

IMPACT OF SALTWATER INTRUSION ON RELATION TO FRUIT GROWING HOUSEHOLDS IN BEN TRE, VIETNAM

Purpose. *Saltwater intrusion affected seriously the livelihood of mangosteen growers in Ben Tre, a coastal province in the Vietnamese Mekong Delta in 2016. This study assesses how saltwater intrusion influenced the livelihood vulnerability of the mangosteen households and communities.*

Methodology / approach. *This study used the United Nations' Livelihood Vulnerability Index (LVI) and a similar index from the Intergovernmental Panel on Climate Change (LVI-IPCC) using data from 196 interviewed mangosteen growers in Cho Lach district, Ben Tre province in 2016 and 2018. A total of twenty-five (25) indicators are applied to calculate the two indices, using data as exposure to saltwater intrusion and natural hazards (5), socio-demographic factors (11), and sensitivity of health, finance, and source of water for domestic use (9).*

Results. *The analysis results show that mangosteen-growing households had a medium vulnerability in 2016 and 2018 based on both indices. However, they were extremely vulnerable due to saltwater intrusion in 2016, and a high household percentage had a moderate value in the vulnerability index. They did not experience how to respond to saltwater intrusion and received a late warning on saltwater intrusion from the local authorities and media. However, mangosteen-growing households had a quick adaptive behavior to shift to new crops to improve their income in 2018.*

Originality / scientific novelty. *The study provides a set of indicators to assess the vulnerability of this low-vulnerable area based on past studies as well as the actual situation of the study area in 2016 and 2018 to determine what factors influenced the main components, LVI and LVI – IPCC. These indicators represented the characteristics of the rural households in Vietnam and other Asian countries. This research also indicated how LVI and LVI – IPCC results differently and when they should be used. The analysis identified the factors influencing the LVI and LVI – IPCC by levels of saltwater intrusion in different years of 2016 and 2018, two different severe and less severe sites, adaptive and non-adaptive households, and their interaction.*

Practical value / implications. *LVI and LVI-IPCC are good indicators for local and regional assessments on how saltwater intrusion and natural hazards affect households' and communities' livelihood and thereby how to guide them to respond promptly in such cases.*

Key words: *saltwater intrusion, natural hazards, livelihood vulnerability, income, Vietnam.*

Introduction and review of literature. Saltwater intrusion has dramatically affected the Mekong Delta of Vietnam in recent years, especially the whole Ben Tre province, one of the coastal areas in this region in 2016 [1; 2; 3; 4]. Saltwater intrusion in 2016 in Ben Tre province attacked seriously the areas that both regularly and rarely confront saltwater intrusion annually. Due to the rapid and abnormal sea level rise in the Mekong Delta during the dry season of 2016, residents in Ben Tre province were not warned of the occurrence of saltwater intrusion until it was too late. Almost all the cultivation areas were seriously damaged this year and the year after in Ben Tre.

Cho Lach is an inland district in Ben Tre province known for its tropical fruit

trees, particularly mangosteen (*Garcinia mangostana*), which is grown in the Mekong Delta and Ben Tre province. Mangosteen growers cut mangosteen trees to move to other crops, mainly planting fruit seedlings to serve Ben Tre province and surrounding provinces, resulting in a major reduction in the area of mangosteen trees in 2017–2018. Furthermore, the return on mangosteen was lower than that of other fruits such as durian, pomelo, and seedlings because mangosteen trees need 8 years to bear fruit and 12–15 years to have a good yield.

The Livelihood Vulnerability Index (LVI) was used to quantify farming households' vulnerability to climate change and variability. Vulnerability to climate change is defined by the IPCC [5] as the degree to which a system is susceptible to, or incapable of, enduring detrimental consequences of climatic change and variability [6]. Vulnerability, according to the IPCC, is a set of functions that includes potential impacts and adaptive capacity. Exposure to vulnerable populations and social sensitivity, dependence on vulnerable resources, and comprehension of resource conditions, are all possible consequences. Livelihood vulnerability can be assessed at the individual, household, and community levels [2; 7; 8; 9; 10].

The next section explains how the sub-components of livelihood vulnerability are assessed and chosen. Exposure to natural hazards or climate change are important factors affecting livelihoods, especially for households or communities heavily dependent on agricultural production or vulnerable [8; 11; 12; 13]. Many studies use livelihood vulnerability index to assess the impact of climate change, flooding, saltwater intrusion, and land and water changes on livelihood and related vulnerable factors [4; 14; 15]. The exposure of climate change can be measured by the duration of drought, saltwater intrusion, change in rainfall or temperature while changes in soil and water quality and quantity supply for irrigation [2; 16; 17; 18]. In this study, this major component is separated into two sub-components, namely the exposure to saltwater intrusion and natural hazards. The natural hazards included changes in weather or rainfall affecting fruit setting and yield of mangosteen. Besides, mangosteen growers were facing unfavorable conditions in soil quality and irrigation water supply. These were the common constraints that the mangosteen growers confronted. It is noted that saltwater intrusion was not common problem in this study site; thus, the change in saltwater intrusion in 2016 and 2018 will be a good example to see how saltwater intrusion affects their livelihood and income.

In terms of adaptive capacity, the first sub-components mostly used are the socio-demographic profile, human capital or resources of the households [8; 19]. The factors of these sub-components usually show the vulnerability of the household heads, who have the most important decisions for the households and their livelihood strategies [2; 11; 20]. In developing countries, agricultural-based households with female-head are often more vulnerable because these families often lack men, who do most of the main labor. The educational attainment and age of the household heads would have a significant impact on their decision on livelihood strategies [7]. The vulnerability to the households' labor force is the proportion of dependents, who are under 15 years old and over 65 years old. The high dependency rate has a direct

impact on livelihood strategies, household income, and expenditure [12; 21].

