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Climate change impacts on rice-based livelihood vulnerability in the lower Vietnamese Mekong Delta: Empirical evidence from Can Tho City and Tra Vinh Province

Dung Duc Tran [a,b], Edward Park [a,*], Huynh Thi Ngoc Tuoi [c,d], Nguyen Duc Thien [b], Vo Hong Tu [e], Pham Thi Anh Ngoc [f], Can Thu Van [g], Pham Kim Long [h], Huu Loc Ho [i], Chau Nguyen Xuan Quang [c,d,*]

[a] National Institute of Education (NIE) and Earth Observatory of Singapore (EOS), Nanyang Technological University (NTU), Singapore

[b] Center of Water Management and Climate Change, Institute for Environment and Resources, Vietnam National University – Ho Chi Minh City (VNU – HCM), Ho Chi Minh, Viet Nam

[c] Hydrology and Water Resources Division, Institute for Environment and Resources, Vietnam National University – Ho Chi Minh City (VNU – HCM), Ho Chi Minh, Viet Nam

[d] Vietnam National University Ho Chi Minh City, Linh Trung Ward, Thu Duc District, Ho Chi Minh City 700000, Viet Nam

[e] College of Rural Development, Can Tho University, Can Tho, Viet Nam

[f] School of Business and Management, RMIT University Vietnam, Viet Nam

[g] Ho Chi Minh City University of Natural Resources and Environment, Viet Nam

[h] Institute of Environmental Science and Technology, Tra Vinh University, Viet Nam

[i] Water Engineering and Management, Asian Institute of Technology, Pathum Thani, Thailand

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ABSTRACT

This paper assesses the livelihood vulnerability and adaptive capacity of rice-based farmers in the lower Vietnamese Mekong Delta (VMD) under the impact of climate change and environmental pressures. We interviewed 600 rice farmers in 19 communes spanning six districts of Can Tho City (middle delta) and Tra Vinh Province (coastal delta). For our analyses, we employed the Livelihood Vulnerability Index (LVI) framework and the LVI approach of the Intergovernmental Panel on Climate Change (LVI–IPCC). Results indicate that both study areas are vulnerable to climate change and environmental pressures, but the potential threat is greater in the coastal province. Farmers there have responded to climate change and environmental pressures by increasing production inputs, scaling up production areas and transforming cropping patterns, though with little investment in new equipment. Yet, their livelihoods from rice cultivation, and agricultural production in general, remain unsustainable under climate change, which is a matter of concern. This study provides empirical evidence of the vulnerability factors that most undermine farmers' adaptive capacity and livelihood sustainability in the study areas. This will help local authorities in providing timely support to agricultural production management.

* Corresponding authors.
E-mail addresses: edward.park@nie.edu.sg (E. Park), cnxquang@hcmier.edu.vn (C.N.X. Quang).

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1. Introduction

Agricultural production is a major source of income and food security for rural populations in developing countries (Aghapour Sabbaghi et al., 2020; Falco et al., 2019; Tran, 2019). In most regions of Southeast Asia, agriculture contributes more than 10% of gross domestic product (GDP), provides more than one-third of jobs and generates income for nearly three-fourths of the poor (Zhai and Zhuang, 2012). Yet, agricultural production is extremely vulnerable to climate variability and change (Murken and Gornott, 2022). For instance, increasing temperatures and more frequent rainfall can undermine farmers' incomes by diminishing agriculture productivity and fuelling outbreaks of plant diseases and pests (Ajetomobi et al., 2011; Nelson et al., 2009).

In a study for the World Bank, Trinh et al. (2013) identified Vietnam as one of the five developing countries most impacted by climate change. The Vietnam Mekong Delta (VMD), the "rice bowl" of Vietnam is also among the world's three most vulnerable deltas. . Farming in the VMD contributes more than half of the nation's total food production and over 80% of its rice exports (Triet et al., 2020). Due to the importance of rice as the nation's staple food and as an income source for millions of VMD residents, concerns over the sustainability of VMD farming systems have risen. Impacts of climate change, especially sea level rise and the associated saltwater intrusion, are expected to significantly affect the delta, putting the livelihoods of delta residents increasingly at risk (Brown et al., 2018; Nicholls et al., 2016). The Ministry of Natural Resources and Environment (MONRE, 2016) has projected that by 2050, rainfall in the VMD region will increase by 2%–5% in the rainy season and decrease by 4%–8% in the dry season, resulting in inundation of 40% of the VMD during the rainy season. In addition to the threat of inundation, 1.8 million ha of the total 39.5 million ha VMD will be affected by higher salinity in the dry season (MONRE, 2016). In the face of these vulnerabilities, the sustainable development of the VMD is a key priority in national socio-economic development plans (Tran et al., 2021b).

Many studies have assessed the vulnerability of households to climate change (Hahn et al., 2009; Ngo et al., 2022; Nguyen and Leisz, 2021; Zhang et al., 2019). In Mozambique's Mabote and Moma districts, for example, Hahn et al. (2009) estimated the vulnerability of smallholder maize farming households to natural hazards and climate change, as well as their adaptation capacities. Zhang et al. (2019) examined the vulnerability of Chinese rural households to climate change in the three dimensions of exposure, sensitivity and adaptability. Tran et al. (2020) assessed the sustainability of farmers' livelihoods in An Giang Province of Vietnam under the impacts of climate change and environmental pressures. Methods frequently used in such studies are the Livelihood Vulnerability Index (LVI) and the Livelihood Vulnerability Index approach of the Intergovernmental Panel on Climate Change (LVI–IPCC). Few of these studies, however, have investigated the vulnerability of rice-based farming systems and rice farmers' perceptions of the climate change impacts and environmental pressures on farming operations. Moreover, given the VMD's vulnerability and its importance in agricultural production for the nation, there is considerable value in vulnerability assessments of rice farmers' livelihoods and their adaptive capacity across the VMD.

The current study assesses the adaptive capacity of rice farmers in the VMD in the middle-delta and coastal areas, Can Tho City and Tra Vinh Province respectively. We examined the livelihoods of rice farmers in these study areas over a recent five-year period, particularly farmers' responses to climate change and environmental pressures and their perspectives on the future. In line with earlier research conducted elsewhere, we applied the LVI and LVI–IPCC methodology to explore the vulnerability of farmers, alongside their adaptive capacity to climate change.

2. Study areas

Can Tho City and Tra Vinh Province, two of the 13 provinces of the Vietnamese Mekong Delta, were selected for study due to their different hydrological conditions, giving rise to different cropping patterns. These two locations are regions most vulnerable to climate change-induced impacts and environmental issues (Huynh et al., 2020). In addition, both areas are located along major rivers (Fig. 1); where the hydrological changes, influenced by climate change and environmental pressures, are sensitive to agricultural activities and livelihoods of many local farmers.

