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Climate change and livelihood vulnerability of the rice farmers in the North Central Region of Vietnam: A case study in Nghe An province, Vietnam

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ABSTRACT

This study aimed at assessing the livelihoods of rice households in Nghe An province of Vietnam. The study was undertaken through household surveys of 396 households in three districts of this province. In this study, the livelihood vulnerability index (*LVI*) was used for investigating the level of vulnerability to climate change of rice households in Nghe An province, pairwise correlation matrix and beta regression were used for examining the factors affecting the level of vulnerability climate stresses. Overall, the computed *LVI* showed that respondents were slightly vulnerable to climate change, indicating that households in the study area still had capacities to cope with the change. The beta regression analysis showed that floods, droughts, cold spells, irrigation, institutional factors, and socio-demographic factors were the major factors significantly affecting rice households' vulnerability in Nghe An province. The findings suggest the need to strengthen the social network between farmers, agricultural cooperatives, and local governments to enhance farmers' capacity to cope with climate-induced issues, especially floods and droughts in the coastal area. Findings also imply the need to provide farmers with input subsidies, effective irrigation systems, training, and consultant services to reduce households' vulnerability. Furthermore, this study also highlights the need to promote official financial services with low interest rates in adopting adaptation strategies for sustainable development of the whole region.

1. Introduction

Climate extremes related to climate change significantly threatened natural resources, food production, and people's livelihoods around the world (Intergovernmental Panel on Climate Change (IPCC) 2014). In Asia, Vietnam is an emerging country that is extremely affected by negative climatic stresses because of its distinctive topography with a long coast of approximately 3,260 km (Le et al., 2017a; Nguyen and Hens, 2019; Hoang et al., 2020; Nguyen et al., 2021; Nguyen and Leisz, 2021). Since the 1990s, climatic stresses, such as erratic rainfalls, unpredicted floods, and storms, have adversely affected crop yields and productivity in Vietnam. Lately, increases in temperature, hot waves, prolonged droughts, and cold spells are the other challenges faced by the populations across the country (Le, 2018; Hoang et al., 2020; Leartlam et al., 2021; McKinley et al., 2021; Nguyen et al., 2021). This situation becomes even more severe because of climate change, which then influences food security and the livelihoods of the whole communities, especially those in the rural areas. Rice is still the main staple food and the main income source of 9 million of farmers in this country. Since rice is highly sensitive to the weather pattern, numerous rice producers are exposed to those climatic stresses, especially smallholder households (Hoang et al., 2020; Le, 2018; Le et al., 2017a; Nguyen et al., 2019; Dao et al., 2019; Sa-adthien et al., 2020). In Vietnam, rice is mainly cultivated in the Mekong Delta (56% of the national productivity of rice), the Central Coast Region (which includes North Central Coast and South Central Coast) (16%), Red River Delta (14%), and other regions (Northeast, Northwest, Central Highlands, and Southeast) (14%) (General Statistics Office of Vietnam, 2020). Compared with other regions in Vietnam, the North Central Coast (NCC) suffers a much higher proportion of extreme weather conditions due to its complex topography with mountains and a long coast of 642 km. Almost one-third of the households in this region experienced different forms of severe weather event(Hoang et al., 2020; Le, 2018; Luu et al., 2020a, 2020b). In the NCC, Thanh Hoa, Nghe An, and Ha Tinh are the three provinces most affected by floods, storms, and other extreme weather events. From 1949 to 2017, Nghe An province experienced 18 storms, compared with Ha Tinh (24 storms) and Thanh Hoa (23 storms). Nghe An received three times of severe weather alerts, followed by twice in Quang Binh and once in Thanh Hoa (National Oceanic and Atmospheric Administration (NOAA), 2018). The North Central Regional Hydro-Meteorological Center (2020) revealed that heat waves and negligible rainfall causing a serious shortage of water in 2020, affected 8,200 ha of agricultural land in the NCC, of which Thanh Hoa and Nghe An had 3,200 ha and 5,000 ha of agricultural land affected, respectively. In addition, droughts and wa-

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ter shortages adversely influenced the livelihoods of people on a large scale of 23,900 ha in the NCC, mainly in Thanh Hoa (9,000 ha), Nghe An (8,900 ha), Quang Tri (4,140 ha), and Ha Tinh (990 ha).

Located in the NCC, Nghe An is the largest province in Vietnam with a total area of 16,500 km^2 and a crowded population of over 3.3 million inhabitants in 2019. Given the combination of complex topography (e.g. mountains, hills, a high density of rivers and streams, and coastal areas), specified geographical location, and the impact of climate change, people living in low-lying areas have been threatened by the risks of heavy rainfalls, storms, and floods since the last three decades (Hoang et al., 2020; Nguyen et al., 2021). With 82 km of coastline, this province is often affected by storms from the East Sea. Floods occur from 5 to 7 times in the summer and fall, droughts occur twice in summer and winter, whereas heat waves and cold spells occur at the peak of the summer and winter, respectively (Nguyen and Hens, 2019; IMHEN and UNDP, 2015; MONRE, 2016; Pham, 2020; Reynaud and Nguyen, 2016; People Committee of Nghe An province, 2020). In 2020, the province had been affected by 15 cold spells, 7 heat waves, 22 storms and flash floods (Nghe An's Department of Agriculture and Rural Development, 2021). On the other hand, in 2020, the prolonged heavy rains caused flash floods in low-lying areas, such as along rivers, streams, and outside of dikes. Those events caused adverse effects on economic growth and human well-being in Nghe An (Hoang et al., 2020; Chen et al., 2019; Sangkhaphan and Shu, 2019). However, resources for the recovery and reconstruction work after climate events in this province are very limited, mainly focusing on urgent and short-term solutions. In an effort to reduce vulnerability to climate change in the rural area, the assessment of the vulnerability of rice communities in Nghe An has been considered a crucial step to provide policymakers with useful complementary material for coping and mitigating environmental risks (Nghe An's Department of Agriculture and Rural Development, 2021; Sujakhu et al., 2019).

