Sensitivity, Exposure*

INTRODUCTION

Climate change unfavorably influences agricultural productivity and has the potential to irreparably destroy the natural resources on which agriculture depends. In middle to high latitudes, moderate temperature increases are likely to have minor beneficial effects on crop yields. In contrast, at low latitudes, even moderate temperature increases can have a negative impact on productivity (Reynolds, 2010). Hence, climate and agriculture are closely related because weather and climate are considered the main factors of agricultural productivity (Jiang et al., 2019). In fact, a slight increase in temperature during summer and winter will remarkably reduce net crop revenue per hectare; on the contrary, a slight increase in spring rainfall will outstandingly increase net crop revenue per hectare (Deressa & Hassan, 2009). Rising temperatures, floods, drought, extreme weather, and desertification will seriously affect agricultural activities, especially in developing countries. Auffhammer et al. (2012) clearly indicate that climate change has made a tremendous impact on hundreds of millions of Indian rice producers and consumers. Unless these negative influences are mitigated through adaptation, climate change will increase unpredictably (Deressa & Hassan, 2009). If the upward trend in temperatures during the growing season continues, resulting in climate change, it is highly likely that yield losses will become more severe in the future (Prabnakorn et al., 2018).

The MRD is considered the largest agricultural and aquaculture production area in Vietnam. Climate change and socio-economic development affect regional sustainability in the MRD (Wang et al., 2021). The MRD plays an important role in food security and socio-economic development; however, it is considered one of the most densely populated and low-lying regions in the world. Hence, it is seriously vulnerable due to flood risk, seawater intrusion, as well as shoreline changes in consequence of sea level rise associated with climate change (Nguyen & Woodroffe, 2016). In fact, the MRD is believed to be the most vulnerable to the effects of sea level rise (Carew-Reid, 2007; Woodroffe et al., 2006). Similarly, according to the IPCC Fourth Assessment, the MRD is regarded as one of the three most vulnerable deltas in the world (Besset et al., 2015). Yusuf & Francisco (2009) confirm that the most vulnerable regions in Southeast Asia include the MRD in Vietnam. The MRD is very sensitive to flood and saltwater intrusion because it is a low-lying coastal area. In the dry season, saline intrusion

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becomes hazardous (Thuy & Anh, 2015). Moreover, Kontgis et al (2019) indicate that climate change not only reduces rice productivity in the Mekong Delta region, but also causes yield losses, even when there is an increase of water and fertilizer supply. Shifts in rice production because of climate change are an important issue since the crop is considered one of the most essential in agricultural production and food security in Vietnam (Wassmann et al., 2004; Wassmann et al., 2009). In short, the sustainability of rice production in the MRD can be heavily affected or even damaged due to potential impacts from climate changes, including floods and salinity (Thuy & Anh, 2015), and farmers in this area are also significantly influenced by climate change (Connor et al., 2020).

The study aims to assess livelihood vulnerability in the MRD by answering three research questions: (1) Does vulnerability to climate change differ between regions of the MRD? (2) Which indicators may be used to assess livelihood vulnerability in the MRD? (3) What are the characteristics of climate change vulnerability in the MRD? Hence, to answer these questions, this study will focus on several objectives including (i) To assess the current situation of climate change in different areas in the MRD; (ii) To analyze the characteristics of vulnerability due to climate change among regions of the MRD; and (iii) To propose possible policy implications for households in the MRD.

RESEARCH OVERVIEW

Vulnerability is the insecurity of an individual or a community in the face of environmental change (Moser, 1996). O´Keefe, Westgate & Wisner (1976) evaluated the social vulnerability mentioned in the 1970s according to the risk and natural disaster model. Then, in Cutter et al. (2000) study, the geographical location factor in vulnerability research was further approached. Climate change causes sea level rise (Kelman & West, 2009) and disproportionate impacts on poor and vulnerable groups including children, the elderly, the sick, and people with disabilities (Dulal et al., 2010). Rural communities along the coastal wetlands of many Caribbean islands were likely to be among the vulnerable groups because they depended primarily on natural resources for their livelihoods comprising agricultural activities, fishing, hunting, and tourism activities (Shah, 2013).

There have been numerous studies on vulnerability with such various aspects as flood vulnerability (Balica et al., 2012; Dandapat & Panda, 2017; Thapa et al., 2020), gender vulnerability (Kakota et al., 2011; Rahman, 2013), water vulnerability (Sullivan, 2011), drought vulnerability (Savari et al., 2022; Zarafshani et al., 2016). In particular, Balica et al. (2012) focused on assessing a Coastal City Flood Vulnerability Index (CCFVI), which was based on susceptibility, exposure, as well as resilience to coastal floods. In this study, nine cities in the world with different types of exposure were investigated. Based on this index, it is possible to demonstrate which cities are most vulnerable to coastal floods in terms of the system's components, such as hydrogeological, administrative-political as well as socio-economic.

Vulnerability assessment, with the climate change contexts, is of primary importance in designing policies on the impacts of climate change (Asfaw et al., 2021). In fact, the vulnerability of people's livelihoods is identified by their susceptibility to risks, their exposure to stressors, and their ability to withstand, recover and respond to their effects (Leary & Kulkarni, 2007). Similarly, integrated regional vulnerability to a given hazard is created by the interaction of three aspects of vulnerability consisting of sensitivity, exposure, and adaptive capacity (De Lange et al., 2010; Liu et al., 2013).

There are different indicators utilized to assess vulnerability in different aspects such as Social Vulnerability Index (SoVI), Economic Vulnerability Index (EVI). Unlike these indicators, the LVI-IPCC method is applied to assess livelihoods' vulnerability to climate change with seven main components including demographic profiles, livelihoods, health status, water status, food status, social networks, disasters and climate change (Vo & Tran, 2022).

Numerous previous studies have been carried out on livelihood vulnerability by applying the LVI-IPCC approach (Amanuel & Musse Tesfaye, 2020; Azumah et al., 2021; Mugandani et al., 2022; Suryanto & Rahman, 2019; Vo & Tran, 2022). Until now, it has been popularly employed to measure vulnerability in various contexts thanks to its many benefits. First, it can be used to evaluate the impact of any policy or program, based on substituting the value of majors or sub-indicators as well as to change and recalculate the total vulnerability index (Hahn et al., 2009). Moreover, LVI's sub-components and weighting structure can be tailored to suit the needs of a certain particular community or research. Furthermore, the LVI-IPCC framework proposes a scientific basis for people, local authorities, as well as policymakers to develop and prioritize appropriate solutions to improve the capacity for climate change adaptation and people's livelihood capital (Nguyen et al., 2021).

