The European Journal of Development Research (2022) 34:272–302
https://doi.org/10.1057/s41287-021-00371-7

ORIGINAL ARTICLE

Factors Influencing Smallholder Rice Farmers' Vulnerability to Climate Change and Variability in the Mekong Delta Region of Vietnam

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Accepted: 29 January 2021 / Published online: 23 February 2021

Abstract
This study analyzed the effects of climate change on rice farmers' livelihoods vulnerability by using primary data elicited from 405 rice farming households in Can Tho, Dong Thap, and Tien Giang provinces in the Mekong Delta Region (MDR) of Vietnam. The Livelihood Vulnerability Index (LVI) showed that Can Tho province was the most vulnerable to climate change, followed by Dong Thap and Tien Giang provinces. In particular, the social index sub-indicator showed high vulnerability. The beta regression analysis identified seventeen significant factors influencing the susceptibility of rice farming households in the study area, such as weather information, flood occurrence, drought occurrence, access to extension services, access to credit, and cooperative membership as well as demographic variables and livelihoods related factors. The LVI result suggests the need for the government to consider raising the priority on households in Can Tho province through adaptation support to improve the resilience and adaptive capacity, especially by enhancing the social network in this area to stimulate support from local authorities and farmer groups. The regression results imply that extension services should provide adequate and timely weather information to equip the farmers to be more prepared for climatic shocks. Moreover, credit facilities with low interest rates should be made available, especially to those who are members of agricultural cooperatives.

Keywords Climate change · Rice farmer · Livelihood vulnerability index · Beta regression · Mekong delta · Vietnam

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Résumé

Cet étude analyse les effets du changement climatique sur la vulnérabilité des subsistances des agriculteurs de riz au Vietnam, utilisant des données primaires obtenues auprès de 405 ménages d'agriculteurs de riz aux provinces Can Tho, Dong Thap, and Tien Giang de la région du delta du Mekong (en anglais : Mekong Delta Region, MDR). L'indice de vulnérabilité de la subsistance (en anglais : Livelihood Vulnerability Index, LVI) montre que la province du Can Tho est la plus vulnérable au changement climatique, suivi par les provinces Dong Thap et Tien Giang. Le sous-indicateur de l'indice sociale montre notamment une vulnérabilité élevé. L'analyse de régression beta identifie dix-sept facteurs significatifs qui influencent la susceptibilité des ménages d'agriculteurs de riz dans la zone d'étude, tels que les informations météo, l'occurrence d'inondations et de sècheresses, l'accès aux services de conseil et développement agricole et au crédit, l'adhésion a une coopérative, ainsi que des variables démographiques et d'autres relationnes a la subsistance. Les résultats LVI suggèrent qu'il est nécessaire que le gouvernement considère augmenter la priorité des ménages dans la province du Can Tho en proposant des aides à l'adaptation afin d'améliorer la résilience et capacite adaptive, notamment en renforçant le réseau sociale dans cette province, pour stimuler le soutien des autorités locales et des groupes d'agriculteurs. Les résultats de la régression impliquent que les services de conseil et développement agricole devraient fournir des informations météo opportunes et adéquates afin que les agriculteurs soient plus préparés aux chocs climatiques. Par ailleurs, des facilites d'emprunt avec des taux bas devraient être mises à disposition, en particulier aux membres des coopératives agricoles.

Introduction

While climate change is a global phenomenon, its adverse impacts tend to be more severe in developing countries as their agrarian economies predominantly rely on rainfed production environments. Climate change is predicted to increase the frequency of natural disasters, and affect crop yields, food security and livelihood vulnerability (IPCC 2014; Mendelsohn 2014; Ali et al. 2017; Jamshidi et al. 2019; Tran et al. 2019a). Smallholder farming households are susceptible to the effects of changing climate due to the lack of capacities to cope with these effects and achieve sustainable livelihoods (Jamshidi et al. 2019; Azumah et al. 2020).

In the context of continued climate change and the adverse impacts of climatic events on communities around the world, livelihoods' vulnerability assessments have gained prominence from scientists. A livelihood is sustainable when it can cope with and recover from stress and shocks caused by natural disasters or human activities, and retain or improve its capacities and assets (natural, physical, human, financial, and social capital) (Scoones 1998; Chambers and Conway 1992; Allison and Ellis 2001). Vulnerability evaluation offers a framework for measuring the sociodemographic, economic, and environmental effects of climatic events on households' livelihoods, which is expected to inform adaptation strategies to enhance their resilience and mitigate climate shocks (Zarafshani and Maleki 2020; Jamshidi et al. 2019).

Vulnerability is defined in various ways, corresponding to specific contexts. According to the Intergovernmental Panel on Climate Change (IPCC) (2001), vulnerability to climate change is defined as the magnitude of exposure or risks to the adverse effect of climate change, including the inability to cope with those risks. FANRPAN (2011) defines vulnerability as the failure to survive under the negative effects of exposure to shocks related to environmental and social variation, and inadequate capability to adapt to those effects. Other scholars note that vulnerability is the magnitude of exposure, sensitivity, and adaptive capacity to any risk of groups of people, locations, or systems (Cutter et al. 2008; Nelson et al. 2009; IPCC 2007; Alhassan et al. 2019).

Based on the standard definition, the vulnerability framework is considered as a powerful framework for assessing vulnerability. Using this framework, Hahn et al. (2009) created an indicator-based vulnerability estimation approach (i.e. Livelihood Vulnerability Index) to assess the vulnerability of households to climate change in Mozambique and since then this approach has been used by scientists globally (Panthi et al. 2016; Adu et al. 2018; Oo et al. 2018; Alhassan et al. 2019; Azumah et al. 2020). The livelihood vulnerability index (LVI) is designed to provide policymakers an overview about sociodemographic, and other related factors that contribute to climate change vulnerability at a district level, provincial level, or regional level.

The Mekong Delta Region (MDR) of Vietnam is the world's third largest delta, known as one of the most productive regions for agricultural activities, accounting for 55% of national rice production and 90% of the national rice exports. In 2019, the whole country produced 42.8 million tons of rice and contributed 6.26 million tons valued at USD 2.76 billion (13.7% of total world rice exports). The agricultural sector employs 37.7% of the MDR's population who are aged 15 years and above (Anthony et al. 2015; GSO 2019). Thus, any damage caused by climate change in the MDR could adversely affect the livelihoods of million people in the MDR as well as food security around the world.

Due to the flat topography at the downstream of the Mekong river basin and a massive amount of water from the upstream, especially during the rainy season, annual floods often occur in the MDR for many days or months. In the MDR located in the tropical monsoon region, many farmers already adapted to inundations during the rainy season, which is referred to as "living with floods", and they even gained additional income aside from growing rice by catching fish and collecting other natural foods from nearby lakes and rivers. Due to climate change, however, unpredictable floods damaged over 2.7 million ha of farmland to the detriment of smallholder farming households (Nguyen et al. 2013; Minderhoud et al. 2020). Besides, the El Niño–Southern Oscillation (ENSO) phenomenon creates considerable variations in precipitation ranging from severe drought to large-scale floods. Because of the ENSO, the rainy season begins later than in years with La Niña and non-ENSO, and rainfall patterns tend to be less and erratic, which heightens the risk of drought (Clauss et al. 2018; Khong et al. 2018; Bui et al. 2019; Le et al. 2019; Nguyen et al. 2019a, 2019b). Moreover, flood and drought may take place due to human activities such as hydropower dam performance, dike construction, and ground water withdrawal, leading to yield reductions and food scarcity (Boretti 2020; Nguyen et al. 2019a, 2019b).