Tra Vinh is a coastal province, with the Tien River to the north and the Hau River to the south. Like much of the coastal VMD, the province is severely affected by saltwater intrusion which is worsening with the effects of climate change (Directorate of Water Resources in Vietnam, 2017). To the east, Tra Vinh is bordered by the East Sea. It borders Vinh Long Province to the west, Soc Trang Province to the south and Ben Tre Province to the north. Tra Vinh has 65 km of coastline, spanning the area between the lower reaches of the Tien and Hau rivers. Total cultivated area was 223,200 ha in 2018, with 66,500 ha planted for winter–spring crops, 155,100 ha planted for summer–autumn and autumn–winter crops, and 1,700 ha planted in other periods. Rice has remained relatively underdeveloped in Tra Vinh. The province's average rice yield was 5.68 tons/ha in 2018, which is lower than the average yield for the delta as a whole (6.89 tons/ha). The province faces many problems due to environmental pressures. It is at particularly high risk of saltwater intrusion, which already causes shortages of freshwater in the dry season, from January to April. Furthermore, over 1 million ha annually are affected by salinity greater than 4 g/l (Dinh, 2016). Tides from the East Sea encroach inland through the Co Chien and Hau rivers. Sea level rise is expected to have major impact on the province's canal system, causing unfavourable flow directions and fluctuations. Drought has become more frequent and long-lasting in areas with high terrain, while lowlands are regularly flooded due to rains and tides. Because of the impact of saltwater intrusion, the province has

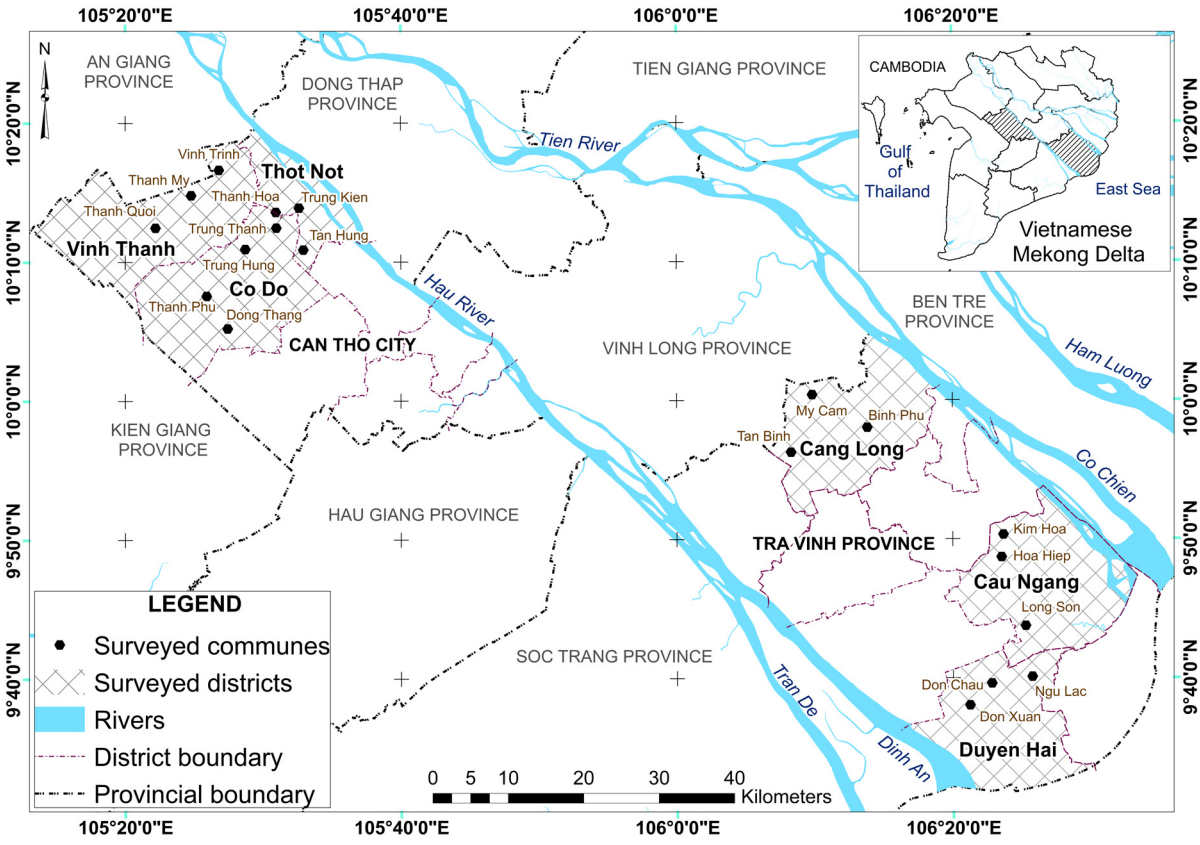

Fig. 1. Can Tho City and Tra Vinh Province and surroundings. Shaded areas indicate the six districts surveyed, and the 19 communes included in this research are also indicated.

advocated converting inefficient farming areas to other crops and fisheries. Some 41.5% of the total converted rice lands, approx. 5,500 ha, has already been converted to vegetables, followed in importance by maize, fruit trees and coconuts (Bong et al., 2018). Outbreaks of plant diseases are expected to become more frequent due to the more severe climatic conditions (Zhu and Trinh, 2010).

Our second study area, Can Tho City, is located on the Hau River and classified as freshwater middle delta. Its terrain is low and flat, made up of alluvium from the Mekong River. Can Tho City's average altitude is 0.8–1 m above mean sea level, and the region extends some 55 km along the west bank of the Hau River. Its total cultivated area was 237,300 ha in 2018, with 82,500 ha planted for winter–spring crops and 154,800 ha planted for summer–autumn and autumn–winter crops (General Statistics Office, 2021). Total rice production was 1,426,300 tons in 2018, with an average yield of 6.01 tons/ha. The region's hydrology is influenced by both upstream floodwaters (from July to November) and salinity intrusion downstream. In recent years, flood frequencies and magnitudes have diminished under the impacts of both hydropower plant development and climate change (Dung et al., 2018c; Hoang et al., 2019; Tran et al., 2021b; Triet et al., 2020; Wesselink et al., 2015). However, salinity intrusion has worsened, and is a growing threat to many farmers' livelihoods (Loc et al., 2021; Nguyen et al., 2020; Tran et al., 2019a,b). In the 2015–2016 winter–spring cropping season – the most extreme drought year in recent record – saltwater intrusion affected some 104,000 ha of rice fields (Directorate of Water Resources in Vietnam, 2017). If sea level rises by 1 m, rice yields here are forecast to fall by 40.5% due to worsening salinity intrusion (MONRE, 2016; World Bank, 2010). Climate change has also negatively affected agricultural production here due to increasing air temperatures, in addition to changes in rainfall, floods, drought, saltwater intrusion and other conditions (Nguyen and Leisz, 2021; Tran, 2019). River flows in the dry season have diminished, causing water shortages upstream (e.g., Vinh Thanh and Thot Not districts, see Fig. 1) and saltwater intrusion in the lowlands (e.g., Vinh Thanh and Co Do districts, see Fig. 1). Sea tides reach increasingly far inland, bringing salty conditions and undermining agricultural production (People's Committee of Can Tho City, 2015). In view of the area's intensive rice farming and its high population density (859 people/km^2, which is three times higher than the national average) (General Statistics Office, 2021), many rice farmers have already experienced adverse effects of climate change on their livelihoods.