METHODOLOGY

The LVI-IPCC method

The LVI includes seven main factors: demographics, social networks, livelihoods, water status, food status, health status, disasters and climate change (Hahn et al., 2009). Each major component is represented through several sub- indicators presented in Table 1. Each sub indicator is measured on a different scale, so it should be standardized first. It is based on the equation applied in the HDI for the calculation (UNDP, 2007), as follows:

$$\text{Index}_{sd}=\frac{s_d-s_{min}}{s_{max}-s_{min}},$$

in which, s_d is the observed sub-component value of each household in district d; s_{min} is the minimum values and s_{max} is the maximum values for each sub-indicator used in district level. Next, the mean of the sub-indicator is calculated as follows:

$$M_d = \frac{\sum_{i=1}^{n} \text{index}_{sd} i}{n}$$

M_d is one of the seven main components of district d in 3 provinces of An Giang, Tra Vinh and Hau Giang including demographics profile (D), livelihood (L), social networks (SN), food status (F), health status (H), water status (W), natural disasters and climate change (ND); index_{sd} i represents each i^{th} sub-component, *n* is the total number of sub-component in the case of each principal component. Then, the mean of each principal component will be calculated to represent the LVI:

$$LVI_d = \frac{\sum_{i=1}^{7} w_{Mi} M_{di}}{\sum_{i=1}^{7} w_{Mi}}$$

$$LVI_d = \frac{w_D D_d + w_L L_d + w_{SN} SN_d + w_H H_d + w_F F_d + w_W W_d + w_{ND} ND_d}{w_D + w_L + w_{SN} + w_H + w_F + w_W + w_{ND}}$$

where LVI_d: the livelihood vulnerability index for district d in the three provinces including An Giang, Tra Vinh and Hau Giang equals the weighted average of the seven principal factors. The weight of each principal factor w_{Mi} is calculated by the sum of the subcomponents of each main factor, in order to ensure that all subcomponents contribute equal weights in the LVI index (Sullivan et al., 2002).

Table 1 illustrates the LVI-IPCC analysis framework for vulnerability measurement including seven main components based on the IPCC measurement framework, inlcuding (i) Exposure (e_d - natural disasters and climate change); (ii) Adaptive capacity (a_d - Demographic profiles; livelihood types and social factors); (iii) sensitivities (s_d - health, food and water status)., as follows:

$$CF_D = \frac{\sum_{I=1}^{N} w_{MI} M_{DI}}{\sum_{I=1}^{N} w_{MI}}$$

where CF_d is the constitutive factor of Intergovernmental Panel on Climate Change including adaptive capacity, exposure, and sensitivity in case of the i^{th} district; M_{di} is the major factor of the i^{th} district; w_{Mi} is the weight for each major factor of the i^{th} district.

The major component of LVI will be classified into factors from IPCC to LVI-IPCC. This framework is calculated as follows:

$LVI\text{-}IPCC_d=(e_d-a_d)*s_d$

The specific steps are as follows:

- Calculation of indexed sub-components and main components (livelihood, demographic profile, and social networks).

- Repeat the same for the contributing factors (sensitivity, adaptive capacity, and exposure,):

$$CF_d = \frac{\sum_{i=1}^{n} w_{Mi} M_{di}}{\sum_{i=1}^{n} w_{Mi}}$$

-Repeat for all districts: $LVI\text{-}IPCC_d=(e_d-a_d)*s_d$

Table 1: Principal components in the Livelihood Vulnerability Index analysis framework for districts in the MRD

Major components	Sub-components	Variable	Explanation	Relevant study
Demographic Profile	The dependency rate	D1	The ratio of the population < 15 years old and > 60 years old to the total population aged 16 - 59	Azumah et al., 2021; Hahn et al., 2009; Hoang et al., 2020; Huong et al., 2019; Vo & Tran, 2022
	The percentage of households with female heads	D2	The percentage of households whose heads were female: If the men work away from home for more than 6 months per year, the women are considered the household heads.	Gravitiani et al., 2018; Hahn et al., 2009; Hoang et al., 2020; Huong et al., 2019; Vo & Tran, 2022
	The percentage of households whose heads attended no school	D3	The proportion of households whose heads did not attend school	Gravitiani et al., 2018; Hahn et al., 2009
	The percentage of households with orphans	D4	The mean standard deviation of the highest water level ercentage of households with orphans	Gravitiani et al., 2018; Hahn et al., 2009; Vo & Tran, 2022
Livelihood	The percentage of households with members working far away	L1	The percentage of households with members working far away	Hoang et al., 2020; Vo & Tran, 2022
	The percentage of households whose main income source was from agriculture	L2	The percentage of households whose main income source was from agriculture	Gravitiani et al., 2018; Hahn et al., 2009; Vo & Tran, 2022
	The average agricultural livelihood diversity index	L3	The inverse of (their agricultural activity number+1)	Hahn et al., 2009; Hoang et al., 2020; Pham et al., 2020; Vo & Tran, 2022
Health	The average time to travel to medical facilities (minutes)	H1	The average time to travel to medical facilities	Azumah et al., 2021; Hahn et al., 2009; Hoang et al., 2020; Vo & Tran, 2022
	The percentage of households with chronic diseases	H2	The percentage of households with chronic diseases	Gravitiani et al., 2018; Hahn et al., 2009; Vo & Tran, 2022
	The percentage of households with one member absent from school or work in the last two weeks because of sickness	H3	The percentage of households with one member absent from school or work in the last two weeks because of sickness	Huong et al., 2019; Vo & Tran, 2022
	The percentage of households with at least one member aged 6 or older participating in health insurance	H4	The percentage of households with at least one member aged 6 or older joining health insurance	Vo & Tran, 2022
Social networks	The average give-and-receive ratio	SN1	The average ratio between (number of types of support each household receives +1) and (number of types of support given to each household +1) in the past month	Gravitiani et al., 2018; Hahn et al., 2009; Pham et al., 2020; Vo & Tran, 2022
	The average loan-to-borrow ratio	SN2	The ratio of households borrowing money to lend in the past month: If the households borrow money but they do not lend money, the ratio = 2:1 or 2; and if they lend money but do not borrow, the ratio = 1: 2 or 0.5.	Gravitiani et al., 2018; Hahn et al., 2009; Vo & Tran, 2022
	The percentage of households without the local authorities support during last 12 months	SN	The percentage of households getting no support from the local authorities during last 12 months	Hoang et al., 2020; Huong et al., 2019; Vo & Tran, 2022
Food	The percentage of households depending on the farm for their daily food	F1	The percentage of households that depended on the farm for their daily food	Azumah et al., 2021; Hahn et al., 2009; Pham et al., 2020; Vo & Tran, 2022
	The average number of months households had to borrow money to buy food (0-12)	F2	The average number of months households had to borrow money to buy food	Azumah et al., 2021; Hoang et al., 2020;