In this context, adoption of adaptation strategies is crucial for farmers to be able to cope with extreme climatic events. In fact, many strategies have been introduced in the MDR, such as adjusting planting calendars, changing planting techniques, managing water resources, diversifying crops and varieties, and diversifying income sources. Among those strategies, crop diversification is particularly preferred, in which they convert all or part of rice land to grow annual crops (vegetables, bean, and sweet potato) and perennial industrial trees (cocoa, coconut, banana, dragon fruit, and pineapple), while developing eco-tourism activities (Tran et al. 2019a). Otherwise, migration to non-farm sectors is the last option (Tuyen 2013; Dang et al. 2014; Smajgl et al. 2015; Ngo 2016; Vu et al. 2016; Nguyen et al. 2020).

Vulnerability of the MDR involves a combination of different issues caused by climate change and its hazards. Previous studies have examined mapping of drought and flood or the vulnerability of farmers in a selected province with specific socioeconomic characteristics and climatic conditions (Nguyen et al. 2013, 2019a; Le 2016; Tran et al. 2016). The literature on the effects of climatic events on rice farmers in the MDR tends to find the effects unspecific to ecological zones (Dang et al. 2014; Berg et al. 2017; Clauss et al. 2018; Bui et al. 2019; Boretti 2020). Lack of zone-specific knowledge of the effects of climate change on farmers' livelihoods is a barrier to the implementation of appropriate livelihood strategies for building farmers' resilience (Panthi et al. 2016; Sarker et al. 2019).

This study attempts to fill this gap in literature by analyzing the effects of climate change on rice farmers' livelihoods in the following three agro-ecological zones in the MDR: alluvial zone (Can Tho province), deep-flood zone (Dong Thap province), and saline zone (Tien Giang province). Those provinces were selected for the study because of the population of rice producers in the area and the vulnerability of the farming households to annual flood and drought. Likewise, several other factors contribute to the households' vulnerability and reduce their adaptive capacities, therefore, this study also analyzed the effects of sociodemographic, institutional and locational factors on the vulnerability of the farming households.

The objective of this study is to assess the vulnerability of smallholder rice farmers in the MDR of Vietnam to climate change and to investigate the factors influencing the vulnerability in the same area. Specifically, this study sought to answer the following research questions:

1. What is the extent of smallholder farmers' vulnerability to climate change in the MDR of Vietnam?
2. What are the factors influencing smallholder farmers' vulnerability to climate change in the study area?

The rest of this study is structured as follows. "Materials and Methods" section presents the evidence of climate change in the study area; "Methods of Analysis" section presents the materials and methods; "Results and Discussion" section presents the results and discussion; and "Conclusion" section provides the conclusions and policy implications.

Climate change in the MDR

Temperature and rainfall are the key climate variables that significantly influence agricultural production. In Vietnam, on average, temperature rose by 0.42 °C during the period 1985–2014 (Dang et al. 2014; MONRE 2016). In addition, in the MDR, it is observed that the rainfall patterns are increasingly unpredictable in terms of timing and distribution over the recent periods (Dang et al. 2014; Lee and Dang 2019a). The timing of rainfall in the MDR shifted over the last 10 years, where precipitation increased toward the end of the rainy season and decreased at the onset of the rainy season and during the dry season, indicating a high risk of inundation in the rainy season and water shortage during the dry season (Nhan et al. 2011; Dang et al. 2014; CCAFS-SEA 2016; Lee and Dang 2019b). Further, it is worth noting that the MDR received low precipitation during the 2006–2015 compared to the preceding two decades due to various impacts of climate change including El Niño events (Dang et al. 2014; Dang et al. 2019; Ngo 2016; CCAFS-SEA 2016; MONRE 2016; Lee and Dang 2019a; Lee and Dang 2019b; Do et al. 2020).

The data from the Southern Regional Hydro-Meteorological Centre of Vietnam (SRHMC) and the National Centre for Hydro-Meteorological Forecasting of Vietnam (NCHMF) showed that during the period 2002–2003, rainfall shortages happened in six provinces of the MDR with the peak values of droughts in Dong Thap and Tien Giang provinces. Also, during the period 2014–2015, extreme droughts occurred in all provinces of the MDR except Tien Giang province. These observations are consistent with the literature (Lee and Dang 2019c, 2020; Tran et al. 2020; Phan et al. 2020; Nguyen et al. 2020).

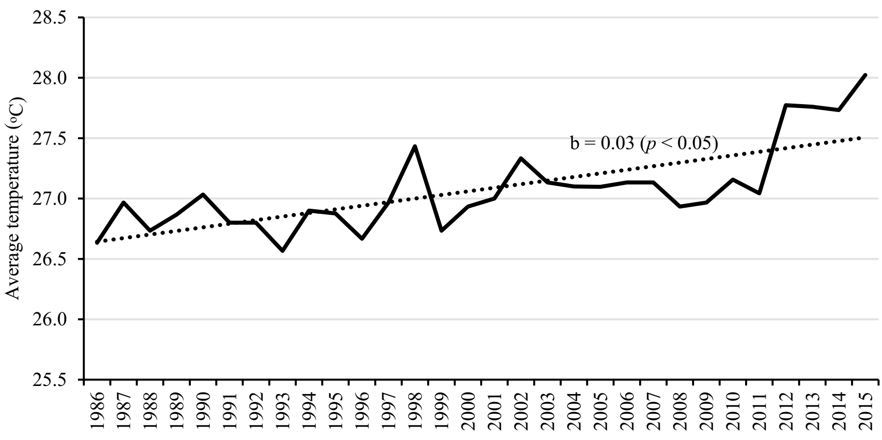

Fig. 1 Annual temperature of the study area spanning 1986–2015. *Source*: SRHMC (2012); NCHMF (2016)

Regarding the temperature trend in the study area, we analyzed historical data (Fig. 1) using regression and estimated the time trend coefficient while controlling for province fixed effects as employed by Eshetu et al. (2016). The result shows that the time trend coefficient was 0.03 ($p < 0.05$) indicating that annual temperature rose by 0.03 °C per annum on average during these three-decades.

Materials and Methods

Study Area

The study was conducted in the MDR of Vietnam. This region is characterized by the tropical monsoon climate with two distinct seasons in the year, including the rainy season (from May to November) and dry seasons (from December to April). The average annual temperature is approximately 27 degrees Celsius; the average annual rainfall is approximately 1130 mm and the average humidity is 75–80%, which is favorable for agricultural development. The MDR has a land area of approximately 40,550 square kilometers (13% of Vietnam's land area), with a population of 17.27 million, which is 18% of the national population, wherein male accounts for 49.8%, and female accounts for 50.2%. Vietnam is the 15th most populous country in the

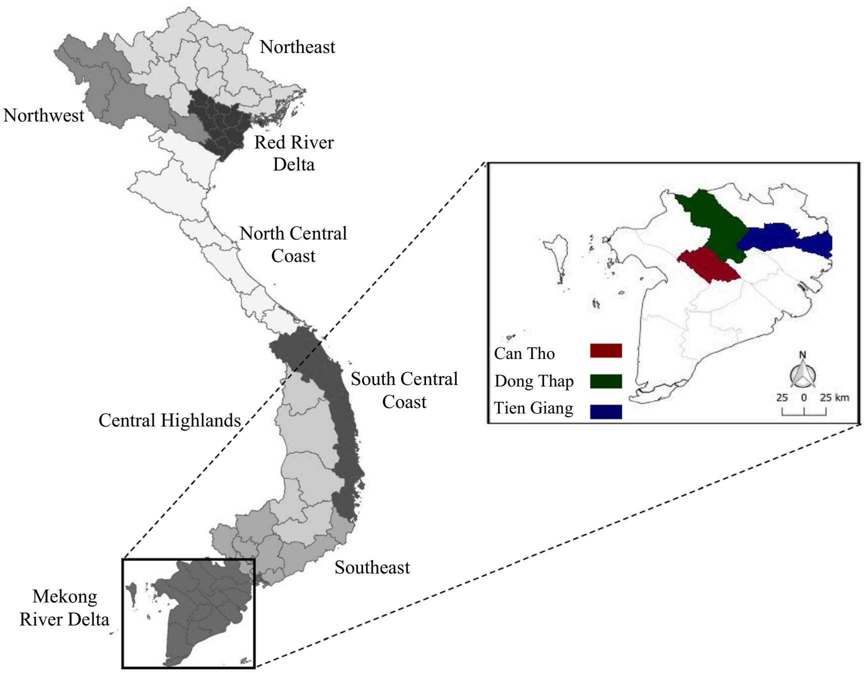

Fig. 2 Study Sites: Tien Giang, Dong Thap, and Can Tho provinces in the Mekong Delta Region. *Source*: Adapted from General Statistics Office of Vietnam (GSO 2019)