3. Methodology

3.1. Data collection

A structured questionnaire was formulated centred on the seven main components of the LVI and LVI–IPCC. The aim was to assess the vulnerability and adaptive capacity of rice farmers to the impacts of climate change and environmental pressures. Basic information was sought on the household heads (age, education, gender, finance and rice farming characteristics), alongside their perceptions of changes in the environment over the past five years and into the future. The questionnaire was designed to be administered in 60 min or less, in order to maintain interviewees' attention.

Two surveys were conducted, respectively, in Tra Vinh Province and in Can Tho City in July and August 2020. In each region, we selected three districts, where rice cultivation is dominant. In Can Tho City, these districts were Thot Not, Co Do and Vinh Thanh. In Tra Vinh Province, these districts were Cang Long, Cau Ngang and Duyen Hai. The selected districts represent a diversity of geographies where farmers' perceptions and characteristics are likely vary, including coastal (Duyen Hai), riverside (Thot Not and Cang Long), inland (Co Do and Vinh Thanh) and bordering on the East Sea and Hau River (Cau Ngang) (see Fig. 1).

Using the questionnaire, we surveyed 600 rice farmers, 300 in Can Tho City and 300 in Tra Vinh Province (for details see Table A.1 in the appendix). Farmers to be interviewed were selected by simple random sampling. Thirty interviews were carried out in each of 19 communes in the six districts to ensure the minimum sample size required for statistical analysis. In fact, the number of interviewees was less important for this qualitative research than achieving saturation in the information gained (Kumar, 2014). Local officials indicated specific rice cultivation locations and characteristics of interest in each commune, which helped us save time in the preliminary research phase. Although age and gender were not deciding factors, we ensured that interviewed household heads had at least five years of experience in rice cultivation.

3.2. Livelihood vulnerability assessment

3.2.1. Livelihood vulnerability index (LVI)

Climate change has a considerable impact on agriculture worldwide, due to the scale of farming in many countries and the sensitivity of agriculture to climate and environmental pressures (Mendelsohn, 2008). Vietnam's economy is highly dependent on agriculture, especially rice. The decline in rice production and productivity under the impact of drought and rising sea level has affected the sustainability of Vietnamese farmers' livelihoods (Redfern et al., 2012). In the study areas, diminishment of cultivatable land areas has led to income disparities between households. In addition, the gender of household heads is a factor in the sustainability of livelihoods and ability to adapt to environmental pressures (Redfern et al., 2012).

The current study applied the livelihood vulnerability approach developed by Chambers and Conway (1992) to compare the extent of vulnerability caused by climate change between Tra Vinh Province and Can Tho City. The approach commonly assesses five main components of household capital: natural, social, financial, physical and human. To these, we added the components of livelihood strategy, and natural disasters and climate change to explicitly incorporate their effects on farmers' livelihood vulnerability and adaptive capacity (Hahn et al., 2009). Hence, LVI in this study was calculated based on seven key components: (i) natural capital, (ii) social capital, (iii) financial capital, (iv) physical capital, (v) human capital, (vi) livelihood strategy and (vii) natural disasters and climate change.

Each component contains different aspects collected through the questionnaire. The components were measured on different scales and thus needed to be standardized. This was done using the following equation (Hahn et al., 2009):

$$\mathrm{Index}_{\mathrm{Sd}} = \frac{S_d - S_{min}}{S_{max} - S_{min}}, \tag{1}$$

where S_d is each aspect in each district (Co Do, Thot Not, Vinh Thanh, Cang Long, Cau Ngang and Duyen Hai), and S_{max} and S_{min} are the maximum and minimum values for each aspect, respectively. Each component of the LVI was calculated as follows:

$$M_d = \frac{\sum_{i=1}^{n} IndexS_{di}}{n}, \tag{2}$$

where M_d is one of the seven major components in each district. Then, the LVI for each district was calculated as follows:

$$LVI_d = \frac{\sum_{i=1}^{7} W_{Mi} M_{di}}{\sum_{i=1}^{7} W_{Mi}}, \tag{3}$$

where W_{Mi} is the weight of each major component, calculated using the aspects making up each component. In this study, the weight relates to the number of sub-components in each component; for example, if component A has two sub-components and component B has three sub-components, B would have a higher weight than A (3 compared to 2). This resulted in LVI values ranging from 0 (least vulnerable) to 1 (most vulnerable).

Table 1
Key components of the LVI–IPCC.

Factors	Key components
Adaptability	Socio-demographic profile Livelihood strategy Social networks
Sensitivity	Human (health, knowledge, experience) Natural resources Finance
Exposure	Natural disasters and climate change

3.2.2. Calculating the LVI–IPCC

The LVI–IPCC is the LVI approach of the Intergovernmental Panel on Climate Change (IPCC). It is presented as an index with three main components: adaptability, sensitivity and exposure (Table 1). To construct the LVI–IPCC for the study areas, we first quantified *adaptability* based on three components: socio-demographic profile of the study areas (i.e., numbers of dependents in households and proportion of households that were female-headed); livelihood strategy (i.e., proportion of farmers growing rice, their ability to invest in equipment, their experiences in dealing with environmental pressures, other sources of income besides rice and their ability/willingness to expand land area); and social networks (i.e., connections between farmers and local authorities and traders). Second, we determined *sensitivity* by basic information on the age, education, rice cultivation experience and number of labour participants in households. Finally, we measured *exposure* as farmers' perceptions of environmental change over the past five years and into the future.

The key components (Table 1) were combined according to the following equation:

$$CF_d = \frac{\sum_{i=1}^{n} W_{Mi} Mdi}{\sum_{i=1}^{n} W_{Mi}}, \tag{4}$$

where CF_d is the contributing factor (adaptability, sensitivity and exposure) for each district, M_{di} is the key component for each district, W_{Mi} is the weight of the key component and n is number of key components in each contributing factor.

The LVI–IPCC index was calculated as follows:

$$LVI - IPCC = (Exposure - Adaptive\ Capacity) \times Sensitivity \tag{5}$$

This resulted in LVI–IPCC values ranging from −1 (least vulnerable) to 1 (most vulnerable).

4. Results

4.1. Household characteristics

Table 2 presents the analysis results for rice farming households in Can Tho and Tra Vinh. Similarities were observed between the two study areas in age of household head, rice cultivation experience and education. The average age of household heads was quite high (about 50 years), and they had an average of 24 years of experience in rice cultivation. However, their education was low; more than 85% of the interviewed household heads had not completed secondary school, and very few household heads had a high school education or higher (1% in Tra Vinh and 0% in Can Tho).