Vulnerability assessments have been studied by a number of scientists around the world. According to the Food Agriculture and Natural Resources Policy Analysis Network, vulnerability is defined as the failure to survive and recover due to the impacts of climate or other shocks due to a deficient capacity to adapt to the shocks (FANRPAN, 2011). According to the Intergovernmental Panel on Climate Change (IPCC), vulnerability assessment is performed by measuring the level of sensitivity and exposure of a community to climate shocks, and the capability of the community to adapt to the impacts of those shocks (IPCC, 2001). Climate shocks and other factors may negatively or positively affect a community, and the effects of climate shocks may be different because of the variance in geographical characteristics and the capacity to cope with the shocks (Intergovernmental Panel on Climate Change (IPCC) 2014, IPCC, 2001, IPCC, 2007). To achieve a sustainable livelihood, it is vital to cope with and recover from all kinds of shocks, continue, or enhance the abilities, and enrich assets in the long term (Chambers and Conway, 1991). Introduced by the Department for International Development (DFID), the sustainable livelihood framework (SLA) considers the connection of different kinds of shocks to the livelihoods, the access to different types of assets to adapt to climatic hazards, and the intervention programs and policies to maintain sustainable livelihoods. SLA involves the relationships of five types of assets, including human asset (e.g. health, education, and training), physical asset (e.g. roads, water, bridges, equipment, machines, and livestock), social asset (e.g. social network and support), financial asset (e.g. savings, credit, business, and remittances), and natural asset (e.g. land, water, soil, forests, and fisheries) (DFID, 1999).

Many global scientists revealed that farmers were exposed and highly sensitive to climatic stresses such as variations in rainfall and temperature, floods, droughts, and other extreme events (Nguyen et al., 2021; Nguyen and Leisz, 2021; Dao et al., 2019; Salik et al., 2015; Tjoe, 2016; Adu et al., 2018; Aryal et al., 2020; Arouri et al., 2015; Kuntiyawichai et al., 2015; Shahzad et al., 2021; He et al., 2021). Aryal et al. (2020) revealed that the poor farmers in Coastal Bangladesh solely depended on agriculture for their livelihoods because they lacked adaptive capacity to climate shocks. Shahzad et al. (2021) found that income, livelihood diversification, social connection, formal education, and perception on climate change were the major factors influencing the livelihoods of local people in the Punjab of Pakistan. According to He et al. (2021), social support, irrigation rate, gender, membership in a cooperative, education level, labor force, endowments, farm size, and financial subsidies significantly influenced the adaptive capacity to cope with natural hazards in China. Several scientists found that climate events, age, education, gender, property, occupation of the household head, household size, sources of income, access to credit, remittances, social allowances, land tenure, machine, transport vehicles, social networks, associations, and weather forecast information significantly impacted household livelihoods in Vietnam (Nguyen et al., 2021; Arouri et al., 2015; Kuntiyawichai et al., 2015; Huynh and Stringer, 2018). Besides, water supply, communication, training, and other services were the other factors that significantly influenced the capacity of farmers to reduce their vulnerability to climate change at the regional level in Greater Mekong Sub-region (Kuntiyawichai et al., 2015). On the other hand, gender has mixed results in the literature, in which the male respondents were found to be vulnerable to climate change, whereas female respondents remained intact (Hanaoka et al., 2018); females were also found to be less vulnerable than males (Nguyen et al., 2021), or females were found to be more vulnerable than males (Aryal et al., 2020; World Bank Group and Asian Development Bank, 2021).

Most of the current literature on the livelihoods of rice households in Vietnam focused on the Mekong River Delta (Tran et al., 2020; Nguyen et al., 2020; Ho et al., 2021) and the Red River Delta (Luu et al., 2020a, 2020b; Casse et al., 2015; McElwee et al., 2017). Even though the NCC is the region most affected by climatic stresses in Vietnam, little notice has been given to this region and there have been only a few typical studies (Nguyen and Hens, 2019; Nguyen et al., 2021; Dao et al., 2019; Nguyen et al., 2017; Huynh and Stringer, 2018; Hoang, 2019). Recently, specific vulnerable communities in the coastal areas have received more attention. However, limited case studies have been quantitatively assessing the vulnerability of rice communities to climate change in the coastal area of Nghe An Province (Nguyen et al., 2021; People Committee of Nghe An province, 2020; Do and Tran, 2017). Towards the sustainable development of the agricultural sector in Nghe An Province, a thorough understanding of vulnerability assessment and possible measures to cope with climate change are urgently needed, which offers room for this study. Yet, some studies have just focused on assessing one climatic factor separately. For instance, some prior studies have focused on investigating the livelihood vulnerability of communities to droughts (Nguyen et al., 2019; Ray et al., 2018; Muthelo et al., 2019), floods (IPCC, 2007; Reynaud and Aubert, 2020; Bangalore et al., 2019; Dang, 2012), heat waves (Le, 2018; Chen et al., 2019; Maharjan et al., 2017), and cold spells (Le, 2018; Chen et al., 2019; Hidalgo et al., 2020). The impacts of vulnerability to multiple climatic stresses in Vietnam have not been well examined, creating difficulties for policymakers to design proper livelihood strategies in the context of increasing extreme climatic stresses (Le, 2018; Nguyen et al., 2019; Casse et al., 2015; Reynaud and Aubert, 2020; Nghiem, 2019; Smit et al., 1999; United Nations Viet Nam, 2014; Nguyen et al., 2018).

Thus, the study aims at assessing the vulnerability to climate change of rice households in the coastal area of Nghe An province and the factors affecting the households' vulnerability to climate change (i.e. drought, flood, heat wave, and cold spell). With respect to the objective, three districts were selected for household surveys of rice farming in the coastal area, namely, Dien Chau, Yen Thanh, and Quynh Luu districts. The outcomes of this study would benefit policymakers in prioritizing the top risks factors for climate change adaptation projects to reduce vulnerabilities and promote sustainable development in Nghe An province as well as other provinces in the NCC. The study is also consistent with the pressure of local authorities and rice communities in

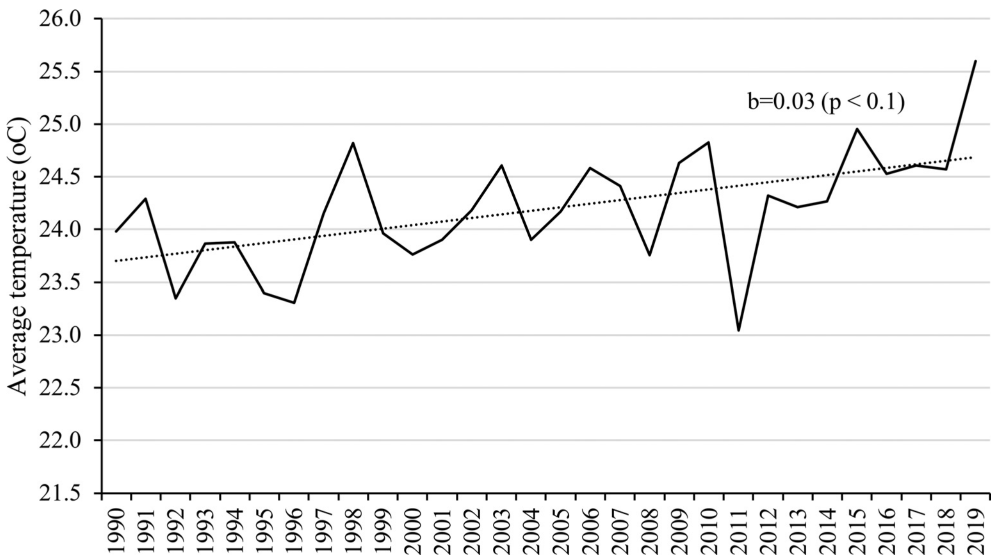

Fig. 1. Annual temperature recorded from Quynh Luu meteorological station from 1990 to 2019.
Source: Vietnam National Center for Hydro-Meteorological Forecasting (2020).