world and the 3rd in Southeast Asia. The delta contributes approximately 18% of the national GDP, primarily from aquaculture and agricultural production, with an average per capita income of approximately USD 2217 in 2018. Rice plating area is estimated at 7.47 million ha, and rice land productivity is estimated at 5.82 tons/ha. The MDR is experiencing the effects of climate change in the form of fluctuating rainfall patterns, more frequent and severe floods and droughts (GSO 2019; Tran et al. 2019b).

This study was conducted in the three provinces, which are representatives for the three distinguished agro-ecological zones, including alluvial zone (Can Tho province), deep-flood zone (Dong Thap province), and saline zone (Tien Giang province) (Fig. 2). Can Tho province is the central area of the MDR with a total population of 1.24 million residents. Dong Thap province with a total population of 1.60 million residents is one of the largest rice-producing areas, and Tien Giang province is the second largest district in the region with a population of 1.76 million residents (GSO 2011).

Sampling Technique and Data Collection

Data used for this study came from primary sources. An initial questionnaire was designed based on literature and was customized to the local context in the Vietnamese language. A pre-test was conducted with 30 randomly selected rice farmers in the study area outside the final sample, and then the final questionnaire was developed by removing ambiguities. The study assumed that household heads were largely responsible for making decisions on each or a combination of livelihood alternatives for utility maximization. Thus, household heads were the target for the interviews (Kuwornu et al. 2014). Prior to the interviews, discussions were held with community leaders to record their opinions and obtain permission for the survey. Subsequently, the leaders of the villages gathered farmers in groups for interviews. On the decided dates, an average of 30 min was spent to go through the questionnaire with each household. The survey was conducted from June 2019 to July 2019.

Table 1 Sample size determination for the study

Province	Population	Minimum sample size suggested by proportionate sampling	District	Actual sample size
Tien Giang	122,845	(122,845/350,018)*400 = 140	Cai Be	70
			Go Cong	74
Dong Thap	156,679	(156,679/350,018)*400 = 179	Chau Thanh	46
			Thanh Binh	90
			Thap Muoi	43
Can Tho	70,494	(70,494/350,018)*400 = 81	Co Do	37
			O Mon	45
Total	350,018	400		405

A three-stage sampling approach was employed. The first stage was the purposive selection of Can Tho, Dong Thap, and Tien Giang provinces in the Southwest of MDR. The second stage was the purposive selection of districts with climate change and variability, while the final stage was the proportionate random selection of rice farmers from the selected districts. The population of rice producers in the three provinces was 350,018 (GSO 2011). Following Yamane (1967) and given an assumed 5% margin of error, the minimum suggested sample size was determined as follows:

$$n = \frac{N}{1 + \mathrm{Ne}^2} = \frac{350,018}{1 + 350,018 \times (0.05)^2} = 400$$

where n denotes the sample size, N denotes the population and e denotes the margin of error. Table 1 shows the overall sample size determination. It is worth mentioning that 405 households were interviewed, implying a smaller margin of error than the 5%, thereby raising the statistical power of the analysis than initially planned.

A structured questionnaire was designed with respect to seven major components and 31 subcomponents of the livelihood vulnerability index (LVI). Farmers were asked about their livelihoods at the time of interviews (in 2019), including information about the sociodemographic profile, livelihood strategies, and water components. Several questions related to the health component (i.e. average travel time to a health facility and average dengue exposure prevention index), food component (i.e. food struggle problem), and social network component (i.e. government assistance and extension service) were asked to address the level and the frequency of households' vulnerability during the past 12 months (2018–2019). Other information related to natural disasters (i.e. numbers of severe events, warning system, and loss of crops and other assets) was covered for the past 5 years (2014–2019), especially reminding them of the weather shocks that had happened during the severe drought in 2015–2016, and flood in 2018, as severe disasters were most likely to be remembered (Hahn et al. 2009).

Methods of Analysis

Measuring Smallholder Rice Farmers' Vulnerability to Climate Change

The study applied both descriptive statistics and econometric analysis to examine the data gathered from respondents. For descriptive statistics, frequencies and percentages were used to analyze the socioeconomic characteristics of the rice farmers in the three provinces.

This study builds on previous research (Hahn et al. 2009; Gerlitz et al. 2016; Adu et al. 2018; Nguyen et al. 2018; Oo et al. 2018; Amuzu et al. 2018) to provide insights into the effect of climate change and socioeconomic and institutional factors affecting the vulnerability of rice farming households in the MDR of Vietnam. Following Hahn et al. (2009), this study adopts the integrated indicator approach, while the livelihood vulnerability index (LVI) was constructed in three selected provinces of Vietnam.

The LVI was derived from all the households selected for the study, using seven major components, namely, health (H), food (F), water (W), sociodemographic profile (SDP), livelihood strategies (LS), social network (SN), and natural disasters and climate variability (NDCV). Each major component includes several sub-components, and the values of each sub-component was calculated on a different scale.

The detailed definition and calculation of sub-components, major components, and the LVI are presented in Supplementary Appendix 1 and Appendix 2. Supplementary Appendix 1 shows the values of 31 sub-components that made up the seven major components, and the overall LVI for the three provinces: Can Tho, Dong Thap, and Tien Giang provinces ($n = 405$). Supplementary Appendix 2 describes the calculation of the sociodemographic major components from four sub-components (dependency ratio index, households where the head had not attended school, female-headed households, and households with orphans) as well as the LVI of Dong Thap province (179 respondents) generated by values of seven major components.

The values of each sub-component were standardized into an index as in Eq. (1).

$$\text{index}_{S_r} = \frac{S_r - S_{\min}}{S_{\max} - S_{\min}} \tag{1}$$

where S_r denotes the mean value of the sub-component indicators for province r, $S_{\min}$, and $S_{\max}$ denote the minimum and maximum values, respectively.

To obtain the index of each major component, the sub-component indicators were averaged using Eq. (2):

$$M_r = \frac{\sum_{i=1}^{n} \text{index}_{S_r}}{n} \tag{2}$$

where M_r denotes the index of one of the major components for province r; index $index_{S_{ir}}$ represents the value of the ith sub-component that makes up each major component, and n denotes the number of sub-components in each major component.