The areas differed more in the gender characteristics of the household heads. In Can Tho, 94% of the interviewed household heads were male, while in Tra Vinh, this was 64%. Female household heads reported spending a lot of time caring for family, in addition to working in the fields. This added care-giving workload can be considered a major factor in the higher vulnerability to climate change of localities with high rates of female-headed households (Chineka, 2016).

Table 3 summarizes the rice cultivation characteristics of the interviewed households, particularly, cultivated area, yield, selling price of each crop and profit (Table 3). Statistical results indicate that Can Tho farmers had larger land areas cultivated for rice, higher yields and greater profit than Tra Vinh farmers.

The average rice cultivation area in Can Tho was twice that in Tra Vinh (2.4 ha/household compared to 1.2 ha/household). Riverside districts such as Thot Not, Cau Ngang and Cang Long and the coastal district of Duyen Hai had particularly small cultivated areas (1.0–1.5 ha/household), while farmers in inland areas had larger land sizes (farmers in Vinh Thanh had an average of 3.4 ha/household while those in Co Do had some 2.4 ha/household).

Considering three seasonal rice crops, average yields in Can Tho were found to be higher than those in Tra Vinh (7.23 tons/ha compared to 5.77 tons/ha). Nonetheless, large differences were found between the three rice crops in Can Tho. The winter–spring crop had the highest yield (8.1 tons/ha), and Thot Not district had the lowest average yield across the three crops (7.07 tons/ha). In Tra Vinh Province, yields were relatively similar across the three types of rice crops, with Cang Long district having the highest yield (6.07 tons/ha).

The average selling price of rice in Tra Vinh was less than that in Can Tho (US $215/ton compared to $239/ton). The lowest price in Tra Vinh was reported for the summer–autumn crop ($199/ton), though this is the crop with the highest selling price in Can Tho ($249/ton). Due to the lower selling price for rice in Tra Vinh, profits from rice cultivation were lower here ($1,430 versus $2,479). Profits were found to be especially low in Duyen Hai and Cau Ngang districts ($1,200 in Cau Ngang and $1,280 in Duyen Hai).

Table 2
Characteristics of household heads in Can Tho City and Tra Vinh Province.

	Co Do	Thot Not	Vinh Thanh	Whole area	Duyen Hai	Cau Ngang	Cang Long	Whole area
Individual characteristics								
N	123	90	87	**300**	120	90	90	**300**
Age (years)	49.7	50.5	48.2	**49.5**	51.7	53.7	49.9	**51.8**
Experience in rice production (years)	24.8	25.2	23.4	**24.5**	23.9	23.8	20.9	**23.0**
Education								
Primary	48%	51%	45%	**48%**	63%	50%	37%	**51%**
Secondary	35%	41%	41%	**39%**	23%	37%	46%	**34%**
Tertiary	17%	8%	13%	**13%**	13%	12%	18%	**14%**
Higher education	0%	0%	1%	**0%**	2%	1%	0%	**1%**
Gender								
Male	93%	96%	94%	**94%**	66%	68%	64%	**66%**
Female	7%	4%	6%	**6%**	34%	32%	36%	**34%**

Table 3
Characteristics of rice production in Can Tho City and Tra Vinh Province.

Variables	Can Tho	Tra Vinh
Farming characteristics		
Farm size (ha)	2.4	1.2
Farm labour (persons)	2.6	2.5
Mean yield (ton/ha)		
Winter–spring (Dec–Mar)	8.1	5.6
Summer–autumn (April–July)	6.9	5.7
Autumn–winter (July–Dec)	6.7	6.0
Selling price (US$/ton)		
Winter–spring (Dec–Mar)	236	222
Summer–autumn (April–July)	249	199
Autumn–winter (July–Dec)	233	225
Profit		
Mean profit/ha (10^6VND)	55	32
Mean profit (US$)	2,479	1,430

Table 4
LVI calculations for key components in Can Tho City and Tra Vinh Province.

Key components	Can Tho	Tra Vinh
1. Human	0.220	0.211
2. Social	0.278	0.208
3. Physical	0.346	0.388
4. Financial	0.252	0.433
5. Natural	0.117	0.263
6. Livelihood strategy	0.522	0.627
7. Natural disasters and climate change	0.391	0.507
LVI (overall)	**0.338**	**0.406**

4.2. Vulnerability assessment using the LVI and LVI–IPCC

The calculated LVI and LVI–IPCC helped to clarify the vulnerability and adaptability of rice farmers in the study areas. The results of the LVI and LVI–IPCC analyses are presented in the sections below.

4.2.1. LVI-Based vulnerability assessment

Fig. 2 and Table 4 present livelihood vulnerability in Can Tho City and Tra Vinh Province. Tra Vinh was found to have a higher average vulnerability than Can Tho (0.406 compared to 0.338). The two study areas differed on five LVI capitals/components. The LVI values for social capital ranged from 0.208 to 0.278, those for financial capital ranged from 0.252 to 0.433 and those for natural capital ranged from 0.117 to 0.263. Values for the vulnerability of livelihood strategies ranged from 0.522 to 0.627, while vulnerability to natural disasters and climate change ranged from 0.391 to 0.507. Similar LVI values were found for human and physical capital — ranging from 0.211 to 0.220 for human capital and from 0.346 to 0.388 for physical capital.

4.2.2. LVI–IPCC-based vulnerability assessment

The LVI–IPCC results indicated greater vulnerability in Tra Vinh than in Can Tho as well (0.039 compared to 0.012) (Tables 5 and 6). Fig. 3 presents the impact on the criteria for adaptability, sensitivity and exposure in the form of a

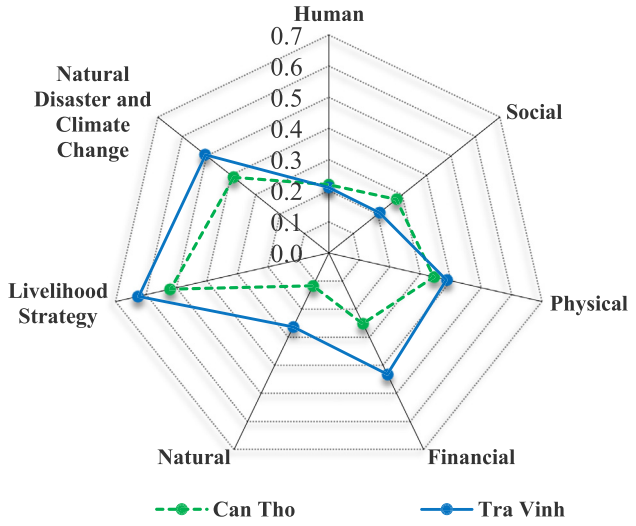

Fig. 2. Spider diagram of LVI-based livelihood vulnerability for Can Tho City and Tra Vinh Province.