Major components	Sub-components	Variable	Explanation	Relevant study
	Crop diversification index	F3	The inverse of (the total number of crops planted by a household +1). For example, a farmer grows pumpkins, corn, and beans; its index = 1 / (3 + 1) = 0.25	Hahn et al., 2009; Vo & Tran, 2022
	The percentage of households saving no product after each harvest	F4	The percentage of households that did not save product after each harvest	Gravitiani et al., 2018; Hahn et al., 2009; Hoang et al., 2020; Vo & Tran, 2022
	The percentage of households without seed reserve	F5	The percentage of households without seed reserve after each harvest	Hahn et al., 2009; Vo & Tran, 2022
Water	The percentage of households hearing of conflicts about water for domestic use	W1	The percentage of households hearing of conflicts about drinking water in their living community	Azumah et al., 2021; Hahn et al., 2009; Huong et al., 2019;
	The percentage of households using natural water sources	W2	The percentage of households often using natural water sources from rivers, lakes, as well ravines for domestic water	Hahn et al., 2009; Huong et al., 2019; Pham et al., 2020; Vo & Tran, 2022
	The average travel time from home to water source	W3	The average travel time that households spent traveling to get water (minutes)	Hoang et al., 2020; Huong et al., 2019; Vo & Tran, 2022
	The percentage of households having no regular source of drinking water	W4	The percentage of households that did not have a regular source of drinking water	Azumah et al., 2021; Gravitiani et al., 2018; Hoang et al., 2020; Huong et al., 2019; Vo & Tran, 2022
	The average inverse of liters of water stored per household (0 - 1)	W5	The inverse of (average of liters of water stored per household +1)	Gravitiani et al., 2018; Hahn et al., 2009; Hoang et al., 2020;
Natural disasters and climate change	The number of droughts, floods, and tornadoes	ND1	The average number of droughts, floods, and tornadoes over the past 5 years	Azumah et al., 2021; Gravitiani et al., 2018; Hoang et al., 2020; Vo & Tran, 2022
	The percentage of households with a member injured or killed by disasters	ND2	The percentage of households with a member injured or killed by disasters	Hoang et al., 2020; Vo & Tran, 2022
	The percentage of households receiving no disaster warnings	ND3	The percentage of households without receiving any disaster warnings (from the government, television, radio, the internet, etc.)	Azumah et al., 2021; Gravitiani et al., 2018; Hahn et al., 2009
	The mean standard deviation of the highest water level [a]	ND4	The mean standard deviation of the highest water level from 2015 to 2019	new indicator
	The mean standard deviation of the lowest water level [b]	ND5	The mean standard deviation of the lowest water level from 2015 to 2019	new indicator
	The mean standard deviation of the average temperature	ND6	The mean standard deviation of the average temperature between 2015 and 2019 by monthly	Gravitiani et al., 2018; Hahn et al., 2009; Hoang et al., 2020; Vo & Tran, 2022
	The mean standard deviation of the average rainfall	ND7	The mean standard deviation of the average rainfall between 2015 and 2019 by monthly	Hoang et al., 2020; Vo & Tran, 2022

Note: [a,b]: Provincial Statistical Yearbooks

Study area

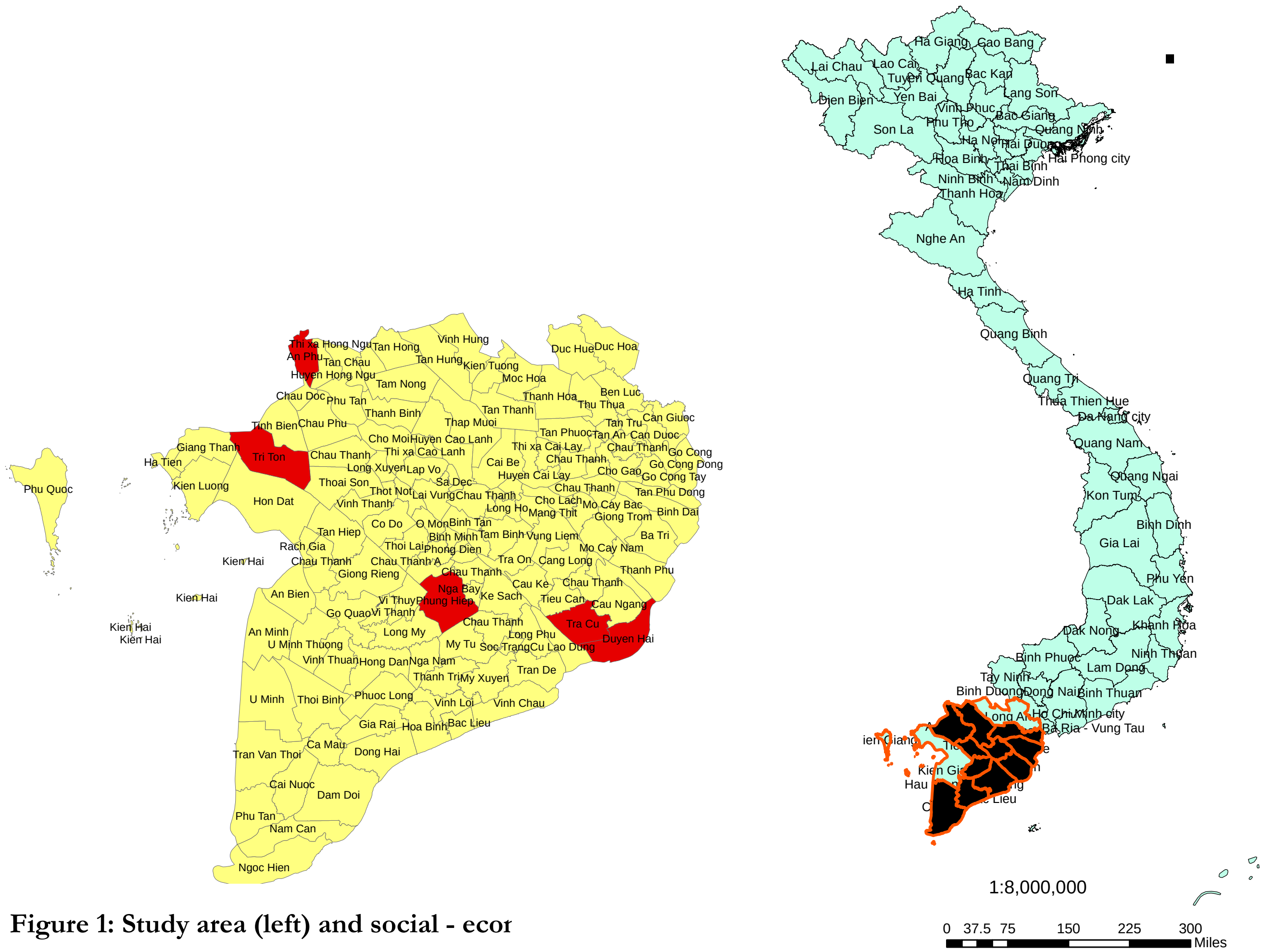


Figure 1: Study area (left) and social - ecor

The MRD consists of three main ecological z
for 2-3 months/year), middle zone (freshwater alluvial area, shallow inundation and mild saline intrusion), and coastal area (more than 6 months of salinity to varying degrees). Therefore, the study area was selected based on the ecological characteristics of three provinces representing three ecological regions: An Giang province in the flooded area, Hau Giang province in the freshwater alluvial area, and Tra Vinh province in the coastal area bordering to the East Sea is affected by the saline intrusion. These provinces are located in vulnerable areas to climate change including drought, salinity intrusion, flooding, and storm surge. The study was conducted with 281 households in three provinces of An Giang, Tra Vinh, and Hau Giang in the MRD region, with random sampling method (Figure 2).