Then, Eq. (3) was used to obtain the LVI for each province:

$$\text{LVI}_r = \frac{\sum_{j=1}^{7} w_{Mj} M_{jr}}{\sum_{j=1}^{7} w_{Mj}} \tag{3}$$

where LVI_r denotes the mean value of the livelihood vulnerability index for province r; M_{jr} denotes the value of one of the major components j of province r; w_{Mj} denotes the weights of each major component j, in which all sub-components contribute equally to the overall LVI_r. It is worth noting that Eq. (3) can be expanded as specified in Eq. (4):

$$\mathrm{LVI_r} = \frac{w_{\mathrm{SDP}}\mathrm{SDP_r} + w_{\mathrm{LS}}\mathrm{LS_r} + w_{\mathrm{SN}}\mathrm{SN_r} + w_{\mathrm{H}}H_{\mathrm{r}} + w_{\mathrm{F}}F_{\mathrm{r}} + w_{\mathrm{W}}W_{\mathrm{r}} + w_{\mathrm{VDCV}}\mathrm{NDCV_r}}{w_{\mathrm{SDP}} + w_{\mathrm{LS}} + w_{\mathrm{SN}} + w_{\mathrm{H}} + w_{\mathrm{F}} + w_{\mathrm{W}} + w_{\mathrm{VDCV}}} \tag{4}$$

Based on the computed LVI, farmers' vulnerability to climate change was categorized into five levels: least ($0 \leq \mathrm{LVI} < 0.31$), low ($0.31 \leq \mathrm{LVI} < 0.47$), moderate ($0.47 \leq \mathrm{LVI} < 0.52$), high ($0.52 \leq \mathrm{LVI} < 0.61$), and extreme levels ($0.61 \leq \mathrm{LVI} \leq 1.00$). This categorization is a modification of the FANRPAN (2011) categorization of farmers' vulnerability to climate change.

Factors Influencing the Vulnerability of Farmers to Climate Change

After estimating the livelihood vulnerability scores, the study proceeded to examine the factors influencing the vulnerability at the household level using the beta regression. When the dependent variable is a proportion between zero and one, the Ordinary Least Squares (OLS) regression yields biased and inefficient estimates due to the skewed distribution of the residuals. Moreover, such dependent variables often violate the OLS's assumptions of normality and homoscedasticity as values tend to be concentrated within the middle range, and less so in the lower and upper limits. The beta distribution is a flexible distribution which can accommodate either symmetrical or skewed distributions and can model continuous random variables that assume values in the standard unit interval (0, 1), such as percentages and proportions (Ferrari and Cribari-Neto 2004; Cribari-Neto and Zeileis 2010; Unlu and Aktas 2017; Azumah et al. 2020).

In this study, the dependent variable is the overall LVI aggregated from various indicators collected from the households.

The beta regression is defined as in Eq. (5) as follows:

$$g(\mu_t) = \sum_{i=1}^{k} x_i \beta_i \tag{5}$$

where $g(\mu_t)$ is assumed to follow a logit link. In this study, x_i is a vector of independent variables, β_i is a vector of estimated parameters, and the subscript i denotes the ith observation in the dataset. Given the logit functional link, the specific empirical model of this study is specified in Eq. (6) as follows:

$$\begin{aligned} \mathrm{LVI} = {} & \beta_0 + \beta_1 \mathrm{Age} + \beta_2 \mathrm{Gender} + \beta_3 \mathrm{Family\ labor} + \beta_4 \mathrm{Farming\ experience} \\ & + \beta_5 \mathrm{Education} + \beta_6 \mathrm{Farm\ size} + \beta_7 \mathrm{Farm\ size\ squared} + \beta_8 \mathrm{Economic\ activity} \\ & + \beta_9 \mathrm{Endowment} + \beta_{10} \mathrm{Off-farm\ income} + \beta_{11} \mathrm{Cooperative\ membership} \\ & + \beta_{12} \mathrm{Extension\ services} + \beta_{13} \mathrm{Land\ renting} + \beta_{14} \mathrm{Access\ to\ credit} \\ & + \beta_{15} \mathrm{Access\ to\ input} + \beta_{16} \mathrm{Access\ to\ storage} + \beta_{17} \mathrm{Access\ to\ transportation} \\ & + \beta_{18} \mathrm{Flood\ experience} + \beta_{19} \mathrm{Drought\ experience} + \beta_{20} \mathrm{Weather\ information} \\ & + \beta_{21} \mathrm{Can\ Tho\ province} + \beta_{22} \mathrm{Dong\ Thap\ province} \end{aligned} \tag{6}$$

Table 2 Definition of variables, measurements and a priori expectations

Variable	Description	Measurement	Expected sign	Relevant literature
Dependent variable	Livelihood Vulnerability index	$0 \leq LVI \leq 1$	N/A	N/A
Sociodemographic factors				
Age	Age of farmer	Years	±	Alhassan et al. (2019), Adzawla et al. (2020)
Gender	Sex of household head	Dummy variable: 1 = Male; 0 = Female	+	Alhassan et al. (2019), Muthelo et al. (2019)
Family labor	Number of labors in the households	Persons	–	Boutin (2014), Alhassan et al. (2019)
Farming experience	Years of rice farming	Years	–	Alhassan et al. (2019), Muthelo et al. (2019)
Education	Level of education	Dummy variable: 1 = Secondary school or above; 0 = Otherwise	–	Alhassan et al. (2019), Biru et al. (2020)
Farm size	The total agricultural area for farming	ha	±	Fertő and Stalgienė (2016), Paudel et al. (2019)
Farm size squared	Square of the total agricultural area for farming	ha	+	Fertő and Stalgienė (2016), Paudel et al. (2019)
Economic activity	Number of income sources of household	Number	–	Alhassan et al. (2019), Adzawla et al. (2020)
Endowment	Asset endowment	USD 1000	–	Ncube et al. (2016), Biru et al. (2020)
Off-farm income	Off-farm income per annum	USD 1000	–	Alhassan et al. (2019), Azumah et al. (2020)
Institutional factors				
Cooperative membership	Membership of farming organization	Dummy variable: 1 = Yes; 0 = Otherwise	–	Alhassan et al. (2019), Azumah et al. (2020)
Extension services	Agricultural extension visits per year	Dummy variable: 1 = Yes; 0 = Otherwise	–	Alhassan et al. (2019), Muthelo et al. (2019)
Land renting	Payment for land if rented	Dummy variable: 1 = Yes; 0 = Otherwise	+	Li and Boehlje (2013), Alhassan et al. (2019)

Table 2 (continued)

Variable	Description	Measurement	Expected sign	Relevant literature
Access to credit	Access to formal credit by household	Dummy variable: 1 = Yes; 0 = Otherwise	–	Debesai et al. (2019), Adzawla et al. (2020)
Access to input	Access to farm input services	Dummy variable: 1 = Yes 0 = Otherwise	–	Antwi-Agyei et al. (2013), Makate and Mango (2017)
Access to storage	Availability of storage facilities	Dummy variable: 1 = Yes 0 = Otherwise	–	Rurinda et al. (2014a, b), Ali et al. (2017)
Access to transportation	Availability of public transportation to markets	Dummy variable: 1 = Yes 0 = Otherwise	–	Morgan et al. (2019), Yu et al. (2019)
Environmental factors				
Flood occurrence	Reported occurrence of extreme flood events in the past five years	Dummy variable: 1 = Yes; 0 = Otherwise	+	Nguyen et al. (2013), Ochieng et al. (2017)
Drought occurrence	Reported occurrence of extreme drought events in the past five years	Dummy variable: 1 = Yes; 0 = Otherwise	+	Debesai et al. (2019), Adzawla et al. (2020)
Weather information	Warning of climatic events by the local authority	Dummy variable: 1 = Yes; 0 = Otherwise	–	Alhassan et al. (2019), Muthelo et al. (2019)
Location				
	Households located in Can Tho province	Dummy variable: 1 = Yes; 0 = Otherwise	±	Dendir and Simane (2019), Azumah et al. (2020)

Table 2 (continued)

Variable	Description	Measurement	Expected sign	Relevant literature
	Households located in Dong Thap province	Dummy variable: 1 = Yes; 0 = Otherwise	±	Dendir and Simane (2019), Azumah et al. (2020)

For the two variables, endowment and off-farm income, one dollar was such a small amount for influencing the dependent variable. Thus, the currency unit was denominated by USD 1000, and therefore the unit increase in independent variables became an increment by USD 1000, to facilitate the quantitative interpretation of the estimated coefficients. As for farm size, a squared term was also included in the regression to measure the potential non-linear relationship between the LVI and farm size (Fertő and Stalgienė 2016; Alhassan et al. 2019).