addressing the main climate stresses confronted by rice farmers. With the prominence on the topics related to the environmental and social effects in Nghe An, it is expected to fill the gap in the literature on the risks of climate change, the vulnerability of farmers, and their current adaptation options for minimizing the impacts of climatic hazards in Vietnam, especially in the target area.

2. Climate change in Nghe An province

Climate change has adversely influenced on natural resources, agricultural production, and livelihoods of farmers in Nghe An Province (Pham, 2020). Based on the historical data from 1986 to 2005, it is projected that by 2100, the temperature in Nghe An will increase by 0.7°C - 3.7°C on average, whereas annual rainfall will increase by 10.2% - 26.4%, as stated by the Ministry of Natural Resources and Environment (MONRE, 2016). By the period 2080 - 2099, it is forecasted that the area will be at risk of flooding in Dien Chau, Quynh Luu, and Yen Thanh with the probability of 27.57%, 16%, and 6%, respectively (Do and Tran, 2017; Nghe An's Department of Water Management, 2017).

In this province, increase temperature, little rainfall, and water shortage often occur from May to July. Those shocks may shorten the growth time, especially the growth time of rice and maize, leading to early flowering and low yields of all crops. The prolonged heat waves often happen from June to July with the maximum temperature from 40°C to 43°C during one week to one month, causing water shortage and significant loss of summer-autumn rice production (i.e., heatwaves in 1998, 2009, 2010, 2012, 2015, and 2020). In 2020, due to insufficient water supply, many pumping stations can only operate below capacity to pump water into the rice fields. Over 5000 ha of rice land was lost by the heat waves and prolonged droughts, whereas the remaining of over 54,000 ha was affected. To prevent the harmful effects of heat stroke people gradually shifted their works to late at night or early in the morning to avoid the sun (i.e. harvesting, tilling, and planting). On the other hand, the reduction of temperature to below 23 °C significantly increased the percentage of empty rice grain. Cold spells often occur from December to February, leading to the death of livestock and loss of winter-spring rice production (i.e. cold spells happened from January to February in 2008, December 2013, December 15–20, 2020) (Hoang et al., 2020; IMHEN and UNDP, 2015; MONRE, 2016).

In addition, floods often occur from September to November. The magnitude and the intensity of floods not only destroy productive assets but also adversely affect the livelihoods of households in the rural areas, especially the coastal area. From 1990 to 2010, Nghe An experienced 34 storms and 29 serious floods, with a total economic loss of 157.4 million USD (Nguyen et al., 2021). In 2020, in the low-lying areas, floods mainly occurred in Dien Chau, Yen Thanh, Quynh Luu, Hung Nguyen, and Thanh Chuong districts. In 2020, the province suffered extreme floods and damages of more than 3,300 houses, 65 million USD, and the livelihoods of 10,000 people. Approximately 2,900 ha of rice were damaged, the estimated loss was 10.6 million USD. About 2,440 ha of maize and vegetables were inundated, of which 957 ha, 126 ha, and 786 ha were in Quynh Luu, Yen Thanh, and Dien Chau, respectively. Submerging also caused the dead of 5,400 poultry, of which 4,700 poultry of Quynh Luu and 200 poultry of Yen Thanh were dead. About 778 ha of aquaculture ponds and small lakes were damaged, of which 343 ha, 222 ha, and 47 ha were in Dien Chau, Quynh Luu, and Yen Thanh, respectively (Steering Committee for Natural Disaster Prevention, Control and Search and Rescue, 2020).

The data from Vietnam National Center for Hydro-Meteorological Forecasting showed that in 1990, 1997–1998, and 2003–2004, prolonged droughts happened in Nghe An due to the late coming of the rainy season and the uneven distribution of rainfall (Vietnam National Center for Hydro-Meteorological Forecasting, 2020). Rainfalls were extremely high in 1996, 2010, and 2013, causing floods across many areas (IMHEN and UNDP, 2015). Fig. 1 shows the temperature trend in Nghe An province based on historical data. The result shows that temperature increased by 0.03°C annually on average for 30 years ($p < 0.10$), which is in line with a study by the Ministry of Natural Resources and Environment (MONRE, 2016).

3. Materials and methods

3.1. Study area

Nghe An province is positioned between 18°33′–20°01′ N and 103°52′–105°48′ E (Nguyen et al., 2020) (Fig. 2). The rainy season is from May to October, and the dry season is from November to April. The average monthly temperature is 27°C in the rainy season and 19°C in the dry season. The highest temperature can reach 42–43°C and the lowest temperature may fall to nearly 0°C. Approximately 80% of the annual rainfalls are distributed in the rainy season and the average rainfall ranges from 1200 mm/year to 2000 mm/year (Pham, 2020; People Committee of Nghe An province, 2020; Nghe An's Department of Agriculture and Rural Development, 2021). The total area of agricultural and forestry land is approximately 1.24 million ha, of which 186,000 ha is covered with paddy rice (about 75%). In 2016, Yen Thanh, Dien Chau, and Quynh Luu districts were the three biggest rice-producing areas, with a total area of 58,000 ha. In 2020, the average