The second sub-components of adaptive capacity are indicators that demonstrate their reliance on agriculture or income sources that are highly vulnerable to climate and natural-environment change [1]. Households with high percentages of income from agriculture are more vulnerable when they increase their exposure to climate change or natural hazards [2; 4]. The high income diversification index, or the number of activities that generate household income, reduces the risk of dependence on only one source of income, especially on agricultural or cultivation income [4]. However, the temporary or long-term migration of the main labor force to seek non-agricultural income helps households have more income, but it also places a burden on the household's remaining labor [8; 20]. Land for production is an important resource of the household that affects the household's livelihood strategy. A large land area helps agricultural production households generate more income [1]. However, households with less land often look for non-farm activities to earn extra income. The high diversification index, especially with non-farm activities, shows that these households are vulnerable [2; 8]. The poverty rate or per capita income is an important criterion that influences livelihood strategies [8].

The third sub-component of adaptive capacity is social networks. These factors represent the social capital of the household [22; 23]. When one household is able to solve problems by themselves instead of relying on external support, it reflects their capacity to cope with difficulties. However, because of a lack of outside communication from relatives, neighbors, and local authorities, it would limit the opportunity to update information, particularly for households that may be slow to receive warning alerts to saltwater intrusion or sudden changes in weather or market prices [24]. Households with relatives involved in or participating in civil organizations would help them update good information or have better opportunities to access external support [22; 23].

Sensitivity is an indicator that reflects households' social vulnerability to their livelihood. They often include health, finance, and domestic water usage [19; 22; 25]. The first sub-component of this group is household health [9; 26]. Health characteristics of the household include the proportion of sick people in the household. A household with members that easily get sick or have chronic diseases would limit household labor or burden on household expenses. The supplementary of this factor is direct expenses to health care or annual medical costs [8; 27]. When a household is vulnerable, they can reduce it by having more members buy health insurance. It can cover most of the medical costs when patients have a health check-up or are admitted to the hospital [28].

The second sub-component of sensitivity is finance [3; 23; 29]. Financial capital is one of the most important factors that directly influences household livelihoods. According to other research [6; 20], food is the second sub-component of sensitivity. However, in the context of Vietnam, financial capacity is more relevant [8]. Access to credit or demand for formal and informal loans is an important indicator of household financial capacity [8]. This factor is extremely crucial when households

intend to adopt or invest in new livelihood strategies. Income from household activities reflects the financial capacity of the household. It should be noted that the lower the household income, the greater the vulnerability. Finally, the amount or ratio of savings to total household income shows the household's ability to accumulate capital. The positive savings indicate an increase in household assets. It is a chance for households to invest more in education, health, and land [4].

The last sub-component of sensitivity is water resources [19; 22], especially domestic water use for household activities [26]. The percentage of households using tap water or not using tap water is the first indicator [30; 31]. In addition, a number of households still use unsafe water sources for daily life, such as rivers and canals, in increasingly polluted conditions. The shortage of domestic water supply would become more serious due to the natural conditions of saltwater intrusion or drought [30].

The purpose of the study. This paper presents both the results of the combined vulnerability assessment at the household and community level by modifying the method that Hahn et al. [6] proposed. The indicators of exposure, adaptive capacity, and sensitivity were reviewed and adapted to the typical characteristics of Ben Tre province. The results of this study help households and communities assess the influence of saltwater intrusion and other natural factors, as well as their own adaptive capacity and social sensitivity in Ben Tre province. The study was conducted in early 2019 to evaluate the effects of saltwater intrusion in mangosteen growing areas in 2016 and 2018.

Methods of data collection. The basis for selecting the interview households is based on two criteria, perennial trees in the inland of Ben Tre, which was mostly not affected by saltwater intrusion in Ben Tre. The assumptions are farmers of perennial trees. They have more difficulty changing livelihood due to long time investment to the perennial trees when they got affected by the saltwater intrusion. Besides, Cho Lach district, Ben Tre province is famous with many fruit gardens and perennial trees. They have less possibility to get affected by saltwater intrusion. However, saltwater intrusion in 2016 suddenly affected and damaged many fruit gardens, including mangosteen. The survey of 196 mangosteen growers in 2019 was conducted to estimate the impacts of saltwater intrusion on income of mangosteen growers in 2016 and how they changed livelihood strategies (adaptation) in 2018. The study sites are presented in Table 1 and Fig. 1.

Table 1

Study sites and sampling size of mangosteen growers in Cho Lach district, Ben Tre province, Vietnam

Study sites	No. of households				Shifted to new crops after 2016
	Grew mangosteen in 2016 ¹	Interviewed	Affected by saltwater intrusion		
			2016	2018	
Long Thoi	260	120	112	6	57
Vinh Hoa	125	76	73	5	25
Total	385	196	185	11	82

Note. Total of mangosteen growers in five villages in Long Thoi and Vinh Hoa communes.

Source: survey in 2019.