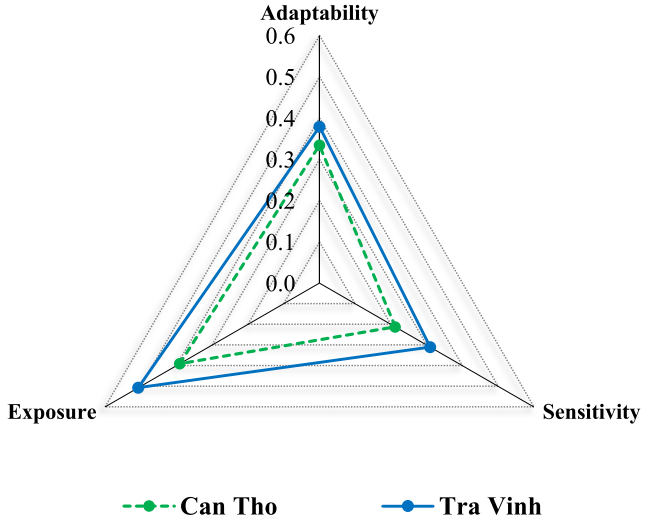

Fig. 3. Triangle diagram of components in LVI–IPCC in Can Tho City and Tra Vinh Province.

Table 5
Key components of LVI–IPCC in Can Tho City.

Components	Co Do	Thot Not	Vinh Thanh	Can Tho
Adaptability	0.347	0.319	0.336	0.334
Sensitivity	0.211	0.220	0.204	0.212
Exposure	0.395	0.378	0.400	0.391
LVI-IPCC	0.010	0.013	0.013	**0.012**

Table 6
Key components of LVI–IPCC in Tra Vinh Province.

Components	Duyen Hai	Cau Ngang	Cang Long	Tra Vinh
Adaptability	0.365	0.384	0.389	0.379
Sensitivity	0.310	0.356	0.264	0.310
Exposure	0.513	0.493	0.515	0.507
LVI-IPCC	0.046	0.039	0.033	**0.039**

triangle diagram. Particularly, the analysis results indicate that factors associated with health, knowledge, skills, land area, finance, climate change and environmental pressure had a greater negative effect in Tra Vinh than in Can Tho.

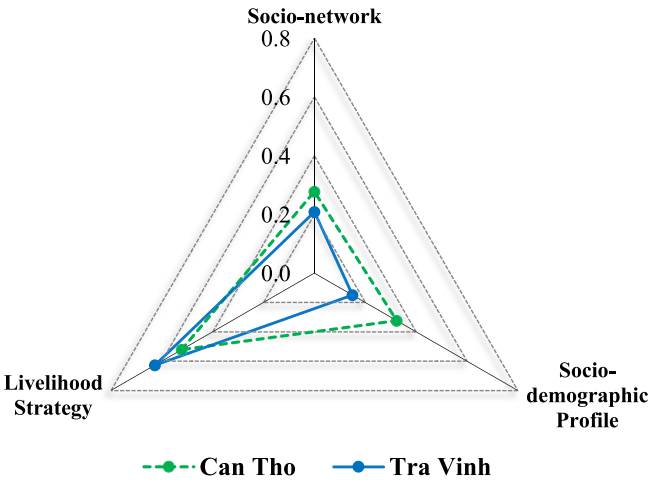

Fig. 4. Vulnerability triangle of factors contributing to farmer adaptability in Can Tho City and Tra Vinh Province.

Adaptability plays an important role in shaping the vulnerability of household livelihoods to any extent of exposure and sensitivity (Qaisrani et al., 2018). For each component of adaptability presented in Table 1, we synthesized characteristics of the research areas in order to accurately quantify the adaptability of farmers in each location to the impact of climate change and environmental pressures. Fig. 4 and Table 7 thus present and compare the adaptability of rice farmers in Tra Vinh and Can Tho.

The extent of social networks in the two study areas was characterized by farmers' ability to connect with and obtain support from local authorities and traders. Tra Vinh farmers indicated regularly connecting with and receiving support from local authorities, to a greater extent than those in Can Tho. This yielded better social networking estimates for Tra Vinh than in Can Tho (respectively, 0.150 versus 0.324). In Can Tho, 52.3% of respondents stated that they did not regularly exchange information with local officials and 61% said they had not received support, compared to 9.6% and 41.4%, respectively, in Tra Vinh. However, weak linkages with traders were seldom reported in either study area (less than 3% of respondents reported weak linkages with traders).

Vulnerability in relation to socio-demographic characteristics was higher in Tra Vinh than in Can Tho (0.326 versus 0.185), due to the greater proportion of female-headed households in the former. In Tra Vinh, some 33.7% of households were female-headed, compared to only about 5.6% in Can Tho. In regard to the number of dependents in households, there was no significant difference between the two study areas (the average number of dependents per household was 2.1 in Can Tho and 1.8 in Tra Vinh).

The vulnerability of farmers' livelihood strategies was assessed as high in both areas (0.627 in Tra Vinh and 0.522 in Can Tho). This was mainly due to the contribution of five factors: (i) the high proportion of farmers who only grew rice (in Can Tho 92% and in Tra Vinh 82%); (ii) the lack of investment in production equipment in the past five years (reported by just 22% of farmers); and (iii) the inability or unwillingness of farmers to expand their rice-growing area (72% of farmers in Can Tho and 81% in Tra Vinh). As for the difference in vulnerability between Tra Vinh and Can Tho, (iv) farmers in Tra Vinh were more aware of the dangers posed by natural disaster (54%) compared to farmers in Can Tho (12%) and (v) the proportion of farmers involved in non-agricultural activities was lower in Can Tho than in Tra Vinh (8.3% compared to 17.3%).

4.3. Environmental pressures from farmers' perspective

The calculated LVI and LVI–IPCC indicate that the livelihoods of rice farmers are being compromised by climate change and environmental pressures. Notably, different environmental problems were reported by farmers in the two study areas, due to differences in geography and farming characteristics. Figs. 5 and 6 present perceptions of the interviewed farmers regarding temperatures, water pollution, quantities of alluvium, effect of drought on availability of production water, groundwater availability, riverbank erosion and saltwater intrusion due to climate change and environmental pressures.

Rice farmers in Can Tho were highly aware of the increasing impacts of higher temperatures, water pollution, sediment shortages and water shortages due to drought (Fig. 5). Specifically, 90% of the interviewed farmers there observed that temperatures had increased in the past five years, with the largest proportion of farmers reporting increases in Thot Not (94.4%). Moreover, most farmers (over 95%) believed that temperatures would continue rising in the future. Water pollution was perceived as less of a current problem by farmers near rivers; but it was considered a problem likely to increase in the future. In Thot Not, 47.2% considered water pollution a problem now, while 62.92% expected it to become more of a problem in the future. On the other hand, more than 50% of those interviewed reported sediment shortages as a problem. Although shortages of water for agricultural production received little attention in the past five years, those

Table 7
Contribution of assessed components to the adaptability of Can Tho and Tra Vinh farmers.