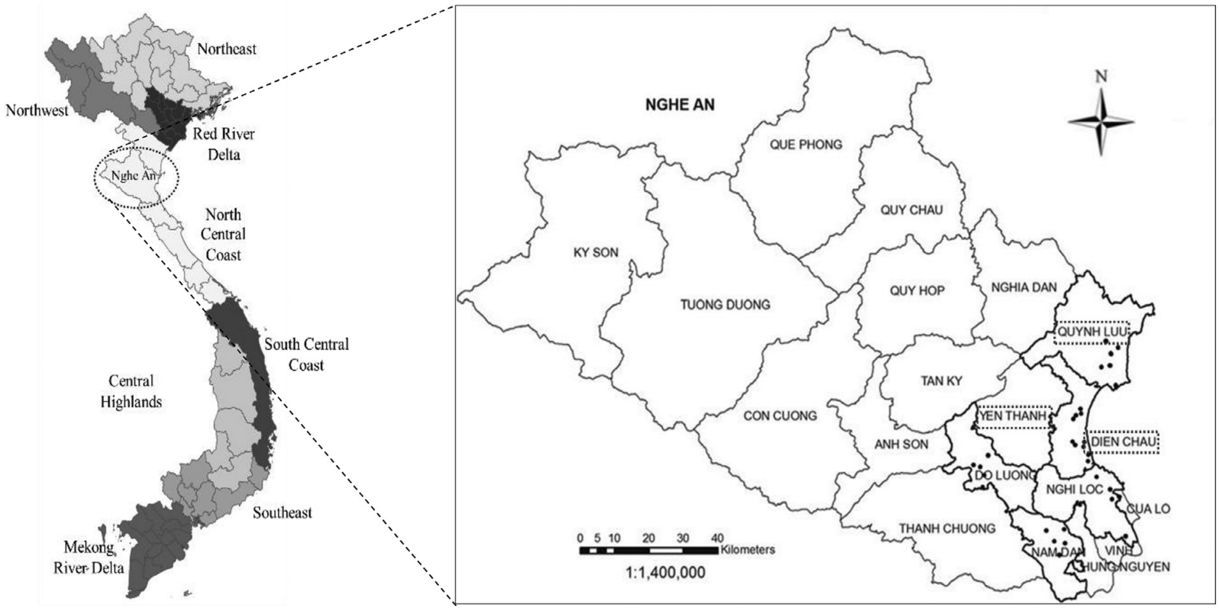

Fig. 2. Map of Study area: Dien Chau, Quynh Luu, and Yen Thanh districts in Nghe An province.
Source: Adapted from Le et al. (2017).

yield of the winter-spring rice crop in Nghe An was 6.7 tons/ha. In particular, the rice cultivation area of Dien Chau, Yen Thanh, and Quynh Luu districts was up to 29,350 ha, achieving an average yield of 7.3–7.4 tons/ha, with several fields achieved the yield of 8.4 - 8.6 tons/ha (Nghe An's Department of Agriculture and Rural Development, 2021).

In the coastal plains of Nghe An, Quynh Luu, Dien Chau, and Yen Thanh districts are located in the lowest part of the province with some areas lying only 0.2 meter above the mean sea level, suggesting the risks of being submerged in the monsoon (Le et al., 2017a; Nghe An's Department of Agriculture and Rural Development, 2021). According to the People Committee of Nghe An province, residents in the three districts have suffered from food security and income loss caused by climate change impacts, including heat waves, drought, storms, and flash floods. Storms, heavy rains, and flash floods occur more frequently. In recent year, Nghe An province is affected by 8–12 storms per year (People Committee of Nghe An province, 2020). Since 2016, heat waves and insufficient water flows have become more frequent in the province, leading to water shortage and agricultural drought on a large scale, particularly in Dien Chau, Yen Thanh, and Quynh Luu districts. However, the water-retaining capacity of most reservoirs in the areas is limited, leading to severe floods in the rainy season and serious water shortage and droughts in the dry season (Nghe An's Department of Agriculture and Rural Development, 2021). According to the statistics published by the Steering Committee for Natural Disaster Prevention, Control and Search and Rescue, 2020, Quynh Luu, Yen Thanh, and Dien Chau were among the districts significantly affected by extreme floods, heat waves, and prolonged droughts. Therefore, the three above districts were purposively selected for climate vulnerability assessment in this study.

3.2. Primary data collection

In this study, a multi-stage sampling method was used for data collection. First, Nghe An province of Vietnam was purposively selected because of its vital role in the regional economy. Second, Dien Chau, Quynh Luu, and Yen Thanh districts were purposively selected because of the frequency and the intensity of climatic stresses and the similarity of geographical, socio-demographic, and economic characteristics of rice households in the coastal area of Nghe An. Third, a proportional sampling method was applied to calculate the sample size. Lastly, the simple random method was applied for data collection in selected districts. The secondary data of the total number of rice households in the three districts were 236,234 (Nghe An's Department of Agriculture and Rural Development, 2021). Adapting Yamane (1967), the sample size of this study was calculated as follows:

Table 1
Sample size by district.

Districts	Population	Proportionate sampling	Actual sample size
Yen Thanh	100,978	(100,978/236,234) *400 = 171	151
Quynh Luu	53,505	(53,505/236,234) *400 = 91	122
Dien Chau	81,751	(70,500/236,234) *400 = 138	123
Total	236,234	400	396

Source: Nghe An's Department of Agriculture and Rural Development, 2021.

$$n = \frac{N}{1 + Ne^2} = \frac{236,234}{1 + 236,234 \times (0.05)^2} = 399.3 \approx 400,$$

where n indicates the study's sample size, N indicates the total number of rice households in the three districts, and e indicates the margin of error at 5%. The sample size by the district for the study is shown in Table 1.

Primary data collection was conducted through a household survey from July to August in 2020. The questionnaire was built and pre-tested with 30 rice households in Dien Chau district to limit the ambiguities, based on the literature. Dien Chau district was chosen for pre-testing because of the high concentration of rice households. After the pre-test, more instructions were included in the questionnaire to help farmers more easily understand all of the questions. Before the interviews, several meetings were organized with the local authority and village leaders to take permission for the survey. On the decided schedules, face-to-face interviews between farmers and the interviewers were performed in the Vietnamese language with the support of local staff. It took approximately 60–90 min to complete the questionnaire for each household.

Following Hahn et al. (2009) and other studies (Sujakhu et al., 2019; Adu et al., 2018; Ho et al., 2021; Suryanto and Rahman, 2019; Ahmad and Ma, 2020), the questionnaire was constructed by using seven major components, including the socio-demographic, livelihood strategy, and water supply components. Respondents were asked several questions associated with households' livelihoods in 2020 (the time of interview) to investigate their adaptive capacity. Besides, to investigate households' sensitivity during the last 12 months (2019–2020), there were several questions associated with health care component (i.e., access to health care service and member with chronic illness), food supply component (i.e., household's food supply produced by their own farm, food supply deficiency, crop diversity, saving crops, and saving seeds), and social network component (i.e., receiving the local authority's assistance, membership of any group, participation in any training, proportional receiving and giving, and proportional borrowing and lending of money). Other questions associated with climatic stresses were asked to investigate households' exposure for the last 5 years (2015–2020) (i.e., number of extreme climatic stresses, receiving climatic information, and income loss because of climatic stresses). In general, 32 sub-components were used in this study (see the Supplementary materials).