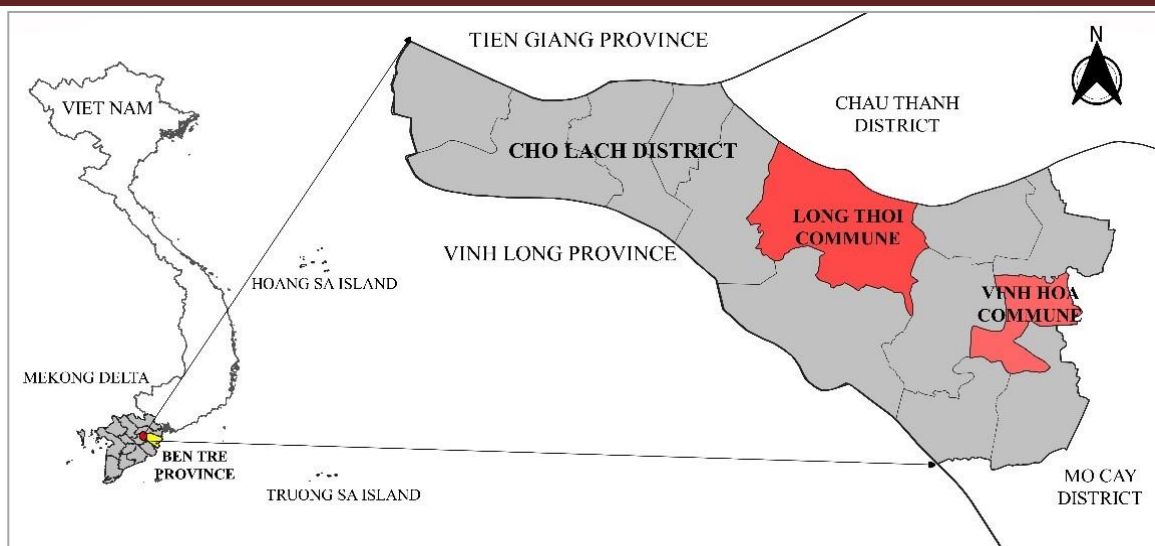


Fig. 1. Study sites of mangosteen growers in Cho Lach district, Ben Tre province

Note. Red area is interviewed communes in Cho Lach district, Ben Tre province.

Source: developed by authors.

Calculation of LVI and LVI – IPCC follows three steps. Normalization of the original values of sub-components is the first step to calculate these indices. The larger the original value, the higher the vulnerability, normalization follows formula (1). Otherwise, the original value increases, the lower vulnerable, formula (2) is applied. The value of the index ranges from 0 to 1. S_d is the original value of the sub-component, and S_{min} and S_{max} are the minimum and maximum values of the sub-components.

$$Index = (S_d - S_{min}) / (S_{max} - S_{min}) \quad (1)$$

$$Index = 1 - (S_d - S_{min}) / (S_{max} - S_{min}) \quad (2)$$

Then, formula (3) is applied to calculate the major components (M_{di}) from n sub-components. The sub-components have 3–4 indicators in this case.

$$M_{di} = \left(\sum_{i=1}^n index_{S_{di}} \right) / n \quad (3)$$

The livelihood vulnerability index (LVI) is produced using formula (4) and a weighted average of eight primary components (m). Exposure to saltwater intrusion (E1), natural hazard (E2), socio-demographic profile (AC1), livelihood strategies (AC2), social networks (AC3), health (S1), finance (S2), and domestic water use are all major components (S3). There are 2–3 indicators for each of the major components. W_{mi} is made up of several important components.

The LVI scale ranges from 0 to 1 (Table 2).

$$LVI = \left(\sum_{i=1}^m W_{Mi} M_{di} \right) / \left(\sum_{i=1}^m W_{Mi} \right) \quad (4)$$

$$LVI - IPCC = (E - AC) \cdot S \quad (5)$$

LVI, the livelihood vulnerability index, modified by the guide of IPCC [5] and Hahn et al. [6], is calculated using formula (5). The three major components include exposure to saltwater intrusion and natural hazards (E), adaptive capacity (AC), and

sensitivity (S). The major components have 2–3 indicators. The value of LVI – IPCC varies from -1 to 1 and can also be normalized from 0 to 1, similar to the LVI scale (Table 2).

Table 2

Scales of LVI and LVI – IPCC

LVI (0–1)	LVI – IPCC (-1 to +1)	LVI – IPCC (0 to 1)	Explanation
0 to 0.2	-1.00 to -0.6	0 to 0.2	No vulnerable
0.21 to 0.4	-0.61 to -0.2	0.21 to 0.4	Moderate vulnerable
0.41 to 0.6	-0.21 to +0.21	0.41 to 0.6	Average vulnerable
0.61 to 0.8	+0.21 to +0.6	0.61 to 0.8	Severe vulnerable
0.81 to 1	+0.60 to +1.0	0.81 to 1	Extremely vulnerable

Source: calculated by authors, range = (max – min) / n.

The average and balanced weight of E1 (saltwater intrusion) and E2 (natural hazards) is the exposure to saltwater intrusion and natural hazards (E). Household characteristics (human resources, AC1), livelihood strategies (factors that diminish the household’s capacity to respond to appropriate adaptive strategies, AC2), and social networks (AC3) all contribute to a household’s adaptive capacity (AC). Social sensitivity (Sensitivity, S) is determined by an average of three (3) factors: health (S2), financial capability (S2), and domestic water consumption (S3).

The T-test and multivariate regression are used to compare the major components, LVI and LVI–IPCC, of mangosteen households in Ben Tre, Vietnam, over two years (2016 and 2018), two interviewed communes (Long Thoi and Vinh Hoa), adaptive households (converted and non-converted new crops), the level of saltwater intrusion affected in 2016 (severe and less severe), and their interactions.

Results and discussion. *Exposure to saltwater intrusion and natural hazards to mangosteen households.* The level of exposure to saltwater intrusion and natural hazards consists of two groups of indicators (Table 3), namely the level of exposure to saltwater intrusion (E1), including the percentage of households affected by saltwater intrusion (E1.1) and percent of households got affected by saltwater intrusion with the same level or more severe than their neighbors (E1.2).

Table 3

The original indicators of exposure of mangosteen households in Ben Tre, Vietnam

Indicators	Year	
	2016	2018
<i>E. Exposure to saltwater intrusion and natural hazards</i>		
E1.1 Percent of households affected by saltwater intrusion	94.4	5.6
E1.2 Percent of households got affected by saltwater intrusion with the same level or more severe than their neighbor	93.4	5.6
E2.1 Percent of households perceived constraints in mangosteen cultivation related to changing weather	37.2	37.2
E2.2 Percent of households perceived constraints in mangosteen related to the water resources	19.9	19.9
E2.3 Percent of households perceived constraints in mangosteen related to the land resources	38.8	38.8

Source: composed by authors from survey in 2019.