The coefficients in the beta regression are quantitatively interpreted as the additional increase or decrease in the log-odds ratio for the dependent variable or the outcome in response to a unit increase in each independent variable or a change from zero to one in the case of dummy independent variables. For numerical independent variables, the coefficient is interpreted as the average change in log-odds ratio for a unit increase in the independent variable, holding other independent variables constant. For dummy independent variables, it is the change in log-odds ratio for a change from 0 to 1 in the independent variable, holding covariates unchanged. As farm size was included in the quadratic form, the change in log-odds ratio for a unit increase in farm size is expressed as follows:

$$\left[\text{the change in log odds ratio for a unit increase in farm size}\right] = 2 \cdot \beta_7 \cdot (\text{Farm size}) + \beta_6 \tag{7}$$

Equation (7) shows that the effect of farm size is nonlinear since the effect changes by farm size. This also enables us to identify the level of farm size that can minimize the value of the LVI, since the minimum LVI is achieved when the value of Eq. (7) is equal to zero.

As mentioned, the coefficients estimated in the beta regression represent the effects on log-odds ratio, not the value of the dependent variable itself. Hence, the marginal effect of each independent variable on the value of the dependent variable was also calculated for convenient in interpretation (Liao 1994).

Table 3 Sociodemographic profile of respondents ($n = 405$)

Variable	Mean	Standard deviation	Minimum	Maximum
Age (years)	52.2	11.5	25	85
Farming experience (years)	27.1	11.2	1	60
Gender (1 for male)	0.89	0.32	0	1
Family labor (persons)	3.0	1.1	1	9
Education (1 for secondary school and above, 0 otherwise)	0.67	0.47	0	1
Farm size (ha)	1.15	1.28	0.10	13.00
Endowment (USD 1000)	5.86	6.91	0.54	50.31
Economic activities (number)	2.3	0.8	1	5
Off-farm income (USD 1000)	2.75	3.11	0.00	25.04

Source: Authors' survey (2019)

This analysis utilized the “betareg” command in STATA version 16 to estimate the parameters of the beta regression. Table 2 presents a description of the variables, measurement, a priori expectation of the sign of the coefficient, and relevant literature.

Results and Discussions

Sociodemographic Characteristics of Rice Farmers in the MDR

The sociodemographic characteristics of the respondents are summarized in Table 3. The average age of the sampled farmers was 52.2 years, with the youngest aged 25 and the oldest 85 years old. Closely related to the age of the farmer is farming experience. In the study area, the majority of rice farmers had at least one year and at most 60 years of experience in rice farming, with the average at 27.1 years. Experience is critical for farming as it helps farmers recognize problems, forecast crop yields, and better adopt agronomic practices for mitigating the extent of vulnerability. Among the respondents, 89% were male and 11% were female. Most of the sampled farmers employed family labor for performing farming activities (including family members below 18 and over 65 years old), with at least one member and at most nine members engaged in rice farming activities.

All the sampled respondents were able to read and write, and 66.7% of them had finished at least secondary school. At primary school level, people mainly learnwriting and reading in Vietnamese language and other basic knowledge (simple arithmetic, historical, geographical, and physical education), whereas knowledge about agronomic practices and adaptation strategies to mitigate climate risks are fulfilled mainly in secondary school. Thus, higher levels of formal education beyond primary education would help farmers comprehend agronomic concepts, especially instructional labels on agricultural inputs and technologies (Adu et al. 2018; Alhassan et al. 2019). The average and minimum size of the sampled farmers was 1.15 and 0.10 ha, respectively, suggesting that rice farming in the study area was dominated by small-scale farmers. Farmers with smallholding tend to practice other economic activities, such as rearing livestock, working

Table 4 Institutional factors ($n=405$)

Variable	Frequency of yes	Percentage of yes
Land renting (1 for yes)	45	11.1
Cooperative membership (1 for yes)	48	11.9
Extension services (1 for yes)	181	44.7
Access to credit (1 for yes)	72	17.8
Access to input (1 for yes)	371	91.6
Access to storage (1 for yes)	221	54.6
Access to transportation (1 for yes)	320	79.0

Source: Authors’ Survey (2019)

Table 5 Environmental factors ($n = 405$)

Variable	Frequency of yes	Percentage of yes
Flood occurrence (1 for yes)	134	33.1
Drought occurrence (1 for yes)	142	35.1
Weather information (1 for yes)	101	24.9

The variable pertains to experience in the past 5 years

Source: Authors' Survey (2019)

Table 6 The computed major components indices and the LVIs for Can Tho, Dong Thap and Tien Giang provinces

Major component	Province			Combined
	Can Tho	Dong Thap	Tien Giang	
Health (H)	0.09	0.08	0.07	0.08
Livelihood strategies (LS)	0.55	0.50	0.60	0.55
Food (F)	0.43	0.43	0.32	0.39
Water (W)	0.09	0.14	0.19	0.14
Natural disaster climate variability (NDCV)	0.38	0.29	0.41	0.36
Sociodemographic profile (SDP)	0.01	0.09	0.08	0.06
Social network (SN)	0.77	0.64	0.67	0.69
Aggregate LVI	0.35	0.32	0.30	0.32

The scale of LVI grades ranged from least ($0 \leq \text{LVI} < 0.31$), low ($0.31 \leq \text{LVI} < 0.47$), moderate ($0.47 \leq \text{LVI} < 0.52$), high ($0.52 \leq \text{LVI} < 0.61$), and extreme ($0.61 \leq \text{LVI} \leq 1.00$) (FANRPAN 2011)

off farm, and running a small business to satisfy households' expenses. In fact, the agricultural production systems in the MDR are largely based on smallholder farms defined as farms with 2 ha or less of landholding, accounting for 93% of all farms (GSO 2011).

The value of asset endowment with the respondents was USD 5860 on average. Nonetheless, there existed a wide gap between the poor and the wealthy, with a range of USD 540 to 50,310. Apart from rice production, many farmers (86.7%) engaged in at least one economic activity to diversify their income sources. Especially, off-farm work was one of the notable economic activities that helped compensate for the loss causing by climate shocks. In this study, this income amounted to USD 2750 per year on average. Yet, several households practiced rice monoculture as their main source of income, leaving them susceptible and sensitive to harsh climate events.

Land renting, cooperative membership, access to inputs, access to storage, transport availability, access to credit, and extension services were the institutional factors considered in this study (Table 4). Only 11% of the interviewed rice farmers rented farmland as they were content with their land holding size and did not have a tendency to enlarge their farm land. On the other hand, many farmers wanted to expand their farm to obtain higher outputs. Approximately 12% of the respondents belonged to a cooperative organization where they shared farming experiences and participated in training courses on agronomic techniques. Approximately 45% of the respondents reportedly received agricultural extension services including on farming practices and climate change adaption strategies, provided by lead farmers and extension agents. The majority of the farmers (92%) in the study area had access to inputs, access to transportation (79%), while more than half of them had access to storage facilities (55%). Finally, 18% of the respondents had availed credit through formal financial institutions in the past twelve months, implying that most rice farmers in the study area had limited financial facilities which would expedite the adoption of climate adaptation strategies.

Three environmental factors (i.e. experiences with flood, drought, and weather information) were considered in the analysis. Approximately 33% and 35% of the respondents had experiences with flood and drought over the period 2015–2019, respectively. Generally, drought and flood in Vietnam occurred frequently and often prolonged, causing losses in crop yields and productive assets (IPCC 2014; GSO 2019). A quarter of the respondents had access to weather information, indicating that the majority did not receive weather forecast in their locality, which would be essential in adopting adaptation strategies (Table 5).