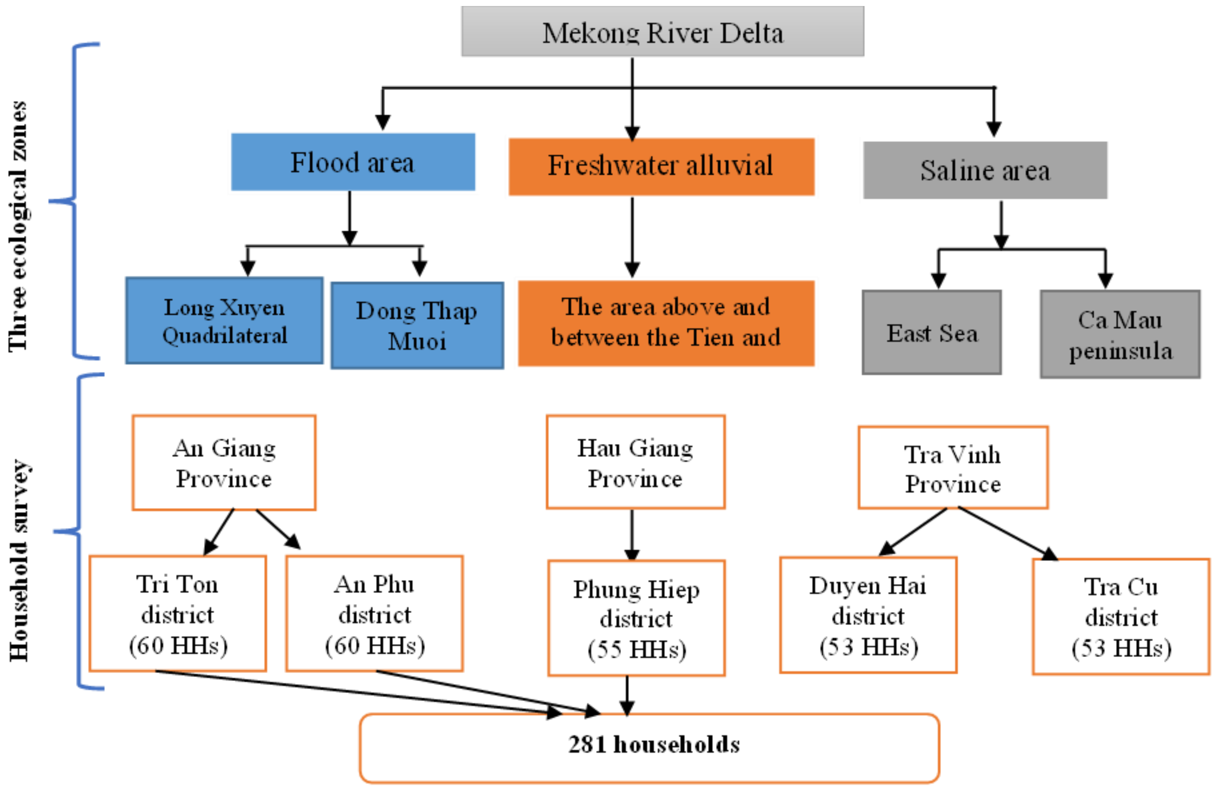


Figure 2: Three ecological zones based on the characteristics of water resources

FINDING AND DICUSSIONS

The climate change trends in the MRD

The change of average temperature, sunshine hours and total rainfall

Climate change has led to global warming, increasing annual temperatures in the MRD. The average annual temperature in the region has increased by 0.7 °C in the past 30 years. By 2019, up to 7 of the 13 provinces in the MRD had the highest temperature in the scale shown in Figure 2, ranging from 27.7 °C to 28.3 °C. In fact, the total number of sunshine hours gradually increased in the period 2017-2019. In 2019, the majority of provinces in the MRD (12 of the 13 provinces) had the highest total number of sunshine hours in the region, ranging from 2,400-2,800 hours, except Ca Mau province with a total of sunshine hours ranging from 2,000-2,100 h.

The total annual rainfall also showed a strong downward trend in the period 2017-2019 (Figure 2). In 2017, 6 out of 13 provinces had a total rainfall of over 2,000 mm, including Bac Lieu (2,131 mm), Long An (2,352 mm), Soc Trang (2,246 mm), Hau Giang (2,088 mm), Kien Giang (2,510 mm) and Can Tho City (2,088 mm), while Ben Tre had the lowest rainfall at only 1,444 mm. However, the total annual rainfall in the 13 provinces of the MRD tended to decrease suddenly. Nearly half of the provinces had a total rainfall of less than 1,500 mm; Ben Tre province remained the lowest with only 753.7 mm, which was 47.81% lower than in 2017 (Figure 3).

Climate change has caused an increase in temperature, prolonged hot weather, a later rainy season, and a sharp decrease in total rainfall compared to previous years. It seriously alters the flow in the downstream area, leading to droughts affecting many rivers of the MDR; as a result, saltwater intrusion is spreading on a large scale, with increasing levels of salinity. Hence, climate change is seriously influencing crop productivity, agricultural production and farmers' lives.