There is a huge difference between the E1.1 and E1.2 between the year 2016 (93.4–94.3 %) and 2018 (5.6 %) due to the serious impact of saltwater intrusion in the study area in 2016. Sub-components of E2 are the constraints of mangosteen cultivation due to the natural hazards such as changing weather (E2.1), water resources (mostly related to the shortage supply of the irrigation water) (E2.2) and land resources (problem soils such as acid sulfate, degraded soils, low or up land, ..., E2.3). These are the common difficulties that mangosteen growers encountered and there is not significantly different between the year 2016 and 2018. Among the constraints of the natural hazards, farmers had more problems with soil characteristics quality (38.8 %). Next, changes in weather (erratic rain) affecting fruit setting and quality of mangosteen fruits were the top concern of mangosteen growers (37.2 %). Lastly, difficulties related to water resources related to the supply or irrigation water quality (polluted water, shortage of irrigated supply, 19.9 %). These figures showed that, this study site rarely got saltwater intrusion; even Ben Tre is a coastal province in the Mekong Delta and Vietnam.

The adaptive capacity of mangosteen households. The socio-demographic factors or human capital resources that affect household livelihood vulnerability are presented in Table 4.

Table 4

Human resources, livelihood strategies and social network of mangosteen households in Ben Tre, Vietnam

Indicators	Year	
	2016	2018
AC1. Socio-demographic profile or human capital resources	-	-
AC1.1 Percent of households with a female head of household	7.1	7.1
AC1.2 Percent of educational attainment of household heads below grade 6 (primary school)	16.3	16.3
AC1.3 Percent of age of household heads higher than 60	23.5	27.6
AC1.4 Percent of dependency (lower than 16 and higher than 65 years old)	17.9	19.8
AC2. Adaptive capacity	-	-
AC2.1 Percent of gross income from cultivation	62.4	72.8
AC2.2 Percent of households had less than 0.5 ha of land	17.3	17.3
AC2.3 Livelihood diversification index (1/total sources of income)*	0.71	0.71
AC2.4 Percent of households with income per capita less than 1.5 million/month	50.5	30.6
AC3. Social networks	-	-
AC3.1 Percent of households received late warning on saltwater intrusion in 2016 or no guide how to reduce impacts of saltwater intrusion after 2016	18.9	18.9
AC3.2 Percent of households with no member involving in local organizations	77.0	77.0
AC3.3 Percent of households seldom got support from relatives, local authorities or neighbors when suffering to difficulties	75.0	75.0

Note. *The number of income sources are from 1 to 4 while minimum number of income-generating activities of the household is 1 and the maximum is 4 from 6 income sources of the households, so AC2.3 will range from 0.25 – 1 with the value of 1 being that the household has only 1 activity.

Source: composed by authors from survey in 2019.

The proportion of female-headed households is not high (7.1 %). However, female-headed households are mostly husband-dead or unmarried, so these households are more vulnerable than other households. In Vietnamese culture, mainly males are the heads of households, and landowners too, so in general, the higher the percentage of female heads, the more socially vulnerable they are. In addition, the age and educational attainment of household heads have a great influence on their livelihood adaptive capacity to both saltwater intrusion and socio-economic changes. Lastly, dependency ratios are also an important factor affecting human capital. There was not much change in human resources between the year 2016 and 2018. However, income and sources of income improved significantly in 2018.

Sources of household income are divided into six groups (Table 5). They are income from cultivation (mangosteen, pomelo, fruit seedlings, and other fruits); livestock (swine, chicken, duck, and goat); civil servants (local organizations, departments, and agencies), services (vehicle repairs, motorcycle taxis, baby sisters and selling lottery tickets), hired labor (agricultural and non-agricultural) and income from relatives. Households had 1 to 4 livelihood activities. The average number of income-generating activities of the household ranges from 1 to 2.5. In 2016, due to the strong influence from saltwater intrusion, more households participated in services and hired labor relatives 2018. In addition, more households had income from livestock in 2018. Households tend to supplement income from temporary services, hired labor, income from relatives, and livestock when income from cultivation decreases. However, this transformation is still very slow among fruit-growing households as their gross income was higher and more stable than that of rice-growing households in this and other studies [1; 4]. Mangosteen households also had less labor than rice households.

Table 5

Livelihood activities of mangosteen households in Ben Tre, Vietnam

Livelihood activities	Year			
	2016 (n = 196)		2018 (n = 196)	
	No. HHs	%	No. HHs	%
Cultivation	196	100.0	196	100.0
Husbandry	22	11.2	25	12.8
Civil servants	14	7.1	14	7.1
Services	25	12.8	27	13.8
Hired labor	24	12.2	20	10.2
Income from relatives	49	25.0	47	24.0

Note. HHs = Households.

Source: composed by authors from survey in 2019.

Regarding indicators affecting the vulnerability of livelihood strategies, the percentage of household income mainly from cultivation in 2016 (62.4 %) and 2018 (72.8 %). Due to the high ratio of cultivation income to total household income, households were seriously affected by saltwater intrusion in 2016. The average monthly income of mangosteen growing households is 5.16 million VND/month (2016) and 6.88 million VND/household/month (2018). Therefore, the rate of income

per capita of less than 1.5 million VND/month is very high in 2016 (Table 6). It is noted that 1.5 million VND per month per person is the poverty line in rural areas in Vietnam [8]. A household with a land area of less than 0.5 ha is considered a household with little land in the locality, so this is an indicator that easily leads to vulnerability to the household's livelihood.

Table 6

Characteristics of household labor and income of mangosteen households in Ben Tre, Vietnam

Parameters	Year					
	2016			2018		
	Mean	Median	STD	Mean	Median	STD
1. Number of members (person/household)	3.1	3.0	1.3	3.1	3.0	1.3
2. Number of labors (person/household)	2.5	2.0	1.2	2.5	3.0	1.3
3. Number of dependents (person/household)	0.5	0	0.8	0.6	0	0.8
4. Total income (million VND/household/year)	61.9	44.3	58.9	165.8	82.6	276.0
5. Income per capita (million VND/person/month)	1.8	1.4	1.7	4.8	2.5	7.7
6. Income per labor (million VND/person/month)	2.0	1.4	2.1	5.0	2.5	7.9

Note. STD is the standard deviation.

Source: composed by authors from survey in 2019.