Farmers' Vulnerability to Climate Change in the MDR

The LVI computed for each province is summarized in Table 6 and the computation of major component indices is presented in Supplementary Appendix 3. On the whole, farmers were "least vulnerable" in terms of social demographic profile (0.06), health (0.08), and water (0.14). Farmers in the study area had "low vulnerability" in terms of food (0.39), and natural disaster and climate variability (0.36); "highly vulnerable" in livelihood strategies (0.55), and "extremely vulnerable" in social network (0.69). As specified in Supplementary Appendix 1, the major component of social network includes five sub-components: households that had not gone to their local government for assistance in the past 12 months, households with no membership with any community, distance to the nearest rice market, households that had received no extension visit in the last one year, and

Table 7 Classified levels of vulnerability of rice farmers in study area

Level of vulnerability	Can Tho		Dong Thap		Tien Giang		Aggregate	
	Freq	Percent	Freq	Percent	Freq	Percent	Freq	Percent
Least ($0.00 \leq LVI < 0.31$)	14	17.1	76	42.5	71	49.3	161	39.8
Low ($0.31 \leq LVI < 0.47$)	67	81.7	103	57.5	73	50.7	243	60.0
Moderate ($0.47 \leq LVI < 0.52$)	1	1.2	0	0.0	0	0.0	1	0.3
High ($0.52 \leq LVI < 0.61$)	0	0.0	0	0.0	0	0.0	0	0.0
Extreme ($0.61 \leq LVI \leq 1.00$)	0	0.0	0	0.0	0	0.0	0	0.0

households that had debt. Except distance to the rice market, these sub-components exhibited values corresponding to "highly vulnerable" and "extremely vulnerable" across the three provinces.

The aggregate LVI indicated the low vulnerability (0.32) of the rice farmers in the study area, in which farmers from Can Tho province (0.35) were relatively, followed by those in Dong Thap province (0.32) and Tien Giang province (0.30). This is in line with Adu et al. (2018) who found that livelihood strategies and social network contributed the most to vulnerability in the Brong-Ahafo region of Ghana, while health and water contributed the least. Adu et al. (2018) and

Table 8 Beta regression results of the determinants of rice farmers' vulnerability to climate change

Dependent Variable = LVI	Coefficient	Standard error	Marginal effect	*p* value
Age (years)	0.0036***	0.0013	0.0008	0.007
Gender (1 for male)	−0.1451***	0.0338	−0.0320	0.000
Family labor (persons)	0.0304**	0.0129	0.0066	0.019
Farming experience (years)	−0.0032**	0.0013	−0.0007	0.016
Education (1 for secondary school and above)	−0.1030***	0.0236	−0.0224	0.000
Farm size (ha)	−0.0380*	0.0214	−0.0082	0.076
Farm size squared (ha^2)	0.0048**	0.0019	0.0010	0.011
Economic activity (number)	−0.0351**	0.0150	−0.0076	0.019
Endowment (USD 1000)	−0.0090***	0.0019	−0.0020	0.000
Off-farm income (USD 1000)	0.0025	0.0042	0.0005	0.546
Cooperative membership (1 for yes)	0.0861**	0.0355	0.0188	0.016
Extension services (1 for yes)	−0.1766***	0.0257	−0.0380	0.000
Land renting (1 for yes)	0.0842**	0.0343	0.0184	0.015
Access to credit (1 for yes)	−0.2927***	0.0313	−0.0609	0.000
Access to input (1 for yes)	−0.0450	0.0406	−0.0098	0.271
Access to storage (1 for yes)	−0.0573**	0.0262	−0.0124	0.029
Access to transportation (1 for yes)	−0.0423	0.0340	−0.0092	0.216
Flood occurrence (1 for yes)	0.2031***	0.0430	0.0444	0.000
Drought occurrence (1 for yes)	0.1472***	0.0379	0.0320	0.000
Weather information (1 for yes)	−0.3233***	0.0376	−0.0676	0.000
Can Tho (vs. Tien Giang)	0.0588*	0.0328	0.0128	0.075
Dong Thap (vs. Tien Giang)	−0.0924**	0.0438	−0.0199	0.035
Constant	−0.4012***	0.0921		
Scale constant	4.7481***	0.0700		
Regression diagnostics				
Number of observations	405			
Likelihood Ratio χ^2 (*p* value)	383.97 (0.000)			
Log likelihood	702.57			

***, **, and * indicate statistical significance at 1%, 5%, and 10% levels, respectively

Sujakhu et al. (2019) also found significant effects of social demographic profile and natural disaster on the vulnerability of farmers.

The computed major components revealed that Can Tho was the most vulnerable in social network, whereas Tien Giang was the most vulnerable in livelihood strategies, water, and natural disaster and climate variability. Tien Giang was the most exposed to natural disaster and climate variability, due presumably to its topography of the coastal area and experience with both flood and drought, while the two other provinces were exposed mainly to flood events. This is consistent with Dendir and Simane (2019) that climate vulnerability varied depending on the agro-ecological zone.

In general, households in the three provinces showed low vulnerability in terms of food and natural disaster and climate variability. The high vulnerability reported in livelihood strategy and extreme vulnerability in social network is due to the high dependency on income from rice and the insufficient support from local authorities, agricultural cooperatives, extension services, and financial institutions (Berg et al. 2017).

The frequency distribution of the aggregate LVI revealed that many of the sampled farmers (60.0%) had low vulnerability to climate change (Table 7). Farmers in Can Tho (81.7%) were the most vulnerable, followed by Dong Thap (57.5%) and Tien Giang (50.7%), which is consistent with the results in Table 6. According to Mbakahya and Ndiema (2015) and Jamshidi et al. (2019), moderate and low vulnerability households needed temporary external assistance from the local authority in case of emergency to cope with the shock, whereas low vulnerability households may be able to cope without external assistance.

Determinants of Rice Farmers' Vulnerability in the MDR

Table 8 presents the results of the beta regression analysis. The likelihood ratio test statistic was statistically significant ($p < 0.001$). The results showed that gender, experience, education, farm size, economic activity, endowment, extension services, access to credit, access to storage, weather information, and Dong Thap province dummy were found to have significant negative influences on rice farmers' vulnerability to climatic change; whereas age, family labor, farm size squared, cooperative membership, land renting, flood occurrence, drought occurrence, and Can Tho province dummy were found to have positive influences on farmers' vulnerability to climate change.

Age of the household heads had a positive influence on the vulnerability to climate events ($p < 0.01$), implying that older farmers were more vulnerable than younger farmers. This may be related to the declining health as the sampled farmers were relatively old on average (Table 3) and many of them stated some physical and mental health concerns. Adaptation strategies might help aging farmers cope with the vulnerability and maintain their livelihoods, while it is difficult to eliminate all the susceptibility among the elderly (UNFCCC 2006; Tan et al. 2013; Doshmangir et al. 2015; Rigg et al. 2019; Mabuku et al. 2019). Farmers are more likely to adopt adaptive strategies when they are in good health conditions and can maintain the motivation. Otherwise, elderly farmers would delegate their land to the next generation and receive remittance from them as a rational livelihood strategy (Rigg et al. 2019). Our result and interpretation are largely consistent to previous studies on determinants of adaptive capacity (FANRPAN 2011; Osumanu et al. 2017; Alhassan et al. 2017; Muthelo et al. 2019; Adzawla et al. 2020).