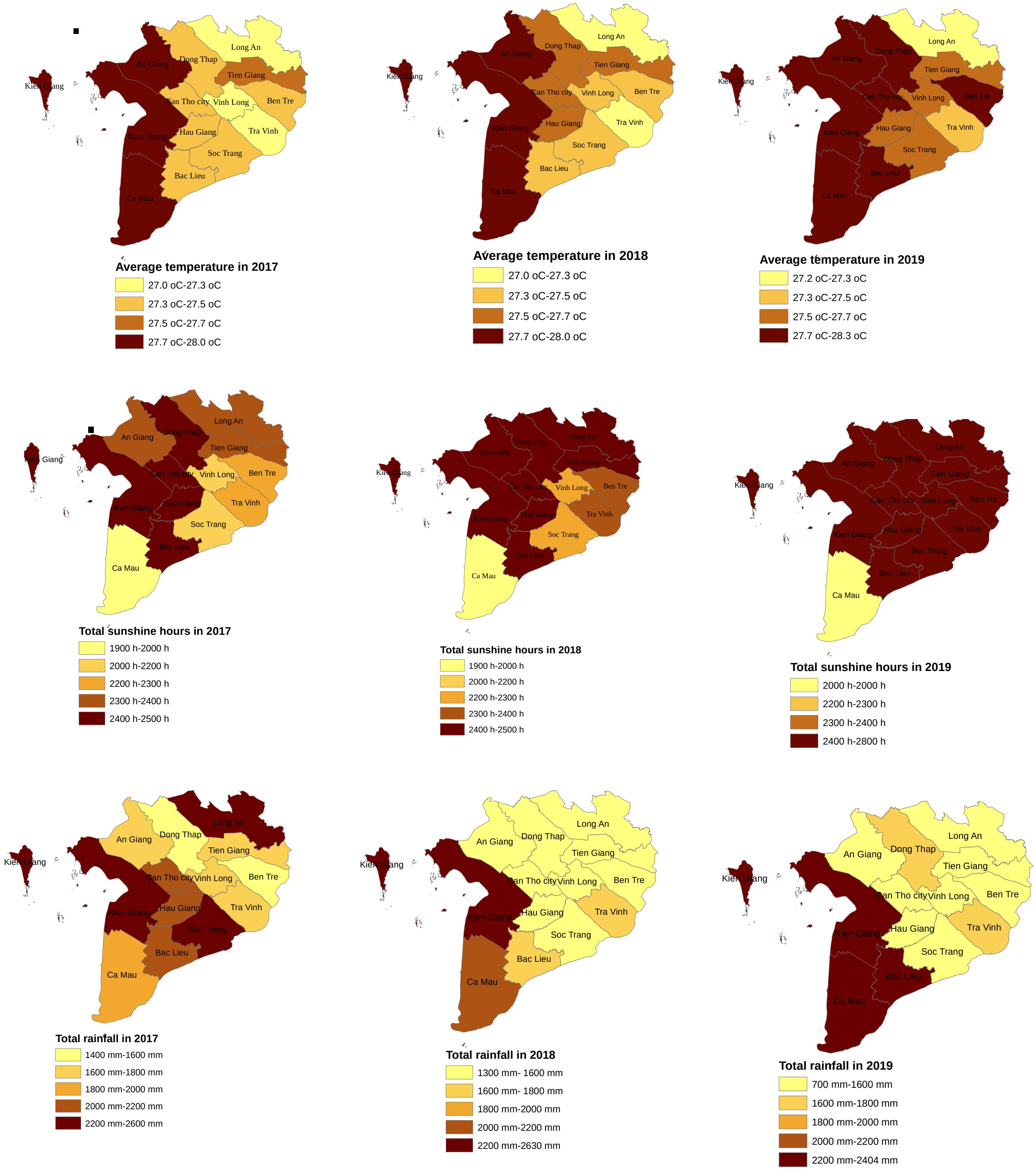
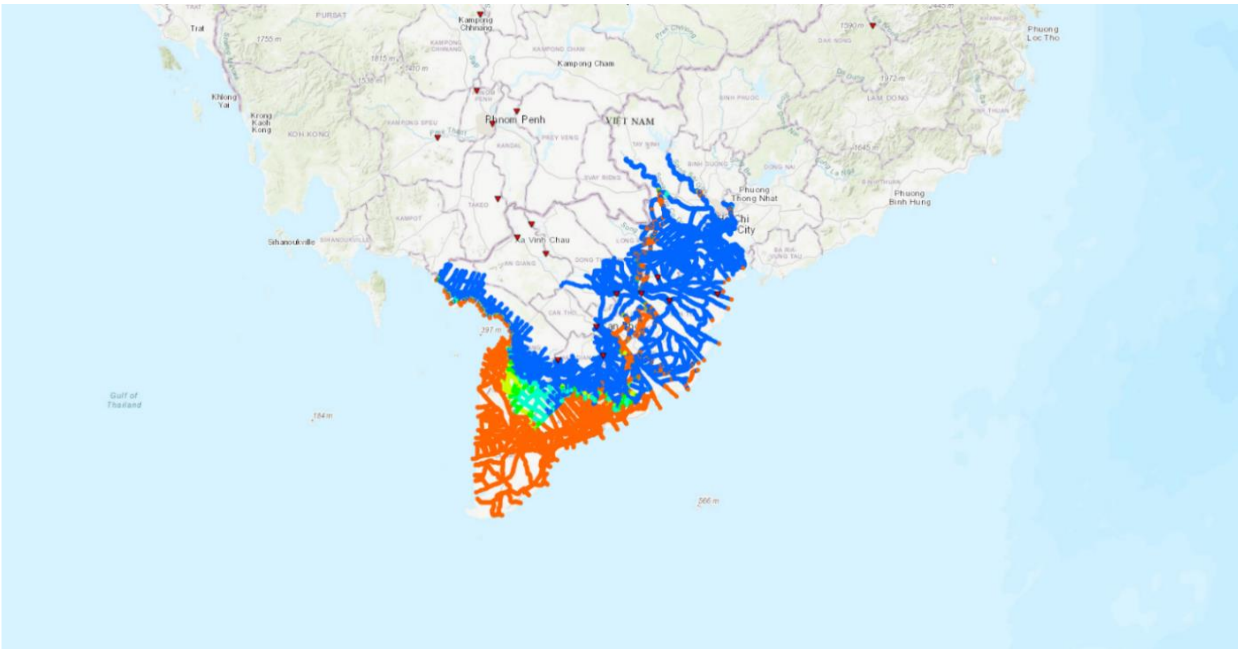


Figure 3: The change of average temperature, sunshine hours and total rainfall in the Mekong River Delta from 2017- 2019
Source: Provincial Statistical Yearbook, ArcGIS 10.8

Saltwater Intrusion



Source: Vietnam Water Resources Data Network (VNWRDN)

Figure 4: Map of salinity distribution in the Mekong River Delta

Saltwater intrusion and increasing intensity and frequency of droughts, combined with other natural disasters in 2019-2020, resulted in a shortage of fresh water, greatly impacting on people's livelihoods in the MRD. Moreover, the 2019-2020 dry and drought season was considered the most severely affected in the MRD due to climate change. Indeed, saline intrusion had an effect on 10 of the 13 provinces in the Mekong River Delta, with a salinity boundary at 4 grams/liter. It has affected about 1.7 million hectares of natural area, accounting for 42.5% of the MRD area (Vietnam Disaster Management Authority, 2020). The map illustrates the distribution of salinity levels in the provinces of the MRD based on 5 salinity levels, including > 4 grams/litre, 3-4 g/l, 2-3 g/l, 1-2 g/l, and less than 1 g/l (Figure 4). In recent years, saltwater intrusion has become one of the biggest challenges for farmer households in agricultural activities in Vietnam (Thanh Danh & Viet Khai, 2014; Thach et al., 2023). In fact, rising sea levels due to climate change reduce hydrological pressure in the MRD, creating conditions for salt water to penetrate deeper into the mainland. The entire coastal area of Tra Vinh province is severely influenced by seawater intrusion as well as high tides. Hence, over 90% of the total agricultural land area (the total of 90,000 hectares) is heavily affected (Thanh Danh & Viet Khai, 2014). Overall, salinity intrusion has been reducing agricultural productivity in the MRD (Khong et al., 2020).