Major components	Sub-components	Contribution (%)		LVI	
		Can Tho	Tra Vinh	Can Tho	Tra Vinh
Social network	Fraction of households (Hhs) lacking connection to local authorities	52.3	9.6	**0.324**	**0.150**
	Fraction of Hhs lacking support from local authorities	61.0	41.4		
	Fraction of Hhs reporting weak links with agricultural extension units	12.9	8.4		
	Fraction of Hhs reporting weak links with traders	3.2	2.3		
Socio-demographic profile	Proportion of dependent household members	77.3	87.7	**0.185**	**0.326**
	Fraction of female household heads	5.6	33.7		
Livelihood strategy	Fraction of Hhs that did not diversify crops (only rice)	91.7	82.5	**0.522**	**0.627**
	Fraction of Hhs that did not invest in production equipment in past five years for climate change mitigation	77.3	78.0		
	Fraction of Hhs not engaged in non-agricultural activities	8.3	17.3		
	Fraction of Hhs reporting experiencing more impacts of natural disasters and climate change in past five years	11.9	54.2		
	Fraction of Hhs reporting they would not expand lands for production	71.7	81.3		

interviewed in Can Tho (with its middle-delta geography) expected this to become a larger problem in the future (reported by about 50% of farmers in Vinh Thanh and 52.54% in Co Do).

In general, the majority of farmers in Can Tho had not experienced, or not noticed, changes in their livelihoods due to the impact of groundwater shortages and riverbank erosion. About half of the interviewed households (167 of the 300 interviewed in Can Tho) expressed concern about groundwater depletion, but very few realized that groundwater resources were decreasing (2.5% and 5%, respectively). Riverbank erosion was of less concern, mentioned by under half of those interviewed. In Co Do and Vinh Thanh, 15.1% and 31.4% of respondents, respectively, considered riverbank erosion a problem that would increase in the future.

Farmers in Tra Vinh were more concerned than those in Can Tho about the effects of climate change and environmental pressures. Over 80% of those interviewed in Tra Vinh reported that temperatures, drought, saltwater intrusion, sediment shortages and water pollution had increased in the past five years and would likely continue to worsen in the future (Fig. 6). Saltwater intrusion was the primary concern, especially increased impact of salinity and drought in the future (mentioned by 98% of the farmers interviewed). Some 95% of farmers said that rising temperatures and drought had increasingly impacted their livelihoods. On the other hand, all farmers interviewed in Cang Long and Cau Ngang districts (100%), and more than 90% of farmers in Duyen Hai district indicated an awareness to the reduction of sediment each year. Additionally, the problem of water pollution was said to be on the rise. It affected 90% of the households interviewed in Tra Vinh. Interestingly, the interviewed farmers were largely unaware of the effect of riverbank erosion on rice production livelihoods (78% to 100% of those interviewed indicated no awareness of this problem). Indeed, only 20 of the 300 farmers knew about this issue, and these were close to eroded areas.

The problem of groundwater shortages was of little concern in Can Tho; however, farmers in Tra Vinh were more concerned about this issue. Some 32% of farmers in Tra Vinh (98 of the 300 farmers interviewed) noted a change in groundwater availability, with 50% of the farmers interviewed in Cang Long being aware of decreases in groundwater. Still, only 30% of the farmers interviewed in Cang Long believed that groundwater depletion would worsen in the future, and 33% of farmers in the remaining two districts of Tra Vin were concerned about this issue for the future.

5. Discussion

5.1. Reflections on farmers' adaptive capacity

The findings suggest that rice farmers in the study area are vulnerable to climate change and environmental pressures, with a greater extent of livelihood vulnerability on the coast (Tra Vinh) than in the middle delta (Can Tho) (see Figs. 2 and 3). Our results are consistent with previous studies assessing the vulnerability of livelihoods in coastal areas of Bangladesh (Toufique and Yunus, 2013) and elsewhere in the VMD (Ho et al., 2021a,b; Thuy and Anh, 2015; Tran et al., 2020, 2019a,b).

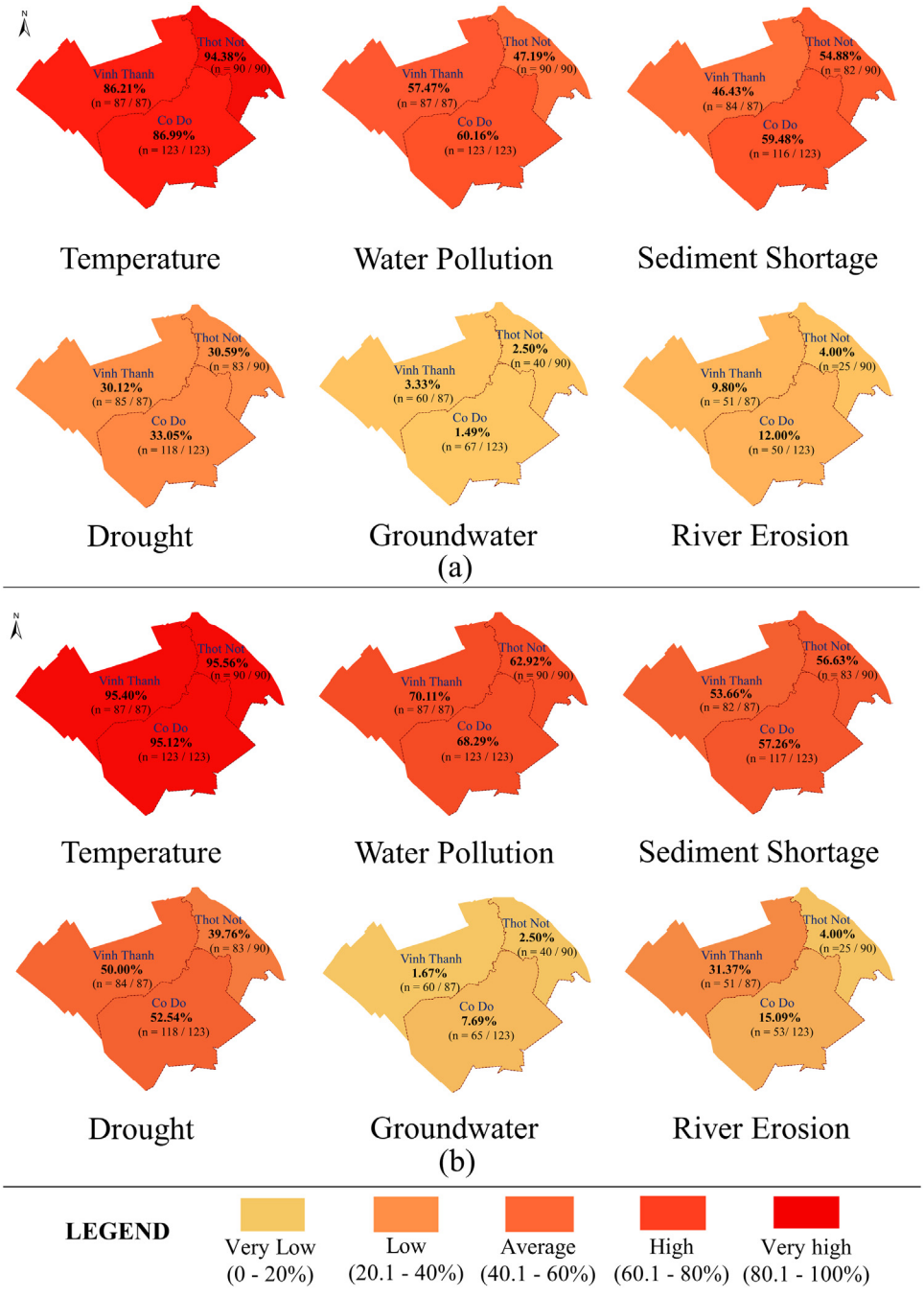

Fig. 5. Perception of Can Tho farmers of the severity of problems under the impact of climate change and environmental pressures (a) in the past five years and (b) into the future.