3.3. Methods of analysis

This study aimed at measuring the level of vulnerability by using both descriptive and econometrical methods. In this study, descriptive statistics were employed to describe the basic characteristics of respondents in the study area, such as frequency, percentage min, max, and standard deviation. Following that, the livelihood vulnerability index (*LVI*) was used to assess the level of households' vulnerability to climatic stresses in the study area. Since the selection of sub-components for calculating the *LVI* may induce potential biased results, econometric method was used to explore the factors affecting the level of vulnerability to climate change of rice community in the coastal area. Moreover, in this province, the local authorities have offered several policies to reduce households' vulnerability. Due to the limitation of government budget, it is necessary to explore which factors should be involved in the latest climate change adaptation policies. The pairwise correlation and beta regression were used to assess the factors affecting their vulnerability to climatic stresses. Based on the findings, policymakers could design appropriate adaptation strategies for this area as well as other areas having similar natural and socioeconomic conditions.

3.3.1. Assessing households' vulnerability to climatic stresses

Scholars around the world have conducted studies on climate vulnerability assessments by using different indicators, such as the socioeconomic vulnerability index (Ahsan and Warner, 2014; Sam et al., 2017), the livelihood effect index (Nguyen et al., 2018; Ahmad and Ma, 2020), the climate vulnerability index (Alam et al., 2017; Pandey et al., 2017), and the *LVI* (Nguyen et al., 2019; Dao et al., 2019; Sujakhu et al., 2019; DFID, 1999; Ho et al., 2021; Suryanto and Rahman, 2019; Ahmad and Ma, 2020; Alam et al., 2017). Out of those indicators, the *LVI* has been widely used by numerous researchers worldwide because of its flexibility. According to current literature, the *LVI* attempts to offer policymakers an overview of various socioeconomic and climate conditions, and other relevant factors that affect vulnerability at different levels (household, district, provincial, or regional levels) and several sub-components may be modified to fit the study area's context. Moreover, using this approach is flexible because it standardizes different measurements for calculating each sub-component (Nguyen et al., 2018; Venus et al., 2021). Adapting the sustainable livelihood framework, the *LVI* is a useful approach to assess households' vulnerability to climate change (DFID, 1999; Hahn et al., 2009). Thus, in this study, the *LVI* was chosen for climate vulnerability assessment in Nghe An province. Given differences in the measurements of each sub-component, it was critical to calculate the index of specific sub-component by using Eq. (1) as follows:

$$index_{S_i} = \frac{S_i - S_{min}}{S_{max} - S_{min}}, \tag{1}$$

where S_i implies the value of a specific sub-component of household *i*, S_{min} implies the minimum value, and S_{max} implies the maximum value.

Next, to compute the value of each major component, Eq. (2) was used as follows:

$$M_i = \frac{\sum_{j=1}^{n} index_{S_{ij}}}{n}, \tag{2}$$

where M_i implies the value of a specific major component of household *i*, $index_{S_{ij}}$ implies the value of specific sub-component j^{th}, and *n* implies the number of sub-components under each major component.

For example, the raw value of "crop diversity" was calculated by using the formula [1/(number of crops + 1)]. A household that cultivated four crops (e.g., rice, maize, sesame, and soybean) would have a "crop diversity" index of 1/ (4 + 1) = 0.20. Crop diversifications adopted by households would reduce their vulnerability to climate stresses. Given different responses of crops to the same climatic shock, this strategy was considered as a solution to reduce the risk of crop loss (DFID, 1999; Ho et al., 2021; Venus et al., 2021).

Finally, Eq. (3) was used to calculate the *LVI* of each household as follows:

$$LVI_j = \frac{\sum_{k=1}^{7} w_{Mk} M_{jk}}{\sum_{k=1}^{7} w_{Mk}}, \tag{3}$$

where LVI_j implies the value of the *LVI* of household *j*, w_{Mk} implies the number of sub-components under each major component *k*, and M_{jk} implies the value of major component *k* of household *j*.

Adapting FANRPAN, 2011), the value of the calculated *LVI* was classified from 0.00 to 1.00 as follows:

- 0.00 - 0.30 as "not vulnerable": Farmers do not recognize their vulnerability yet. Hence, policy interventions need to improve their awareness and resilience to climate shocks.
- 0.31 - 0.46 as "slightly vulnerable": Farmers are vulnerable to climate shocks, but they have capacities to cope with those shocks and recover. Hence, policy interventions need to strengthen their capacities to cope with shocks.
- 0.47 - 0.51 as "moderately vulnerable": Farmers are temporarily vulnerable at the time the shock happens. Hence, policy interventions need to provide external support to help them recover after shocks.
- 0.52 - 0.60 as "highly vulnerable": Farmers are facing hardship due to the frequency of severe climate shocks. Hence, policy interventions need to urgently and continuously provide external support to help them recover after shocks.
- 0.61 - 1.00 as "extremely vulnerable": Farmers are facing high risks at an emergency level. Hence, policy interventions need to urgently provide thorough supports from experts.

3.3.2. Factors affecting households' vulnerability to climatic stresses in Nghe An province

In this study, the beta regression was employed to investigate the effects of socioeconomic, institutional, and environmental factors on households' vulnerability to climatic stresses (Intergovernmental Panel on Climate Change (IPCC) 2014; Nguyen et al., 2018). The Ordinary Least Squares (OLS) assumes a normal distribution and the homoscedasticity of all values which are focused on the middle range. Instead, rate, proportion, or percentage tend to be skewed distribution in the lower and upper limits. Moreover, beta regression can be used for continuous dependent variables, ranging from zero to one, excluding the endpoints zero and one. Compared with the OLS, the beta regression is more appropriate to measure the *LVI* of each household in this study, which ranges from 0.19 to 0.62 (Ho et al., 2021; Cribari-Neto and Ferrari, 2004; Cribari-Neto and Zeileis, 2010). In the regression, the outcome is the *LVI* of each household and a total of 24 explanatory variables were used, including the climatic stresses. Some new factors (i.e. transportation, agricultural mechanization, and irrigation) were also included in the regression, which was expected to reduce the *LVI* (Table 2).

Table 2
Explanation of variables in beta regression.