Damages caused by Natural Disasters

Climate change and natural disasters have had a tremendous impact on agricultural production in the MRD. In fact, damage caused by natural disasters seriously influenced people, housing and agricultural production activities in the MRD, with a total damage value of 3,006 million USD in 2019. Ca Mau and Bac Lieu are the most severely affected localities, with total estimated damage values of 1,930 million USD and 805 million USD, respectively. In Ca Mau, natural disasters damaged about 4,118 houses, 20,167 hectares of rice and 340 hectares of crops.

Table 2: Damages caused by natural disasters in 2019

Province	Human damage		Housing damage (House)	Agricultural damage		Total value of damage caused by natural disasters (thousand USD)
	Number of dead and missing people	Number of injured people		Damaged rice area (Ha)	Damaged crop area (Ha)	
Long An	2	8	722	250	1.9	1,125.99
Tien Giang	-	5	483	-	-	2,988.29
Ben Tre	-	1	262	-	-	252,669.65
Tra Vinh	-	-	60	163	-	73.63
Vinh Long	-	3	237	445	151	1,593.18
Dong Thap	10	5	947	1,413	21.4	1,713.74
An Giang	-	-	-	1,580	99	3,921.37
Kien Giang	1	1	13,045	-	-	5,454.70
Can Tho	1	2	345	-	-	361.26
Hau Giang	1	-	265	-	-	232.52
Soc Trang	1	5	487	15,485	2,207.19	979,16
Bac Lieu	1	-	263	1,245	12,636.00	805,158.46
Ca Mau	29	4	4,118	20,167	340	1,930,029.28
Total	***46***	***34***	***21,234***	***40,748***	***15,456.49***	***3,006,301.24***

Source: Statistical yearbook of provinces in 2019

Note: Exchange rate 1 USD= 23,224 VND

Livelihood Vulnerability Index (LVI)

Appendix A1 illustrates the results of each sub-indicator in each major component in An Giang, Tra Vinh, and Hau Giang provinces. Next, the components will be normalized in the Livelihood Vulnerability Index (LVI) calculation. Table 2 shows the LVI index for five districts after aggregating the sub-components into seven principal components.

Demographic profile: this index was relatively low in these localities. Tri Ton district had the highest index of 0.126 points, indicating that households in Tri Ton district had more vulnerable demographics than those in other districts. This difference was mainly due to the fact that households in Tri Ton district had a high proportion of dependents, a high percentage of female heads of households, and a lower education level of the household head.

Livelihood: the livelihood strategy vulnerability index was at a high level in all districts, over 0.6 points. Households in Tra Vinh province were more vulnerable compared to comparison with those in other provinces. The indexes of Duyen Hai and Tra Cu districts were 0.757 and 0.736, respectively. People in the two districts mainly depended on agricultural activities (0.774 and 0.698 points, combined with a high index of diversification of agricultural livelihoods of crops and livestock, fishing (Duyen Hai: 1.121 and Tra Cu: 1.152). Most agricultural production activities depend heavily on weather conditions, so if natural disasters occur, farmers will be more vulnerable. However, the index of the percentage of households with members working far away was lower than others (Duyen Hai: 0.377 and Tra Cu: 0.359). Households whose members work in other places or participate in non-agricultural activities will have more diversified income sources. Hence, if a disaster occurs in the locality, the household will be less vulnerable.

Health status: this index ranged from 0.119 to 0.204, which showed that most of the households in these districts were less vulnerable in terms of health status. In fact, the majority of households with health insurance, merely 5% of households in Tri Ton district and 6.67% of households in An Phu district, had no members aged 6 or older participating in health insurance. There was not much difference in the average time to medical facilities, ranging from 12.95 minutes to 15.47 minutes. An Phu district was more vulnerable in terms of health factors than others (0.204 points). It was mainly because the average time to visit health facilities and the proportion of households without members aged 6 and older participating in health insurance was higher in other districts (Table 3).

Table 3: Values of the major components of the LVI

Major components	Sub-components	Tri Ton	An Phu	Duyen Hai	Tra Cu	Phung Hiep
Demographic Profile	D1	0.053	0.043	0.035	0.068	0.073
	D2	0.183	0.117	0.076	0.189	0.273
	D3	0.217	0.117	0.245	0.189	0.055
	D4	0.050	0.050	0.000	0.000	0.000
		0.126	**0.082**	**0.089**	**0.111**	**0.100**
Livelihood	L1	0.517	0.550	0.377	0.359	0.418
	L2	0.700	0.583	0.774	0.698	0.855
	L3	0.818	0.788	1.121	1.152	0.697
		0.678	**0.640**	**0.757**	**0.736**	**0.657**
Health	H1	0.189	0.232	0.202	0.232	0.223
	H2	0.150	0.15	0.226	0.189	0.255
	H3	0.400	0.367	0.094	0.094	0.000
	H4	0.05	0.067	0.000	0.000	0.000
		0.197	**0.204**	**0.131**	**0.129**	**0.119**
Social networks	SN1	0.304	0.261	0.479	0.407	0.278
	SN2	0.433	0.400	0.464	0.403	0.430
	SN3	0.717	0.733	0.434	0.793	0.855
		0.485	**0.465**	**0.459**	**0.534**	**0.521**
Food	F1	0.550	0.483	0.585	0.566	0.673
	F2	0.066	0.056	0.008	0.018	0.025
	F3	0.400	0.413	0.438	0.375	0.106
	F4	0.317	0.400	0.396	0.396	0.309
	F5	0.517	0.383	0.849	0.679	0.236
		0.370	**0.347**	**0.455**	**0.407**	**0.270**
Water	W1	0.133	0.200	0.132	0.132	0.455
	W2	0.150	0.367	0.359	0.377	0.200
	W3	0.140	0.129	0.144	0.139	0.082
	W4	0.033	0.050	0.000	0.000	0.000
	W5	0.110	0.080	0.004	0.006	0.010
		0.113	**0.165**	**0.128**	**0.131**	**0.151**
Natural disasters and climate change	ND1	0.508	0.508	0.508	0.508	0.508
	ND2	0.000	0.067	0.000	0.000	0.000
	ND3	0.333	0.350	0.151	0.245	0.091
	ND4	0.406	0.406	0.042	0.042	0.325
	ND5	0.524	0.524	0.027	0.027	0.194
	ND6	0.025	0.025	0.014	0.014	0.010
	ND7	0.029	0.029	0.120	0.120	0.086
		0.261	**0.273**	**0.123**	**0.137**	**0.173**
LVI		**0.291**	**0.256**	**0.262**	**0.262**	**0.236**