As expected, gender (i.e. the male dummy) had a negative effect on vulnerability to climate change ($p < 0.01$), implying that in the case of severe climatic events, female headed households engaged in rice farming were more vulnerable compared to male headed households. This might be because female-headed households tend to have less access to land, inputs, information, and other socioeconomic opportunities such that they are the more affected by climatic stresses due to low adaptive capacities (Alhassan et al. 2019). Previous studies also revealed that male-headed households often had a greater probability of adopting new agricultural technologies as coping strategies, whereas females were more vulnerable to the effects of climate change due to their lower access to productive resources (Ncube et al. 2016; Chandra et al. 2017; Asrat and Simane 2017, 2018; Awuni et al. 2018; Adzawla and Baumüller 2020). Chandra et al. (2017) found in Mindanao, the Philippines that extreme climatic events had led women farmers to migration, and aggravated discrimination, food insecurity, and poverty.

In contrast to expectations, family labor was found to have a positive relationship with vulnerability to climate change ($p < 0.05$). This might be because family laborers working in rice production results in low income per capita compared to engaging in off-farm activities as part of their livelihood strategy. While the result is consistent to Maddison (2006), Boutin (2014), and Ahmad et al. (2020), Mahaarcha (2019) argued that family labor may help the households adopt some of the adaptive practices to cope with negative effects of climate change in Kanchanaburi Province, Thailand. Alhassan et al. (2019) also stated that at the peak of the rice season in the Northern Region of Ghana, utilization of family labor helps smallholders be less vulnerable as hired labor is less productive than family labor as a result of the incentive structure.

As expected, farming experience had a negative effect on vulnerability to climate change, where a one-year increase in farming experience led to a reduction in LVI by 0.0007 ($p < 0.05$). This may be because farmers with longer farming experiences have more awareness of past climate events (the amount of rainfall, frequency of droughts and floods) and knowledge about appropriate agronomic practices to alleviate the adverse effects (Muthelo et al. 2019). Furthermore, in the context of climate shocks, many farmers receive assistance from the government due to the significant role of the rice sector in national food security and overall socioeconomic stability. As farmers gain experiences in adopting adaptive strategies to those shocks, they may take advantage of utilizing access to social network, access to credit and subsidy (i.e. seeds, fertilizer, and water pumping funds) provided by the government to maintain their livelihoods (CGIAR 2013; O'Neal 2017; Clauss et al. 2018; Nguyen et al. 2018; Jerez 2020; Dai et al. 2020). This result is consistent with Abid et al. (2015) who revealed in Pakistan that experience in farming had a positive relation with the probability of choosing adaptation measures, such as changing crop varieties, modifying plantation dates and type of fertilizers.

Level of education had a negative influence on households' vulnerability ($p > 0.01$), indicating that an increase in formal education would reduce farmers' vulnerability to climate change. Previous studies showed that well-educated farmers had adequate capacity to understand climatic events and adaptation mechanisms and apply suitable agronomic practices and improved agricultural technologies to reduce their vulnerabilities. Higher education may help farmers secure alternative livelihood options and enhance their income earning capacity (Mamba 2016; Alhassan et al. 2019; Biru et al. 2020; Adzawla et al. 2020).

Farm size showed a non-linear effect on vulnerability to climate change as both farm size and its square had statistically significant coefficients. In particular, the positive coefficient on the squared term indicates that added farm size raised the households' vulnerability after a certain level of farm size (Paudel et al. 2019). Equation (7) and the two coefficients imply that the value of LVI was minimized when farm size was at the critical level of 3.96 ha. This situation may be because in some cases, applying an improved technology is more effective than increasing farmland further (FAO 2018; Hossen et al. 2020). This finding is consistent with Fertő and Stalgienė (2016) who found that large farms in Lithuania became riskier and more vulnerable to droughts compared to relatively small-scale farmers practicing intensification options. Moreover, Mahaarcha (2019) found in Kanchanaburi, Thailand that large land size required more investment to cope with adverse effects of climate change compared to small land size.

Economic activity had a negative effect on vulnerability to climate change. Households with one more income source had the LVI lower by 0.0076 on average ($p < 0.05$). This is consistent with the a priori expectation because income diversification would reduce the dependence on farm income which is typically sensitive to climatic shocks (Panthi et al. 2016; Zarafshani and Maleki 2020; Adzawla et al. 2020; Adzawla and Baumüller 2020). While the number of economic activities was significant, the result also shows insignificant effects of off-farm income, indicating that having multiple sources of income matters, but increasing the amount of income does not.

Asset endowment had a negative effect on vulnerability to climate change. An increase in asset endowment by USD 1000 would reduce the LVI by 0.0020 ($p < 0.01$). The implication is that farmers with large wealth were more tolerant of climatic shocks since they may encash their asset items or take credit to smooth their consumption (Rurinda et al. 2014a, 2014b; Ncube et al. 2016; Biru et al. 2020; Aniah et al. 2019; Adzawla et al. 2020).

Against expectations, membership with agricultural cooperatives had a positive effect on vulnerability ($p < 0.05$). Being a member of a cooperative raised the LVI by 0.0861, despite the alleged importance of agricultural cooperatives in building farmers' adaptive capacities (Sujakhu et al. 2018; Azumah et al. 2020; Adzawla et al. 2020). Our finding is somewhat consistent with Alhassan et al. (2019) who found in Ghana that farmers' membership with cooperatives was useless in improving crop yields or reducing vulnerability to climate risk. Sujakhu et al. (2019) also argued that membership with socially disadvantaged groups was one of the key drivers of vulnerability in Nepal. In contrast, in Thailand, cooperatives provide employment directly through their own businesses or indirectly through non-members, contributing to steady income for farmers toward diminishing rural–urban migration. Moreover, financial cooperatives provide financial services to their individual members for multiple purposes (e.g. cooperatives provide financial incentives to their members through dividend (Suwanna and Nuttiporn 2014; Jitmun et al. 2020).

As expected, extension services had a negative effect on the vulnerability ($p<0.01$), indicating that participation in extension programs caters to developing adaptive capacity. In the study area, extension workers from the local authorities introduce new varieties, new crops, and advanced technologies. They deliver training courses, visit paddy fields, and organize meetings for at least 40% of farmers in the region, where they use demonstrations, printed materials, Internet, and radio for communication (Sattaka et al. 2017). Farmers who engage in extension programs may be more enthusiastic about applying crop management practices (Guteta and Abegaz 2015). Extension services may include sharing knowledge about crop production, disease prevention and treatment, constructing irrigation facilities, and improving skills (Mahaarcha 2019; Muthelo et al. 2019; Azumah et al. 2020; Alhassan et al. 2017, 2019). Furthermore, most farmers in the study area reported that they had good relationship with their neighbors and mutually shared information and experiences on a regular basis. This is consistent with Nakano et al. (2018) who emphasized the role of farmer-to-farmer dissemination of technologies and improved practices.

The variable, land renting met its expectation of a significant positive effect (0.0842) on the LVI ($p<0.05$). This may be because farmers have less incentives to invest in long-term adaptation strategies on rented land, such as planting perennial crops, soil conservation techniques, and building irrigation system. In addition, farmers who rent land need to pay farmland rent, which raises vulnerability to financial stress (Li and Boehlje 2013). Moreover, the rented land may be isolated from their own farms, thereby increasing the cost of farming and transport, and therefore, reducing their profit margins (Osumanu et al. 2017; Alhassan 2019).

Access to credit had a negative effect on vulnerability to climate change, which is consistent to a priori expectation ($p<0.01$). This is because farmers with access to credit could invest more capital into their economic activities with which to improve resilience and recover from natural hazards (Opiyo et al. 2014; Nazari et al. 2015; Ncube et al. 2016; Debesai et al. 2019; Adzawla et al. 2020). Ndamani and Watanabe (2015) and Adzawla et al. (2020) found that financial constraints and limited access to credit were major barriers to climate adaptation and the growth of the agriculture sector in Ghana.