Variable	Explanation	Measurement	Expected sign	Related research
Dependent variable: *LVI*	Livelihood Vulnerability index	LVI ∈ [0, 1]	N/A	N/A
Socio-demographic factors				
Age	Age of household head	Years	+/-	(Nghe An's Department of Agriculture and Rural Development, 2021; Adu et al., 2018; Ho et al., 2021; Bangalore et al., 2019)
Age squared	Square of age of household head		+	(Adu et al., 2018; Ho et al., 2021; Bangalore et al., 2019)
Gender	Sex of household head	Binary: 1 if Male; 0 if Female	–	(Adu et al., 2018; Shahzad et al., 2021; Ho et al., 2021)
Family laborer	Number of laborers in family	Persons	–	(Hoang et al., 2020; People Committee of Nghe An province, 2020; Ho et al., 2021; Casse et al., 2015)
Education	Years of education of household head	Years	–	(Leartlam et al., 2021; Adu et al., 2018; Ho et al., 2021)
Farm size	Total area for agricultural activities	ha	+/-	(Hoang et al., 2020; Leartlam et al., 2021; Adu et al., 2018; Ho et al., 2021)
Farm size squared	Square of the total area for agricultural activities		+	(Hoang et al., 2020; Leartlam et al., 2021; Ho et al., 2021)
Income sources	Number of household's income sources	Number	–	(Nguyen and Hens, 2019; Nguyen et al., 2019; People Committee of Nghe An province, 2020; Ho et al., 2021)
Property	Total value of household's property	1000 USD	–	(People Committee of Nghe An province, 2020; Sujakhu et al., 2019; Ho et al., 2021; Bangalore et al., 2019)
Off-farm income	Annual off-farm income	1000 USD	–	(Leartlam et al., 2021; Dao et al., 2019; Ho et al., 2021)
Institutional factors				
Farmers' association	Member of any farmers' association	Binary: 1 if yes; 0 if otherwise	–	(Leartlam et al., 2021; People Committee of Nghe An province, 2020; Bangalore et al., 2019)
Agricultural cooperative	Members of agricultural cooperative	Binary: 1 if yes; 0 if otherwise	–	(Leartlam et al., 2021; People Committee of Nghe An province, 2020; Sujakhu et al., 2019; Nghe An Farmer's Association, 2020)
Training	Number of participating annual agricultural training	Times	–	(Leartlam et al., 2021; Ho et al., 2021; Bangalore et al., 2019)
Formal credit	Availability of access to formal credit	Binary: 1 if yes; 0 if otherwise	–	(Hoang et al., 2020; Nghe An's Department of Agriculture and Rural Development, 2021; Sujakhu et al., 2019)
Transportation	Availability of public transportation	Binary: 1 if yes; 0 if otherwise	–	(Ho et al., 2021)
Irrigation	Availability of access to irrigation	Binary: 1 if yes; 0 if otherwise	-	(Sujakhu et al., 2019; Bangalore et al., 2019)
Agricultural mechanization	Availability of access to machine	Binary: 1 if yes; 0 if otherwise	-	(Ho et al., 2021)
Climatic factors				
Floods	Number of extreme flood events in period 2015–2020	Times	+	(Sa-adthien et al., 2020; Reynaud and Nguyen, 2016; Nguyen et al., 2020)
Droughts	Number of extreme drought events in period 2015–2020	Times	+	(Nguyen et al., 2019; Ray et al., 2018; Vietnam National Center for Hydro-Meteorological Forecasting, 2020)
Heat waves	Occurrence of extreme hot wave in period 2015–2020	Binary: 1 if yes; 0 if otherwise	+	(MONRE, 2016; Reynaud and Nguyen, 2016; Maharjan et al., 2017)
Cold spells	Occurrence of extreme cold spell in period 2015–2020	Binary: 1 if yes; 0 if otherwise	+	(Le, 2018; Reynaud and Nguyen, 2016; He et al., 2021)
Climate information	Warning of climate information by the local authority	Binary: 1 if yes; 0 if otherwise	–	(Shahzad et al., 2021; Ho et al., 2021; Bangalore et al., 2019)
Location factors				
Dien Chau	Households lived in Dien Chau district	Binary: 1 if yes; 0 if otherwise	+/-	N/A
Quynh Luu	Households lived in Quynh Luu district	Binary: 1 if yes; 0 if otherwise	+/-	N/A

The specific beta regression was generated, as in Eq. (4):

$$LVI = \beta_0 + \beta_1 \text{Age} + \beta_2 \text{Agesquared} + \beta_3 \text{Gender} + \beta_4 \text{Education} + \beta_5 \text{Family\_laborer} + \beta_6 \text{Income\_sources} + \beta_7 \text{Property} + \beta_8 \text{Farm\_size} + \beta_9 \text{Farm\_size\_squared} + \beta_{10} \text{Off\_farm\_income} + \beta_{11} \text{Agricultural\_cooperative} + \beta_{12} \text{Farmer\_association} + \beta_{13} \text{Training} + \beta_{14} \text{Formal\_credit} + \beta_{15} \text{Transportation} + \beta_{16} \text{Agricultural\_mechanization} + \beta_{17} \text{Irrigation} + \beta_{18} \text{Heat\_waves} + \beta_{19} \text{Cold\_spells} + \beta_{20} \text{Floods} + \beta_{21} \text{Droughts} + \beta_{22} \text{Climate\_information} + \beta_{23} \text{Dien\_Chau} + \beta_{24} \text{Quynh\_Luu} \tag{4}$$

For numerical variables, the coefficients are explained as an additional change in the log-odds ratio of the outcome by a unit rise of each explanatory variable, holding other explanatory variables unchanged. Likewise, changing from 0 to 1 in the binary or dummy explanatory variable leads to an additional change in the log-odds ratio of the outcome, holding other explanatory variables unchanged. Moreover, the marginal effect of each explanatory variable on the outcome was estimated for convenience in explaining the results (Ho et al., 2021; Cribari-Neto and Ferrari, 2004). For example, "gender" is a binary variable that takes the value of one for male household head and zero for female. Once gender negatively affects vulnerability to climate stress, it implies that male farmers are less vulnerable than females, holding other explanatory variables unchanged. For other binary variables (i.e., agricultural cooperative, formal credit, transportation, agricultural mechanization, irrigation, and climate information), those factors are expected to reduce households' vulnerability to climatic stresses because they may improve farmers' capacity and their resilience to recover from natural hazards. For instance, "irrigation" takes the value of one for "yes" and zero otherwise. Once the observed parameter of this variable shows a negative effect on the *LVI*, suggesting that irrigation reduces household' vulnerability to climate stress, holding other explanatory variables unchanged. Furthermore, "hot waves" and "cold spells" increase vulnerability to climate stresses, suggesting that a change in temperature causes risks to livelihoods. For numerical variables, such as "age", an increase in the age of household head by one year will generate a change in the log-odds ratio of *LVI*, holding other explanatory variables unchanged. Similar explanations are used for other variables (i.e., family laborer, education, income source, property, off-farm income, and training). Similarly, floods and droughts lead to physical and financial losses, causing livelihood uncertainty for households (Le, 2018; Sa-adthien et al., 2020; Reynaud and Nguyen, 2016; Ho et al., 2021; Casse et al., 2015; Muthelo et al., 2019). According to Nghe An Farmer's Union, 2018, being member of an agricultural association, farmers are protected by legitimate rights and receive several benefits, such as facilities, access to funds and credits, consulting services, and supports in production, business, and livelihoods. On the other hand, according to Nghe An Cooperative Alliance, 2020, being a member of cooperatives, farmers receive consulting services, training courses, and supports (i.e. inputs, subsidies, funds, access to credit, market information, off-farm works, and others) from the cooperatives and enterprises in producing and selling their commodities. Moreover, members may have the access to participate in the network of experts and farmers who have experience in climate change adaptation for knowledge sharing towards the sustainable development of the region.