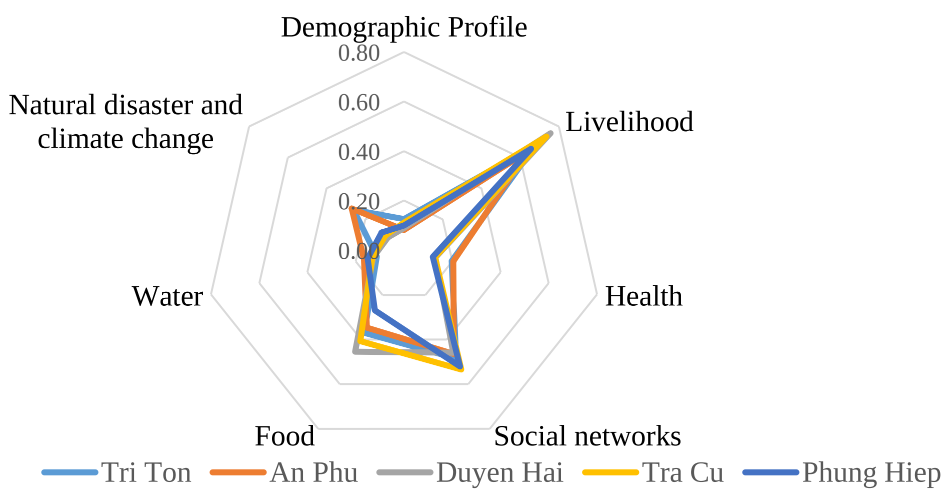
* Note: LVI ranges from 0 (least vulnerable) to 0.8 (most vulnerable)

Social networks: Tra Cu (0.534) and Phung Hiep (0.521) districts had a higher vulnerability in the social network factor, mainly because the percentages of households that did not get support from the local authorities were quite high in Tra Cu and Phung Hiep districts, 0.793 and 0.855 respectively.

Food: most households produced their own food for daily living through activities such as farming, and fishing. Therefore, in An Giang province, the food vulnerability indexes of the two districts were at an average level (Tri Ton: 0.370 and An Phu: 0.347), which meant Tri Ton district was more vulnerable to food than An Phu. Tra Vinh province had a higher level of food vulnerability than An Giang and Hau Giang provinces (Duyen Hai: 0.455 and Tra Cu: 0.407). The main reason was that the indicators of the proportion of households depending on farms for food and the proportion of households not saving seeds and products in Duyen Hai and Tra Cu districts were higher than in other districts.

Water status: An Phu district was less vulnerable in terms of demographic profile, social networks, health, livelihood strategies and food status, with the exception of water status. An Phu district had a higher index of the percentage of households having conflicts about domestic water, the percentage of households using natural water sources, and the percentage of households without regular water supply (0.200; 0.367 and 0.050). However, the difference in water vulnerability between these two districts was not too large, ranging from 0.113 (Tri Ton district) to 0.165 (An Phu district).

Natural disasters and climate change: An Giang province had a higher level of vulnerability to natural disasters and climate change (Tri Ton: 0.261 and An Phu: 0.270). In fact, the percentages of households in Tri Ton and An Phu districts that did not receive natural disaster warnings were higher than those in other districts. Moreover, The standard deviation of the highest (0.524) and lowest (0.025) water levels also fluctuated in Tri Ton and An Phu districts more than in other regions. As the upstream province of the MRD, An Giang is considered the most vulnerable province to the effects of floods. About 6.5% of communes are at high risk of flooding because most of them located in An Phu are preponderantly agricultural regions with relatively poor populations (Van et al., 2024). Hence, to respond to floods, floodwater retention, flood-resistant infrastructure, market stability as well as environmental sustainability are ranked first in the sustainability of farmers' livelihoods (Tran et al., 2018).



Source: Household survey data, 2021

Figure 5: Spider diagram of seven components

The scale of the histogram ranges from 0 (least vulnerable) in the center of the figure to 0.8 (most vulnerable). The LVI was highest in Tri Ton district, with 0.291 (Figure 5). In fact, the indicators on demographic profile, health, social network, natural disasters and climate change in Tri Ton district were higher than those in other districts. Duyen Hai and Tra Cu districts had the same vulnerability index, at 0.262; followed by An Phu district (0.256). Phung Hiep district was the lowest vulnerability, with 0.236. Overall, households in the five regions were the most vulnerable on the livelihood strategy index (Figure 6), with a high degree of vulnerability, ranging from 0.64 to 0.757. In fact, the livelihood diversification indexes in the localities were still quite high. In other words, households did not diversify in their livelihood activities to create additional income sources to improve their lives.

LVI – IPCC Framework

Table 4: IPCC factors that contribute to vulnerability

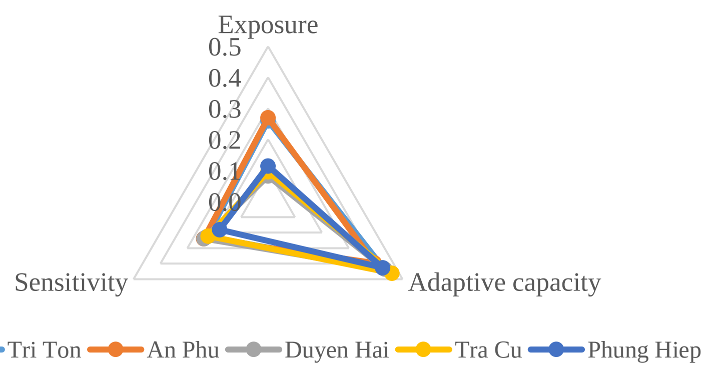
Factors that contribute to IPCC vulnerability	Tri Ton	An Phu	Duyen Hai	Tra Cu	Phung Hiep
Exposure (e)	**0.261**	**0.270**	**0.083**	**0.096**	**0.115**
Natural disaster and climate change	0.261	0.270	0.083	0.096	0.115
Adaptive capacity (a)	**0.430**	**0.396**	**0.435**	**0.461**	**0.426**
Demographic profile	0.126	0.082	0.089	0.111	0.100
Livelihood	0.678	0.640	0.757	0.736	0.657
Social networks	0.485	0.465	0.459	0.534	0.521
Sensitivity (s)	**0.227**	**0.239**	**0.238**	**0.222**	**0.180**
Health	0.197	0.204	0.131	0.129	0.119
Food	0.370	0.347	0.455	0.407	0.270
Water	0.113	0.165	0.128	0.131	0.151
LVI-IPCC	**-0.038**	**-0.030**	**-0.084**	**-0.081**	**-0.056**

** Note: LVI-IPCC fluctuates between -1 (least vulnerable) and 1 (most vulnerable)*

Source: Household survey data, 2021

Tri Ton district was more vulnerable in terms of the LVI, at 0.291. However, based on the IPCC framework, the results showed that households in An Phu and Tri Ton districts were more vulnerable than households in other districts, at $\text{LVI-IPCC}_{\text{An Phu}}$ = -0.03 and $\text{LVI-IPCC}_{\text{Tri Ton}}$ = -0.038. An Phu district had a lower LVI vulnerability index than other localities, at 0.256. However, based on the LVI-IPCC, households in An Phu district had the highest level of vulnerability, mainly because An Phu district had a higher value of s = 0.239 and exposure e = 0.270 than other areas (Table 4).