Access to storage facilities had a negative effect ($p<0.05$), indicating that those with access to storage facilities were less vulnerable to climate change. Without storage facilities, farmers are unable to store enough of harvest, which undermines food security (Rurinda et al. 2014a, 2014b; Ali et al. 2017).

Flood occurrence raised vulnerability to climate change ($p<0.01$), confirming that the occurrence of severe floods poses a threat to livelihoods. Along with the loss of life and damage to properties, it also triggers a spread of infectious diseases due to water contamination, coupled with the lack of basic services and medicines. A loss of residences leaves farmers even more susceptible to climatic shocks. Besides, a loss in crop yields diminishes households' purchasing power, and exacerbates food shortages, hunger, and poverty. Due to the tremendous losses in agriculture production, farmers considered floods as a much greater risk than other natural disasters (Ali et al. 2017; Adzawla et al. 2020; Ochieng et al. 2017). Herrera et al. (2018) found that varying rainfall patterns in Nicaragua reduced households' production and income generating capacity and that rising food prices further reduced household food security. Without coping with this type of risks, they would probably face a recurrent decline in food consumption.

Likewise, drought occurrence had a positive effect on vulnerability ($p<0.01$) Drought decreases crop production, crop yields, and reduces farm income as many farmers rely on rainfall for crop production as well as other housework. Unlike other hazards, drought can last for months or even for years so that its negative effects can be prolonged through degradation of soil and weakened adaptive capacity of farmers, leaving them less resilient and socially disrupted. In this regard, drought is one of the most severe natural hazards that leads to social, economic, and environmental losses (Nazari et al. 2015; Ncube et al. 2016; Debesai et al. 2019; Muthelo et al. 2019; Adzawla et al. 2020; Zarafshani and Maleki 2020). Our finding is consistent with Osumanu et al. (2017) that in Ghana, droughts and floods have caused land degradation, soil erosion, and soil infertility, and decreased planting area, which caused livelihood insecurity and heightened poverty levels among rural households. Similarly, Manalo et al. (2020) found that farmers in drought-prone communities in the Philippines considered drought as a threat that left them more vulnerable. Severe droughts caused soil rack and low or even no yield, causing people to eat maize instead of rice as well as low quality food provided as aid. Many farmers borrowed money from banks and other lenders to maintain their livelihoods or even migrated to other provinces to work as a gold miner.

Access to information about climatic conditions contributed to lowering farmers' vulnerability to climatic stresses ($p<0.01$), implying that those who received timely forecast were less vulnerable to climate change. Proper warning systems can reduce the damage by increasing social awareness at the right time and place, which may prompt farmers to adopt adaptation measures (e.g., diversification in income sources, precautionary savings, diversification in crops, implementation of risk management strategies before and after the disaster strikes) (Ullah et al. 2016; Asrat and Simane 2018; Muthelo et al. 2019). In this study, however, only a quarter of the respondents had access to early warning information. Past studies found the usefulness of daily weather forecasts on rainfall, temperature, and humidity as well as early warning on extreme events, provided by the national and local authorities through television, radio, online newspapers, and traditional newspapers (Kuswanto et al. 2019; Ncube et al. 2016). In addition, Adzawla et al. (2020) found that households in Ghana relied on informal networks when shocks occurred, as a coping mechanism for social disadvantages and the adverse effects of climate change.

Lastly, the location fixed effects for both Can Tho and Dong Thap were significant. On average, the LVI in Can Tho was higher by 0.0588 than in Tien Giang. In contrast, the LVI in Dong Thap was lower by 0.0924 than in Dong Thap. This could be due to the differences in agro-ecological zones in which Can Tho lies in lower altitude than the two other provinces located in the upstream MDR (Panthi et al. 2016; Ly 2017; Ali et al. 2017; and Adzawla and Baumüller 2020). This is in line with Dendir and Simane (2019) who found that climate vulnerability differs based on the agro-ecological location of farmers and that vulnerability to climate change is higher in lowland agro-ecological zones. The difference in the LVI between Dong Thap and Tien Giang may not be attributed to agro-ecological zones. In any case, the province dummies capture all unobservable province-specific factors, which reduces the omitted-variable bias in the estimated effects of the other key factors in the analysis.

Conclusion

Climate change can bring serious consequences to smallholders in Vietnam, as well as in other parts of the world. This study examined the vulnerability of smallholder rice farmers in the MDR of Vietnam to climate change and identified the determinants of the vulnerability as represented by the LVI. The study expanded the literature on households' vulnerability and also compared the livelihood vulnerabilities across three provinces: Can Tho, Dong Thap, and Tien Giang. The livelihood vulnerability of farm households was lower for male farmers, younger farmers, and those with longer farming experiences (if age is the same), larger landholding, more economic activities, extension services, access to credit, higher education, access to storage facilities, access to climate information, and higher wealth. Location-wise, farmers in Can Tho province were the most vulnerable compared to the other provinces.

Therefore, first, it is recommended that local authorities provide smallholder rice farmers with sufficient access to forecast information and warning systems regarding weather, seasonal drought, and flood. Second, it is essential to provide adequate training programs for farmers in the MDR to be operated by extension offices and agricultural cooperatives (Asrat and Simane 2018; Su et al. 2019). Third, livelihood diversification has the potential to reduce vulnerability through the promotion of local business opportunities for farmers by the government and non-governmental organizations. Further, it is important for the government to manage the establishment and the quality of institutional agencies that provide better credit facilities to farmers, especially those who belong to agricultural cooperatives or other organizations to guarantee successful adoption of climate change adaptation strategies (Rurinda et al. 2014a, 2014b). Furthermore, adaptation to drought and flood by adjusting agricultural practices upon receiving forecast information is crucial in minimizing crop losses. Irrigation facilities and water-saving technologies should be strengthened to reduce the over-dependence on rainfall (Osumanu et al. 2017; Tran et al. 2019b; Adzawla et al. 2020). In addition, practicing climate smart agriculture such as changing cropping patterns and planting flood-tolerant and drought-tolerant crop varieties is also crucial (Lipper et al. 2014; Lunduka et al. 2019; Zarafshani and Maleki 2020). The government should also consider a higher priority to Can Tho province through adaptation programs especially in the aspects of social network building.

The main contribution of this paper is that it provided evidence of the factors influencing the vulnerability of rice farming households in the MDR of Vietnam, which will inform policies for improving the resilience and adaptive capacity in coping with climatic shocks. On the other hand, the main limitation of this paper is the reliance on cross-sectional data and use of dummy variables to represent experience with drought and flood, which might not exactly reflect the extent of climatic shocks. Hence, it is recommended that further research be conducted by using secondary data on frequency and occurrence of natural disasters, as well as daily rainfall and temperature. In addition, it will be useful if further research takes into account other factors potentially influencing livelihood vulnerabilities such as farmers' perception of climate risks and the cost of implementing adaptation strategies. Lastly, this study focused on the quantitative research method. Further research may as well execute qualitative in-depth inquiries and content analysis to better elucidate the mechanism behind the quantitative evidence obtained in this study. Conducting contextualized research in the MDR using the mixed methods will provide for opportunities for furtherance of local insight into the climate vulnerability issues.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1057/s41287-021-00371-7.

Acknowledgements This research was funded by the Asian Institute of Technology Vietnam's 25th Anniversary Scholarship (AITCV Silver Anniversary Scholarship). The authors acknowledge the support provided by the staff members and students of Tien Giang University, Vietnam, who participated in the field activities. The authors also thank the farmer respondents who kindly agreed to answer survey-related questions.

Compliance with Ethical Standards

Conflict of interest The authors declare no conflict of interest regarding the submission and publication of this manuscript.

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