Farmers with strong social networks or social capital can use social media to keep up with local information such as local news, weather, and market pricing. In fact, many households pumped salinity water into their fruit gardens after receiving information about saltwater intrusion late in early 2016. Following the saltwater intrusion in 2016, the community organized a number of initiatives to assist residents with saltwater intrusion forecasts and how to mitigate the effects of saltwater intrusion. Despite the fact that the percentage of households who did not receive information concerning saltwater intrusion was 18.9 % in both 2016 and 2018, the number of houses that did not receive information differed between the two years. The majority of households said no one in their family worked for the government, non-profits, or municipal governments (77.0 %). They were socially susceptible, as evidenced by this indicator. Furthermore, when they are in difficulty, they rarely seek assistance from strangers. These families were either able to solve their difficulties on their own or lacked the necessary links with other people or organizations to receive immediate help. Mangosteen growers were really shocked when they were affected by saltwater intrusion in 2016. However, they had experienced how to deal with it and were very careful when pumping water into their gardens, as explained by the interviewers in 2019.

Sensitivity of mangosteen households. The sensitivity on health has three sub-components, one of which is the ratio of people in the household who did not buy health medical insurance to total household members (S1.1, 7.0 %), implying that 93.0 % of household members had medical health insurance (Table 7). Vietnam has programs in place to assist the poor, such as encouraging people to purchase medical

health insurance. The average annual treatment cost (S1.3, 1.8 million VND/household/year) and the percentage of household members with chronic diseases (S1.2, 14.8 %) are both low-vulnerable. The average cost of treatment for the entire household does not include payments for medical examinations and medications when the household is hospitalized and has health insurance. The average cost of treating diseases per household per year is 1.8 million VND. Households whose members are hospitalized or frequently get sick members, on the other hand, pay around 12 million VND each year.

Table 7

Characteristics of sensitivity of mangosteen households in Ben Tre, Vietnam

Indicators	Year	
	2016	2018
S1. Health	-	-
S1.1. Percentage of members without health insurance/total number of members	7.0	7.0
S1.2. Percentage of households with people suffering from frequent illnesses or chronic diseases	14.8	14.8
S1.3. Treatment expenditures per family per year (million VND)	1.8 (2.2)	1.8 (2.2)
S2. Finance	-	-
S2.1 Percentage of households lacking capital for production	22.4	22.4
S2.2 Total household income (million VND/household/year)	61.9 (58.9)	165.8 (276.0)
S2.3 Percentage of households with no savings/no money accumulated from income	82.1	82.1
S3. Source of water for domestic use	-	-
S3.1 Percentage of households using river and canal water for domestic use	70.9	70.9
S3.2 Percentage of households affected by domestic water due to saltwater intrusion	13.5	0
S3.3 Percentage of households not using tap water	49.0	49.0

Note. Figures in the parenthesis are standard deviation.

Source: composed by authors from survey in 2019.

In terms of financial capacity, this is a particularly important factor for farm households in Vietnam. Financial capacity to contribute and the reproduction and adjustment of livelihood strategies when affected by saltwater intrusion. According to the interviews, 22.4 % of households said that they have difficulty finding capital for production (S2.1). As a result, following the 2016 saltwater intrusion, these households have limited ability to shift to new crops, particularly mangosteen. Household income is an important indicator that affects the household's ability to reinvest and affects basic household expenditures (S2.2). However, households are less likely to accumulate (saving or investing) (S2.3).

The supply of domestic water is a unique factor that affects the everyday lives and health of the mangosteen households (S3). Domestic water from surface water and groundwater that has not been treated or is simply handled in the home is still used by up to 70.9 % of households. To save money on tap water, many households

mix the use of tap water with river / well water for residential use. In comparison to many Mekong Delta rural communities, the percentage of households using tap water was 49.0 %, which is considered low. Saltwater intrusion affected domestic water sources in 13.5 % of households in 2016, and when the family was not affected by saltwater intrusion in 2018, the household was not affected by domestic water sources.

Livelihood vulnerability index of mangosteen households. The LVI computation reveals that saltwater intrusion increased the value of LVI in 2016 (0.43) compared to 2018 (0.35) (Table 8). Because the majority of household members have health insurance and the fraction of households with chronic diseases is minimal, health sensitivity is low to moderate. However, as a restriction, the average number of household members is 3.1, which is low in comparison to other research in Vietnam and the Mekong Delta [1; 2; 4]. Domestic labor is required for livelihood shifts, while agricultural hired labor is becoming increasingly rare. Furthermore, the value of LVI was unaffected by human capital, the characteristics of family heads, or dependency. The mean of the key components, as well as the range of variation (standard deviation), are displayed in the Table below. The major contributors of LVI of mangosteen households are presented in Fig. 2.