Figure 6 illustrates the household vulnerability triangle to the impacts of climate change. It illustrates the factors that contribute to exposure, adaptability, and sensitivity.



Source: Household survey data, 2021
Note: 0: Low contributor to vulnerability to climate change
0.5: High contributor to climate change vulnerability

* Exposure (e)

Households in An Phu and Tri Ton districts were more affected by climate change ($e_{\text{Tri Ton}}$: 0.261; $e_{\text{An Phu}}$: 0.270). An Giang was one of the MRD provinces most heavily influenceded by floods and climate change every year

(Can et al., 2013). When floodwaters fell from upstream along with rainfall, they caused flooding, affecting production activities, especially in summer-autumn and third-crop rice production areas (Hong et al., 2012). In contrast, Duyen Hai and Tra Cu districts inTra Vinh province, were mainly impacted by saline intrusion due to their long coastline and coastal production areas (Thanh Danh & Viet Khai, 2014; Nguyen et al., 2020; Tran et al., 2022). In addition, the intricate system of rivers and canals in Tra Vinh also contributed to increasing saltwater intrusion into the interior fields (Lan, 2011).

* Adaptive capacity (a)

Households in Tra Cu and Duyen Hai districts were less resilient in terms of demographic profiles, livelihood strategies, and social networks ($a_{Tra\ Cu}$: 0.461; $a_{Duyen\ Hai}$: 0.435) than in Tri Ton, An Phu, and Phung Hiep districts ($a_{Tri\ Ton}$: 0.430; $a_{An\ Phu}$: 0.396 and $a_{Phung\ Hiep}$: 0.426). Households in Tra Cu and Duyen Hai districts had lower adaptive capacity (Tran et al., 2022) because they were more vulnerable compared to indicators of livelihood strategies and social networks.

* Sensitivity (s)

In terms of health, food, and water factors, households in An Phu and Duyen Hai districts were more sensitive ($s_{An\ Phu}$: 0.239; $s_{Duyen\ Hai}$: 0.238) to the impacts of climate change than others. Research results showed that An Phu district was more vulnerable in terms of health factors than other localities (Table 3), mainly due to the higher proportion of households whose members had to miss work or school due to sickness, less time to visit health facilities as well as a higher percentage of households with no members aged 6 or older participating in health insurance. In addition, households in this locality had conflicts about domestic water as well as using natural water sources and the percentage of households without regular water supply (0.200; 0.367 and 0.050) was higher than others.

CONCLUSION AND POLICY IMPLICATIONS

Climate change has been strongly affecting people's livelihoods in Tri Ton and An Phu districts (An Giang province), Duyen Hai and Tra Cu districts (Tra Vinh province), and Phung Hiep district (Hau Giang province). Overall, An Phu and Tri Ton districts, the floodplains along the Mekong River, are more vulnerable than other regions ($LVI\text{-}IPCC_{An\ Phu:}$ -0.03; $LVI\text{-}IPCC_{Tri\ Ton}$: -0.038), due to more vulnerability in terms of exposure and sensitivity factors. Extreme natural disasters, such as floods, storms, landslides, saltwater intrusion, are increasing and unpredictable, which significantly affects people's livelihoods, especially agricultural activities. To reduce livelihood vulnerability due to climate change in these districts in particular and the MRD in general, it is necessary to combine temporary solutions as well as improve adaptability in the long term.

Based on the obtained research results, the study proposes several solutions, including raising awareness about climate change, improving production techniques, diversifying income sources, diversifying crops and livestock, and increasing cooperation in production. Crop diversification will help limit pests and diseases, reduce the impact of extreme weather, contribute to improving income, and reduce risks compared to price fluctuations when growing only one type of agricultural product. In addition, local authorities need to build and replicate diverse livelihood models which are suitable for each sub-region, meet market needs and adapt to climate change. Structural transformation and farmer support activities in sustainable crop development are also emphasized.

Conflict of Interest Statements

There is no conflict of interest.

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Appendix A1: Component factor values, maximum and minimum values of the LVI

Major components	Sub-components	Unit	Tri Ton	An Phu	Duyen Hai	Tra Cu	Phung Hiep	Max	Min
Demographic Profile	D1	-	0.21	0.17	0.14	0.27	0.29	4	0
	D2	%	18.3	11.7	7.55	18.87	27.27	100	0
	D3	%	21.67	11.67	24.53	18.87	5.45	100	0
	D4	%	5.00	5.00	0	0	0	100	0
Livelihood	L1	%	51.67	55.0	37.74	35.85	41.82	100	0
	L2	%	70.00	58.33	77.36	69.81	85.45	100	0
	L3	-	0.44	0.43	0.54	0.55	0.4	0.5	0.17
Health	H1	minute	12.95	15.45	13.70	15.47	14.91	60	2
	H2	%	15.00	15.00	22.64	18.87	25.45	100	0
	H3	%	40.00	36.67	9.43	9.43	9.09	100	0
	H4	%	5.00	6.67	0	0	7.27	100	0
Social networks	SN1	-	1.39	1.23	2.05	1.78	1.29	4	0.25
	SN2	-	1.15	1.10	1.12	1.11	1.15	2	0.5
	SN3	%	71.67	73.33	43.40	79.25	85.45	100	0
Food	F1	%	55.00	48.33	58.49	56.60	67.27	100	0
	F2	month	0.33	0.28	0.04	0.09	0.13	5	0
	F3	-	0.52	0.53	0.550	0.500	0.29	1	0.2
	F4	%	31.67	40.00	39.62	39.62	30.91	100	0
	F5	%	51.67	38.33	84.91	67.92	23.64	100	0

Appendix A1: Component factor values, maximum and minimum values of the LVI

Major components	Sub-components	Unit	Tri Ton	An Phu	Duyen Hai	Tra Cu	Phung Hiep	Max	Min
Water	W1	%	13.33	20.00	13.21	13.21	45.45	100	0
	W2	%	15.00	36.67	35.85	37.74	20.00	100	0
	W3	minute	4.20	3.88	4.32	4.16	2.47	30	0
	W4	%	3.33	5	0	0	0	100	0
	W5	1/liter	0.11	0.08	0.004	0.006	0.016	1	0
Natural disasters and climate change	ND1	-	5.08	4.9	2.241	2.245	1	10	0
	ND2	%	0	6.67	0	0	0	100	0
	ND3	%	33.33	35	15.09	24.53	9.09	100	0
	ND4	Cm	49.22	49.22	5.12	5.12	39.39	121.13	0
	ND5	Cm	113.1	113.1	5.90	5.90	42.01	216.03	0
	ND6	^0C	1.04	1.04	0.94	0.94	0.90	9.6	0.82
	ND7	Mm	94.53	94.53	124.2	124.2	113.2	412.51	85

Source: Calculated from household survey data and Provincial Statistical Yearbooks