In this study, the currency unit was changed from 1 USD to 1,000 USD for easy interpretation of property and off-farm income' parameters. This study expected the non-linear effects of age and farm size on the *LVI*. Thus, the variables of age squared and farm size squared were used in the regression. A pairwise correlation matrix was applied to consider potential connections between the *LVI* and the explanatory variables (Table 5).

Microsoft Excel and STATA version 17 were employed to calculate all the major and sub-components, the *LVI*, the pairwise correlation matrix, and the parameters of all variables in the regression. The explanations of all variables that appeared in beta regression are presented in Table 2.

4. Results and discussion

4.1. Descriptive statistics of rice households in Nghe An province

Tables 3 provides an overview of the basic characteristics of the surveyed households in Nghe An province. Table 3 reveals that the mean age was 55 years old, implying a high proportion of older farmers in the study area. Most household heads were male (79%), the average number of family laborers was three. Households reported that wage laborer wase a big issue during the peak time of the cropping season, especially for those households who lacked family laborers. A vast majority (98.7%) of the sampled respondents had participated in formal education, thereby enhancing their ability to maintain their livelihoods. In this area, farm size had a small value, which ranged from 0.02 ha to 2.35 ha. Households realized that livelihood diversification significantly improved their incomes, such as off-farm work with an average income of 1,370 USD. Values of households' properties ranged from 40 USD to 66,420 USD, implying a big gap between the poor and the rich people.

More than half of the respondents participated in farmers' associations (53%) and an agricultural cooperative (71%) to gain access to formal credit, climate information, and market information. Farmers' associations in Nghe An province offered consulting activities, funds, input support programs, extension visits, and training classes to achieve the National Target Program on building new countryside since 2010 (Nghe An Farmer's Association, 2020). Most households had access to transportation (98%), agricultural mechanization (86%), and irrigation (73%). Therefore, many households had sufficient resources for agricultural production. More than 50% of the surveyed households reported that they had not received any training courses, which might impede their capacity to cope with the impacts of climatic stresses and improve the total productivity. The results show that more than 75% of respondents in the study area suffered from abnormal temperature fluctuations (either heat waves or cold spells). They experienced 5 floods and 3 droughts, on average. In general, climatic stresses frequently happened in Nghe An province, causing crop failures as well as destroying households' assets (IMHEN and UNDP, 2015; People Committee of Nghe An province, 2020; Nghe An's Department of Agriculture and Rural Development, 2021).

4.2. Assessing households' vulnerability to climatic stresses

Following FANRPAN, 2011, Table 4 shows that 76% of the sampled households in the study area were slightly vulnerable to climatic stresses, which caused income losses for households in the coastal area (Nguyen et al., 2019; Dao et al., 2019; Ho et al., 2021). Yen Thanh was less vulnerable to climatic stresses than the other districts because of its topography (Dao et al., 2019). In general, households in the study area were vulnerable because of the frequency and intensity of unpredicted climate shocks. Hot waves and cold spells often occurred in the study area, which hampered the growth of both plants and animals (Le, 2018; Chen et al., 2019; Kolawole et al., 2016). Yet, respondents had the capacity to cope with climate-induced stresses in the study area. Many households received government supports for disaster relief (i.e. foods and financial support) and agricultural subsidies such as climatic stress-tolerant rice varieties, funds, and technical training for sustainable development of agriculture. In the flood-prone areas of Nghe An province, farmers were encouraged to grow rice varieties with a growth period of less than 100 days such as VT-NA2, VT-NA6, Thien Uu 8, Khang Dan 18, HT1, and BT09 for the summer-autumn crop. This crop was sown early to finish the harvest at the end of August, before the rainy season came. Direct seeding in the early summer-autumn crop was limited, farmers used transplants right after harvesting summer-autumn rice to avoid flooding. Due to low rainfall, several farmers switched from rice

Table 3
Sociodemographic characteristics of respondents (*n = 396*).

Variable	Frequency	%	Mean	S.D.	Min.	Max.
Sociodemographic characteristics of respondents						
Age (years)	–	–	55.24	10.70	28	79
Gender (1 if male)	314	79.29	0.79	0.41	0	1
Family laborer (persons)	–	–	2.73	1.60	0	8
Education (years)	–	–	8.18	2.62	0	16
Income sources (number)	–	–	3.48	0.85	2	7
Property (1000 USD)	–	–	3.50	7.94	0.04	66.42
Off-farm income (1000 USD)	–	–	1.37	1.75	0.00	10.44
Farm size (ha)	–	–	0.24	0.19	0.02	2.35
Institutional factors						
Farmers' association (1 if yes)	210	53.03	0.53	0.50	0	1
Agricultural cooperative (1 if yes)	280	70.71	0.71	0.46	0	1
Training (times)	–	–	0.19	0.45	0	2
Formal credit (1 if yes)	232	58.59	0.59	0.49	0	1
Transportation (1 if yes)	388	97.98	0.98	0.14	0	1
Agricultural mechanization (1 if yes)	339	85.61	0.86	0.35	0	1
Irrigation (1 if yes)	289	72.98	0.73	0.44	0	1
Climatic factors						
Climate information (1 if yes)	272	68.69	0.69	0.46	0	1
Heat waves (1 if yes)	304	76.77	5.00	3.64	0	20
Cold spells (1 if yes)	302	76.26	3.47	2.76	0	15
Floods (times)	–	–	5.18	3.73	0	15
Droughts (times)	–	–	3.28	3.25	0	10

Table 4
Levels of households' *LVI* by districts in the study area.