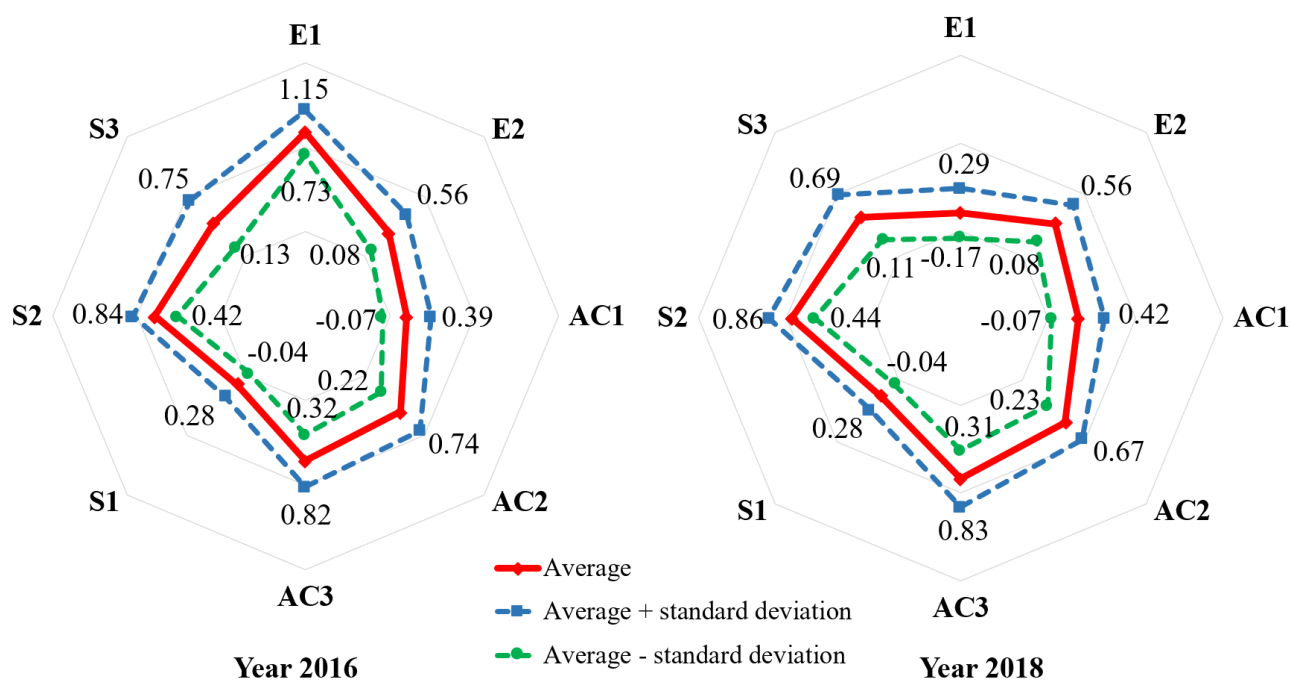


Fig. 2. Major contributors of LVI of mangosteen households in Ben Tre, Vietnam

Note. Scale explanation in Table 2.

Source: developed by authors from the survey in 2019.

The LVI–IPCC level in 2016 was lower than in 2018, and the LVI–IPCC level in 2018 was negative, indicating that livelihoods were less vulnerable to saltwater intrusion and natural hazards (Table 8). In other words, in 2016, saltwater intrusion and natural factors were the main causes of livelihood vulnerability. However, in 2018, the consequences of low livelihood capacity and natural hazards will reduce

LVI and LVI – IPCC. Despite the fact that livelihood vulnerability was not high, many households were severely or very exposed as a result of sick people, investments in new crops that did not pay off, or a small land area. As a result, the LVI – IPCC value was either extremely high or critically susceptible (Fig. 3). Demonstrations Fig. 2 and 3 depict the variability of eight important LVI and LVI – IPCC components. They are crucial pieces of knowledge for understanding the significance of LVI and LVI – IPCC.

Table 8

Major contributors of LVI and LVI – IPCC of mangosteen households in 2016 and 2018

Indicators	Year					
	2016			2018		
	Mean	STD	Ranking	Mean	STD	Ranking
E1	0.94	0.21	Extremely severe	0.06	0.23	No
E2	0.32	0.24	Moderate	0.32	0.24	Moderate
AC1	0.16	0.23	No	0.18	0.24	No
AC2	0.48	0.26	Average	0.45	0.22	Average
AC3	0.57	0.25	Average	0.57	0.26	Average
S1	0.12	0.16	No	0.12	0.16	No
S2	0.63	0.21	Severe	0.65	0.21	Severe
S3	0.44	0.31	Average	0.40	0.29	Average
LVI	0.43	0.09	Average	0.35	0.09	Moderate
E	0.57	0.17	Average	0.21	0.17	Moderate
AC	0.39	0.15	Moderate	0.39	0.14	Moderate
S	0.40	0.15	Moderate	0.39	0.14	Moderate
LVI – IPCC	0.07	0.10	Average	-0.06	0.09	Average

Notes. STD = Standard deviation.

Scale explanation in Table 2.

Source: composed by authors from survey in 2019.

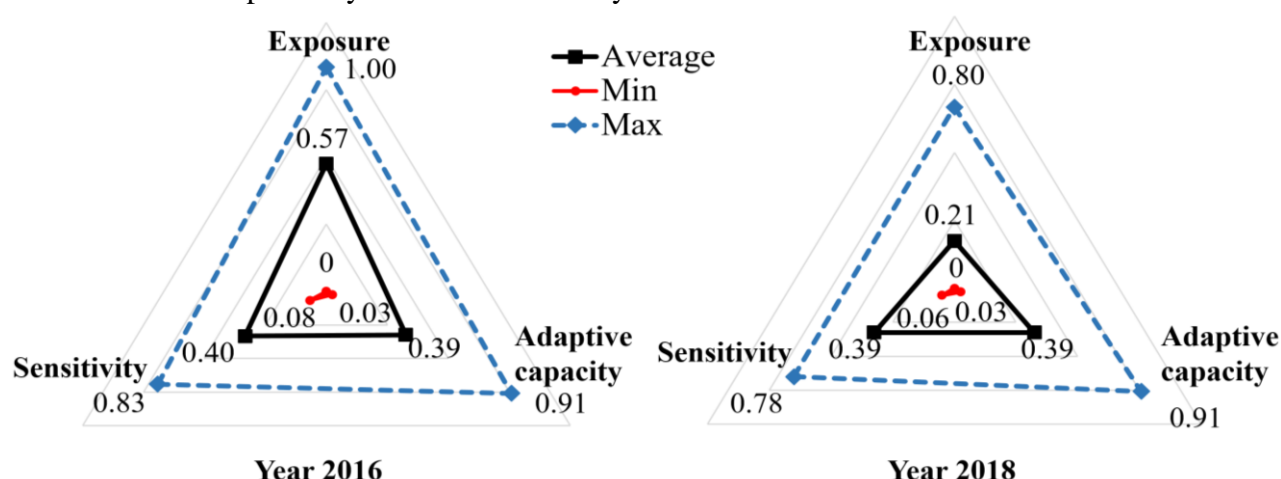


Fig. 3. Major contributors of LVI – IPCC of mangosteen households in Ben Tre, Vietnam

Note. Scale explanation in Table 2.