The severe impacts of the drought and saltwater intrusion events of 2015–2016 and 2019–2020 can be taken as empirical evidence of the livelihood vulnerability of coastal rice farmers. In these years, thousands of coastal rice farmers lost part or all of their rice harvest and associated income (Lee and Dang, 2019; Nguyen et al., 2020, 2018; Nguyen, 2017a; Tran et al., 2021a.). In particular, coastal farmers have a very small land area for rice, though their livelihoods are completely dependent on rice production. Half of the surveyed farmers in Tra Vinh owned less than 1 ha of rice land, though more than 82% of them had rice-based livelihoods. This makes them highly vulnerable to disaster or shock, should it occur. Can and Vo Hong (2019) also reported that the majority of coastal farmers had less than 1 ha of agricultural land. Their findings and our results here indicate that coastal farmers have low adaptive capacity to climate change, and they face enormous challenges in crop transformation and diversification (Harvey et al., 2014; Ngo et al., 2022). However, our results revealed

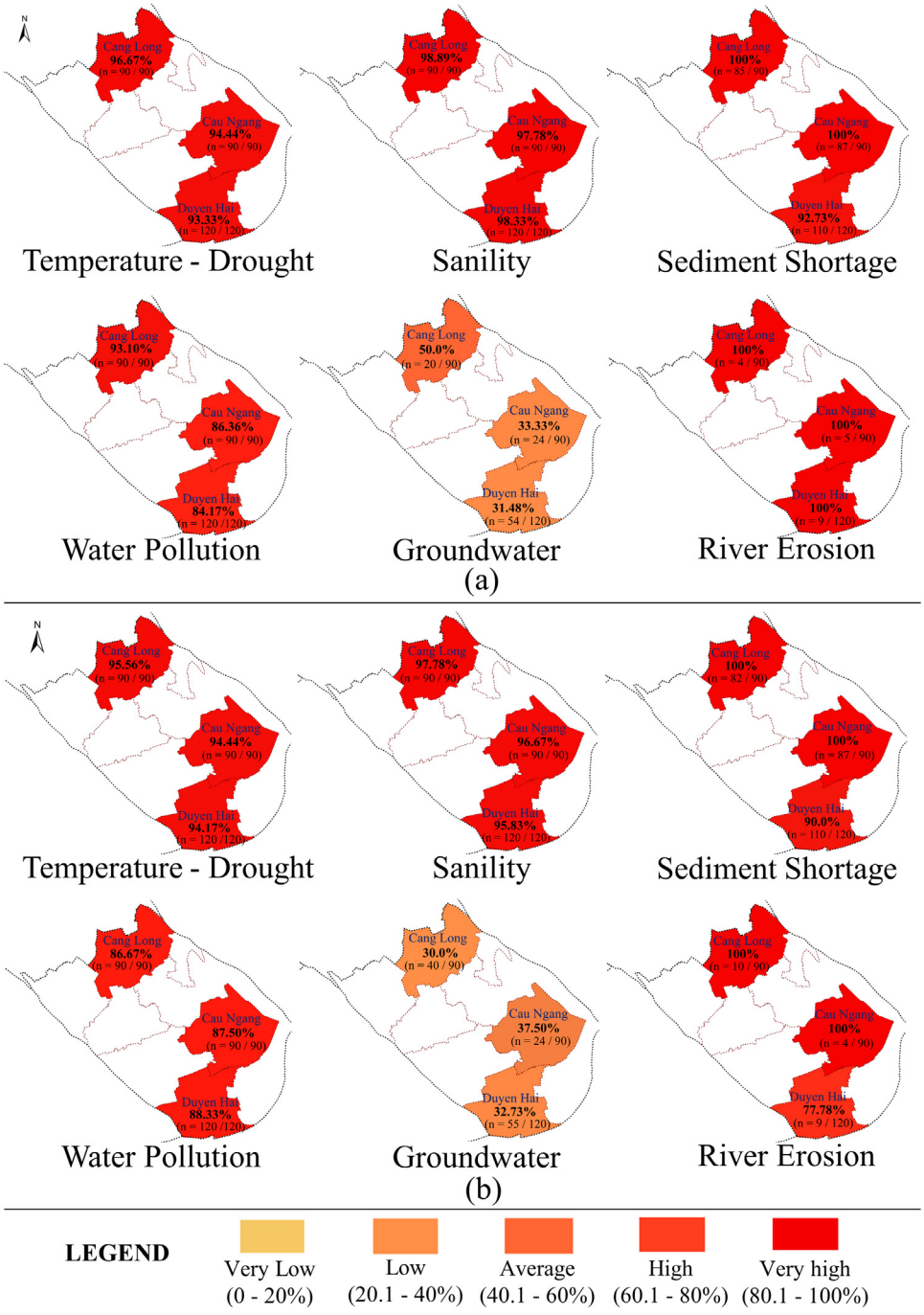

Fig. 6. Perception of Tra Vinh farmers of the severity of problems under the impact of climate change and environmental pressures (a) in the past five years and (b) into the future.

higher social networking found in Tra Vinh compared to Can Tho because farmers in Tra Vinh have had more regular and urgent support from local authorities due to the higher impacts of salinity intrusion.

The adaptive capacity of rural households is often determined by their ability to mitigate risks (Murken and Gornott, 2022; Smit and Skinner, 2002). Although Tra Vinh's rice farmers had a higher adaptive capacity (0.379 in Tra Vinh versus 0.334 in Can Tho), the province's unfavourable geography results in greater exposure and lower ability to respond to natural disasters. In other words, the livelihood vulnerability of farmers in Tra Vinh is greater than that in Can Tho City. Moreover, the high proportion of female-headed households in Tra Vinh (33.7% compared to 5.6% in Can Tho) increases the vulnerability index of Tra Vinh farmers to environmental pressures. A similar result was reported for Trinidad and

Tobago by Shah et al. (2013). The frequency of natural disasters also affects farmers' adaptive capacity, sensitivity and exposure level (Ahsan and Warner, 2014). Farmers in Tra Vinh reported a higher disaster awareness than those in Can Tho because they had more experience in responding to natural disasters. This finding suggests that crop production in Tra Vinh is under greater threat from environmental pressures than in Can Tho, which has adverse effects on yields and profit from rice cultivation.