Source: developed by authors from survey in 2019.

Comparison analysis among major components, LVI and LVI – IPCC of

mangosteen households. T-test and multivariable regression results compare major components, LVI and LVI-IPCC indices between the two interviewed communes, households with and without crop conversion after 2016, and areas affected by less and more saltwater intrusion between 2016 and 2018 (Tables 9 and 10). Due to the impact of saltwater intrusion in 2016, the LVI and LVI – IPCC in 2016 were higher than those of mangosteen growers in 2018. In addition, households that have changed their livelihoods after 2016 have significantly improved their income in 2018, so their LVI is less vulnerable than those that have not.

Table 9

Major components, LVI and LVI – IPCC of mangosteen households in Ben Tre, Vietnam

Parameters	Communes		Shifted to new crop after 2016		Affected by saltwater intrusion		Total	Ranking
	Long Thoi	Vinh Hoa	Yes	No	Severe	Less severe		
Exposure (E)								
2016	0.58 ^a	0.56 ^a	0.57 ^a	0.56 ^a	0.60 ^{bbb}	0.44 ^{aaa}	0.57	Average
2018	0.22 ^a	0.21 ^a	0.20 ^a	0.22 ^a	0.23 ^{bb}	0.16 ^{aa}	0.21	Moderate
Adaptive capacity (AC)								
2016	0.41 ^{aa}	0.36 ^{bb}	0.37 ^a	0.40 ^b	0.38 ^a	0.43 ^b	0.39	Moderate
2018	0.40 ^{aa}	0.36 ^{bb}	0.37 ^a	0.40 ^b	0.38 ^a	0.41 ^a	0.39	Moderate
Sensitivity (S)								
2016	0.35 ^{aaa}	0.47 ^{bbb}	0.38 ^a	0.41 ^b	0.40 ^a	0.37 ^a	0.40	Moderate
2018	0.34 ^{aaa}	0.47 ^{bbb}	0.36 ^{aaa}	0.41 ^{bbb}	0.39 ^a	0.38 ^a	0.39	Moderate
LVI								
2016	0.42 ^a	0.44 ^a	0.41 ^a	0.44 ^b	0.43 ^a	0.41 ^a	0.43	Average
2018	0.34 ^a	0.37 ^a	0.33 ^{aaa}	0.37 ^{bbb}	0.35 ^a	0.35 ^a	0.35	Moderate
LVI-IPCC								
2016	0.06 ^{aa}	0.09 ^{bb}	0.08 ^a	0.07 ^a	0.09 ^{bbb}	-0.00 ^{aaa}	0.07	Average
2018	-0.06 ^a	-0.07 ^a	-0.06 ^a	-0.07 ^a	-0.06 ^{bb}	-0.10 ^{aa}	-0.06	Average

Note. Means with the same letter to a, aa, and aaa are not statistically significant at 10 %, 5 %, and 1 %, respectively, between households from the two interviewed communes, households with and without crop conversion after 2016, and households affected by saltwater intrusion severely and less severely (less than 40 % of cultivation areas are affected by saltwater intrusion).

Source: data analyzed by authors from survey in 2019.

Both communes of Vinh Hoa and Long Thoi were similarly damaged by saltwater intrusion in 2016 and 2018. Vinh Hoa commune (0.36), on the other hand, is less vulnerable to adaptive capacity than Long Thoi commune (0.41), whereas Vinh Hoa commune (0.47) is more subject to social sensitivity than Long Thoi commune (0.35). The two communes are categorized as moderately vulnerable by the LVI and LVI – IPCC. However, in 2016, Vinh Hoa commune's LVI – IPCC (0.09) was greater than Long Thoi commune (0.06).

In 2018, households that shifted to new crops (0.33) are less vulnerable than those that did not (0.37) in the two groups of households that changed their livelihoods after 2016. Households undergoing capacity transition are also more likely to be affected. In 2016, converters had better reactions and sensitivity than

non-converters. Crop-converting households in Vinh Hoa commune are less sensitive to livelihood threats than non-converters.

Households with less than 40 % of their cultivated area affected by saltwater intrusion were classified as less severely affected by saltwater intrusion, while those with more than 40 % of their cultivated area affected by saltwater intrusion were classified as severely affected by saltwater intrusion. Between 2016 and 2018, there was no difference between severely and less severely affected families in terms of main components, LVI and LVI-IPCC. However, families that are more sensitive to saltwater intrusion and natural hazards (E) were exposed to more saltwater intrusion and natural hazards (E) in 2016, and the LVI – IPCC is also higher. Households that are more severely affected by saltwater intrusion and converted their crops are those with higher E and LVI – IPCC.

Table 10

**Factors affecting LVI and LVI – IPCC of the mangosteen households
in Ben Tre, Vietnam**

Variables	E	AC	S	LVI	LVI – IPCC
Commune (1 = Vinh Hoa, 0 = Long Thoi)	-0.01 ^{ns}	-0.08 ^{***}	0.11 ^{***}	0.00 ^{ns}	0.02 ^{ns}
Shifted (1 = yes, 0 = no)	-0.08 [*]	-0.01 ^{ns}	-0.11 ^{***}	-0.06 ^{**}	-0.02 ^{ns}
Saline (1 = severe, 0 = less severe)	0.04 ^{ns}	0.01 ^{ns}	-0.02 ^{ns}	0.00 ^{ns}	0.01 ^{ns}
Year (1 = 2016, 0 = 2018)	0.27 ^{***}	0.02 ^{ns}	-0.01 ^{ns}	0.06 ^{**}	0.08 ^{***}
Year x commune	-0.01 ^{ns}	-0.00 ^{ns}	-0.01 ^{ns}	-0.01 ^{ns}	0.03 ^{ns}
Year x shifted	0.02 ^{ns}	-0.00 ^{ns}	0.02 ^{ns}	0.01 ^{ns}	0.00 ^{ns}
Year x saline	0.09 ^{**}	-0.02 ^{ns}	0.02 ^{ns}	0.02 ^{ns}	0.05 [*]
Shift x saline	0.08 [*]	-0.06 [*]	0.07 [*]	0.02 ^{ns}	0.06 ^{**}
Shift x commune	-0.03 ^{ns}	0.07 ^{**}	0.03 ^{ns}	0.04 [*]	-0.06 ^{***}
Constant	0.19 ^{***}	0.43 ^{***}	0.38 ^{***}	0.36 ^{***}	-0.09 ^{***}
No. of observations	392	392	392	392	392
R ²	0.55	0.06	0.17	0.18	0.40
Multicollinearity	4.67	4.67	4.67	4.67	4.67
Heteroskedasticity	0.36	0.08	0.60	0.28	0.27
Autocorrelation	0.10	0.98	0.99	0.36	0.98

Notes. Figures in the table are coefficient of the regression;

*, ** and *** are significant at $\alpha = 10\%$, 5% and 1% respectively and ns is not significant at 10% .

Source: data analyzed by authors from survey in 2019.

Distribution analysis of LVI and LVI – IPCC in 2016 and 2018 shows that 54.1 % of households are rated as moderately vulnerable in 2016, while this index is 24.5 % in 2018. (Fig. 4a). Therefore, the impact of saltwater intrusion in 2016 directly affected the livelihood vulnerability rating of mangosteen growing households. If the LVI – IPCC is normalized to 0–1, the percentage of households with a range of from average to extremely in 2016 (70.4 %) is higher than in 2018 (13.8 %) because the LVI is the average of 8 sub-components while LVI – IPCC is only averaged from 3 sub-component of E, AC, and S.

The LVI – IPCC emphasizes negative or positive values that imply a greater vulnerability to saltwater intrusion and natural hazards than the adaptive capacity (Fig. 4b).

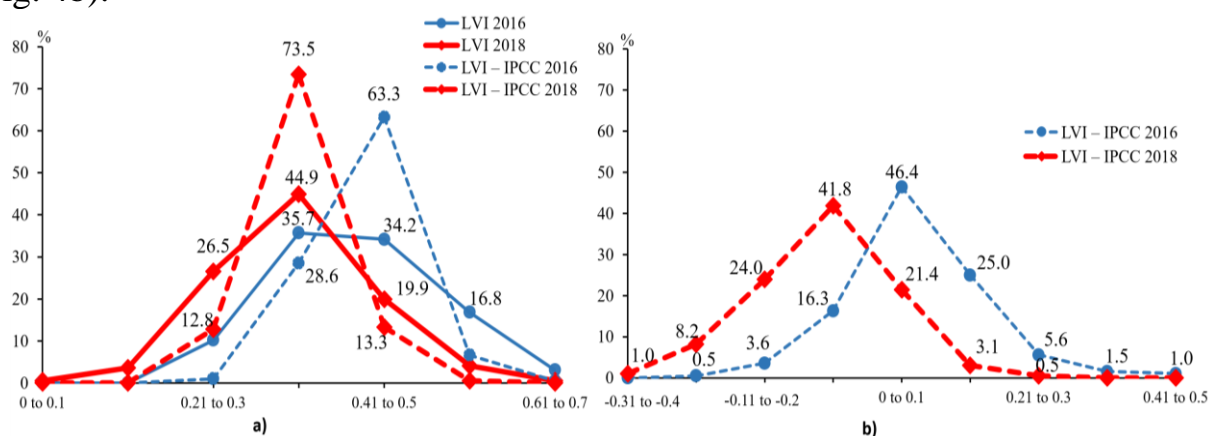


Fig. 4. LVI and LVI – IPCC among mangosteen households in Ben Tre, Vietnam
Source: developed by authors from survey in 2019.

This is an indication that the household should be aware of the effects of the exposure (saltwater intrusion and natural hazards) on their livelihood. Both LVI and LVI – IPCC can be used by local governments to identify priorities for better adaptation strategies to lower the vulnerability of households' livelihoods, particularly in areas subject to significant saltwater intrusion or natural hazards. In comparison to the LVI and LVI – IPCC values, the choice of indicators and numbers (weights, w_i) has a direct impact on the LVI and LVI – IPCC. As a result, comparing livelihood vulnerability indices across regions and countries should be done with caution [31; 32]. The characteristics of distinct sub-components in published studies demonstrate their usual livelihood risk. A few articles have estimated LVI and LVI – IPCC using different sub-component counts and weighting methodologies [3; 6; 29; 33].

Conclusions. The Livelihood Vulnerability Index is a method for determining how climatic and environmental changes affect household livelihoods. The findings from a combined LVI and LVI-IPCC analysis in 2016 and 2018 were applied to compare the effects of saltwater intrusion on livelihood changes, particularly the income of mangosteen growers, in Ben Tre province, Vietnam. Mangosteen growers' livelihoods are severely impacted by saltwater intrusion and the detrimental consequences from changing weather, water, and soil conditions. Some households changed their basic living and production conditions after 2016 and are now less exposed to livelihood changes from saltwater intrusion. Now, they also have high rates of health insurance and low rates of chronic diseases and the mangosteen households are less sensitive to social changes. Low income for some mangosteen growers, on the other hand, reduced the ability to invest and collect assets. Many mangosteen growers were shocked by the saltwater intrusion in 2016. However, it inspired mangosteen growers to be more careful in dealing with saltwater intrusion in the following years. In the short term, the growers shifted quickly to new crops which resulted in higher incomes. Mangosteen trees require several years of investment

before harvesting, and thus they would suffer a loss or damage in the long run if not responding to the new conditions. The first priority for maintaining the mangosteen region in Cho Lach, Ben Tre, is to engage technical assistance to improve the fruit quality and productivity. Also, increased skills in relation to market access will also aid mangosteen growers in maintaining their household income over time.

There is a need to monitor the saltwater intrusion and natural hazards exposure and livelihood changes to see how adaptive activities improve mangosteens' income and livelihood conditions. It would be good lessons to other fruit production areas in the Mekong Delta and Vietnam.

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