Climate change has amplified the livelihood vulnerability of rice farmers in the Mekong Delta, but the causes of vulnerability may vary geographically. Saltwater intrusion in the coastal area and reduction of alluvium in paddy fields (located near rivers) have both been identified as sources of livelihood vulnerability here (Bergqvist et al., 2012; Kondolf et al., 2018). In fact, the current study found saltwater intrusion to be the primary challenge affecting coastal farmers' livelihoods, while water pollution and alluvium shortages were perceived as main challenges in the Can Tho middle-delta region (see Fig . 5 and 6). The construction of dike systems for triple rice cultivation and to prevent flood and salinity intrusion has resulted in soil degradation and reductions of alluvium, leading to lower rice productivity (Huu, 2011). To compensate for reduced alluvium and to increase productivity, farmers have used more chemical fertilizers and pesticides, leading to the additional problems of soil and water pollution (Nguyen, 2017b). Hence, more environmentally-friendly fertilizers should be considered to avoid soil degradation exacerbated by climate change and other environmental pressures. For instance, microalgae, sa bio-fertilizer for rice cultivation, has been found to adapt effectively to the changing climate with their nitrogen fixation ability while also benefiting the plants and soil (Dineshkumar et al., 2018; Toan et al., 2021). Nanofertilizer is another promising alternative for sustainable rice farming systems that can simultaneously assist in ecological restoration (Al-Mamun et al., 2021; Jiang et al., 2021; Pandey, 2018).

Calculated LVI and LVI–IPCC values were quite high in the Cau Ngang district of Tra Vinh Province (LVI = 0.420 and LVI–IPCC = 0.039) as the district is located adjacent to the Co Chien River and the East Sea (see Fig. 1). Due to its geographical features, the livelihoods of farmers in Cau Ngang are often threatened by saltwater intrusion. This particularly affects farmers in places adjacent to the sea. In the dry season, saltwater intrudes far inland via the Co Chien River and underground aquifers. This is considered to be the root cause of the gradual demise of traditional farming and, indeed, all available local livelihoods (Hossain et al., 2012).

5.2. Limitations and future outlooks

This study used the LVI and LVI–IPCC to investigate rice farmers' perceptions of the changing climate and environmental pressures, and the impacts that these have on their rice farming activities. Although rice farmers' vulnerability and adaptive capacity to climate change were explicitly determined, and differences were explored in adaptive capacity between a coastal and middle-delta region, two limitations of the research should be taken into account. First, the interviews were mostly conducted at farmers' houses, and less in the fields, which could have influenced the responses (Dung et al., 2018b,a). Though interviews at the homes of household heads is convenient for interviewers, limited observations of land cultivation could be made. On the other hand, if interviews are conducted in the field, the interviewer must compete for farmers' limited time and attention. Thus, the responses may be biased in each of the two interview situations. Second, to increase the reliability of the findings, and to obtain a more complete picture, other delta provinces should be considered (Tran et al., 2021a.). Problems related to groundwater and riverbank erosion were not widely acknowledged in our study areas, and their impacts on rural livelihoods remained unclear. Therefore, these factors were not considered as causes of livelihood vulnerability in the case study areas.

6. Conclusions

This study used two livelihood vulnerability indexes, the LVI and the LVI–IPCC to assess rice-based farmers' vulnerability and adaptive capacity in the lower area of the Vietnamese Mekong Delta. Our findings, based on interviews with 600 farmers, indicate that farmers' livelihoods in the coastal Tra Vinh Province were more vulnerable than those in the middle-delta Can Tho City. Our analyses point to several main conclusions.

First, in coastal areas, farmers have less adaptive capacity than in the middle delta; in other words, livelihoods are more vulnerable in the coastal districts than in the middle delta. Indeed, changing livelihoods to adapt to climate change and environmental pressures will be considerably more challenging in the coastal areas. This is due to the typically small arable land size of coastal farmers, and the fact that many farmers here are unable or unwilling to expand their land area, often due to their lack of experience and fear of risks associated with natural disasters. Moreover, the relatively high proportion of female-headed households in the coastal areas limits adaptability, as it constrains labour availability, among other reasons. Therefore, in the coastal regions particularly, local authorities would benefit from strategies and policies to strengthen knowledge and skills and encourage the proactive development of off-farm activities to cope with environmental pressures and salinity intrusion.

Second, increasing temperatures, more frequent drought, environmental pollution, reductions in sediment (Can Tho City) and saltwater intrusion (Tra Vinh Province) are perceived as the primary problems in the study areas. These have greatly impacted farmers' livelihoods and will become more serious in the future. Farmers' lack of concern in both study areas about groundwater extraction and riverbank erosion can be explained by the fact that the interviewed farmers had not yet been confronted with the effects of these threats at their cultivation locations. Thus, these threats had not

yet directly affected the farmers' livelihoods. However, in view of the high potential risk posed by these threats, we recommend that they be evaluated more specifically and systematically in the future, to develop sustainable livelihood strategies. For instance, future studies might focus interviews in areas already severely affected by groundwater shortages along the coast and in areas experiencing riverbank erosion, to feed into supportive measures for essential adaptations in the future.

CRediT authorship contribution statement

Dung Duc Tran: Conceptualization, Methodology, Visualization, Software, Writing – original draft. **Edward Park:** Conceptualization, Writing – review & editing. **Huynh Thi Ngoc Tuoi:** Data curation, Visualization, Writing – original draft. **Nguyen Duc Thien:** Data curation, Visualization, Writing – original draft, Writing – review & editing. **Vo Hong Tu:** Writing – original draft, Writing – review & editing. **Pham Thi Anh Ngoc:** Writing – original draft, Writing – review & editing. **Can Thu Van:** Conceptualization, Data curation. **Pham Kim Long:** Data curation, Writing – review & editing. **Huu Loc Ho:** Resources, Data curation. **Chau Nguyen Xuan Quang:** Conceptualization, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

See Table A.1.

Table A.1
Numbers of interviews regarding various environmental pressures in the study areas.

Number of interviews	Can Tho City $N = 300$			Tra Vinh Province $N = 300$		
Number of interviews (n) *in districts*	Co Do (123)	Thot Not (90)	Vinh Thanh (87)	Duyen Hai (120)	Cau Ngang (90)	Cang Long (90)
(a) In the past 5 years						
Temperature	123	90	87	120	90	90
Water pollution	123	90	87	120	90	90
Reduction of sediment	116	82	84	110	87	85
Drought	118	83	85	120	90	90
Groundwater	67	40	60	54	24	20
River erosion	50	25	51	9	5	4
(b) In the future						
Temperature	123	90	87	120	90	90
Water pollution	123	90	87	120	90	90
Reduction of sediment	117	83	82	110	87	82
Drought	118	83	84	120	90	90
Groundwater	65	40	60	55	24	40
River erosion	53	25	51	9	4	10

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