Level of vulnerability (*LVI*)	Dien Chau Frequency	%	Quynh Luu Frequency	%	Yen Thanh Frequency	%	Combined Frequency	%
Not vulnerable	0	0.0	4	3.3	2	1.3	6	1.5
Slightly vulnerable	91	74.0	92	75.4	118	78.1	301	76.0
Moderately vulnerable	23	18.7	22	18.0	26	17.2	71	17.9
Highly vulnerable	8	6.5	4	3.3	5	3.3	17	4.3
Extremely vulnerable	1	0.8	0	0.0	0	0.0	1	0.3

Note. Value of *LVI* was classified from 0.00 to 0.30 as "not vulnerable", 0.31 to 0.46 as "slightly vulnerable", 0.47 to 0.51 as "moderately vulnerable", 0.52 to 0.60 as "highly vulnerable", and 0.61 to 1.00 as "extremely vulnerable", according to FANRPAN, 2011.

farming to short-term vegetables (e.g. coriander, green onion, garlic chive, lettuce, fish mint, peppermint, Indian taro, and water spinach), herbals (e.g. solanum procumbens, plane tree, maidenhair fern, and green chiretta), maize, beans, and forest plantation. Since 2010, Nghe An province had been planting 15,000 ha of forest each year, contributing to the increase of the province's forest cover at the end of 2014 to 54.6%. Acacia plantation became a tool for poverty alleviation and sustainable development in the rural areas (People Committee of Nghe An province, 2020; Nghe An's Department of Agriculture and Rural Development, 2021; Vu et al., 2020).

4.3. Assessing the factors affecting rice households' vulnerability to climatic stresses

Firstly, Table 5 shows a correlation matrix for assessing the relationships between the *LVI* and 24 independent variables. The correlation between these variables was computed by using Pearson correlation. The correlation coefficients ranged from −0.254 to 0.309, indicating that they were not highly correlated. In Table 5, out of the 24 variables, 11 variables were significantly correlated with the *LVI* at 1% level of confidence, and only farm size variable was significant at 5% level.

Next, the beta regression results for assessing factors affecting rice households' vulnerability to climatic stresses shown in Table 6 show that 17 factors significantly influenced households' vulnerability index ($p < 0.01$). Cold spells, education, income sources, and agricultural cooperatives reduced households' vulnerability to climatic stresses. Floods, droughts, gender, family laborer, property, off-farm income, formal credit, irrigation, and Dien Chau district dummy increased households' vulnerability to climatic stresses. Age and farm size had non-linear effects on household' s vulnerability to climate stresses.

The result implied that aging farmers were more vulnerable than young farmers because they were less likely to engage in livelihood diversification. Land use change and all farming activities require labor force, investment budget, and time for conversion, especially for horticulture and forestry. Aging farmers are facing health problems and have less opportunities to seek additional incomes. Even when they engage in agricultural diversification, their production costs are also higher than those of the youth due to higher labor costs. On the other hand, young farmers are more enthusiastic about learning advanced farming techniques for climate change adaptation solutions (Leartlam et al., 2021; Huynh and Stringer, 2018; Ho et al., 2021; Muthelo et al., 2019; Kolawole et al., 2016; Vu et al., 2020; Rigg et al., 2019(Mabuku et al., 2019)).

Gender positively influenced a household's vulnerability to climatic stresses, indicating that a male-headed household was more vulnerable to climatic stresses than the counterpart. This finding may be because in the rural area, male members perform more heavy works on farms, and they are responsible for earning the main household income. Female members play an important role in taking care of children and doing housework. Moreover, many women were supported by the local authority and Women Union to participate in both on-farm and off-farm works for financial independence (i.e. raising animals, making handicrafts, food processing, and doing small businesses). Given different roles between male and female members in a family, the females were less vulnerable than the males in this situation (Shahzad et al., 2021; ; Balikoowa et al., 2019(Owusu et al., 2021).

Table 5
Pairwise correlation between the household vulnerability to climate change (*LVI*) and independent variables.

Variable	Pearson correlation coefficient	Level of significance
Age	−0.254	0.01
Age squared	−0.250	0.01
Gender	0.277	0.01
Family labor	0.208	0.01
Education	0.017	–
Income source	−0.017	–
Property	0.063	–
Farm size	−0.109	0.05
Farm size squared	−0.060	–
Off farm income	0.309	0.01
Farmer association	−0.027	–
Agriculture cooperative	−0.139	0.01
Training	−0.156	0.01
Formal credit	0.157	0.01
Transportation	0.035	–
Agricultural mechanization	0.015	–
Irrigation	0.088	–
Heatwaves	0.053	–
Cold spells	0.059	–
Floods	0.144	0.01
Droughts	0.158	0.01
Climate information	−0.073	–
Dien Chau	0.131	0.01
Quynh Luu	−0.088	–

Unlike expectation, family laborers increased households' vulnerability to climatic stresses, a rise of the family laborer by one person would increase *LVI* by 0.63% point. Given the average monthly income from rice business was only 60 USD in the study area, family labors who engaged in traditional agriculture experienced income hardship to overcome the impacts of climatic events. The harsh natural conditions and climate events over the years have made life more difficult for them ((Hoang et al., 2020; Sileshi et al., 2019);). Nghe An province has a large labor force, creating a lot of pressure on job creation. Although the People Committee of Nghe An province has implemented many solutions such as developing handicraft villages, industrial parks, and creating jobs for laborers but it has not yet met the requirements of the society. On the other hand, many laborers have quitted or lost their jobs in the urban area due to the outbreak of COVID-19 pandemic since early 2020. Labor unemployment has led to a waste of human resources, affecting the livelihoods of many households and the socioeconomic development in this province (Hoang et al., 2020; People Committee of Nghe An province, 2020; Casse et al., 2015).

Education strengthened households' capacities to reduce the vulnerability and enhance their livelihoods, an additional year of farmers' education would decrease the *LVI* by −0.21% point. Previous studies revealed that higher educated people had a higher probability of adopting new techniques and engaging in employment (Hoang et al., 2020; Leartlam et al., 2021; Le et al., 2017a; Tjoe, 2016; (Balikoowa et al., 2019). As stated by Kuchimanchi et al. (2021), a high level of education would benefit farmers in Telangana, India by building their capacity in farm management, seeking additional income, and coping with any shocks caused by climate stresses or other extremes.

Income sources reduced households' vulnerability to climatic stresses. Households with an additional income source had a probability of decreasing the *LVI* by −0.79% point. Many studies have confirmed this finding. Several households have modified the crop patterns and animals in accordance with the changes in weather pattern (Le et al., 2017b; Nguyen and Hens, 2019; Leartlam et al., 2021; Nguyen et al., 2019; Dao et al., 2019). In recent years, due to low rainfall, several farmers have switched from rice farming to up-land crops (i.e. maize, sugar cane, onion, livestock grass, and vegetables), generating about 7 to 10 times higher economic efficiency than rice farming. Moreover, farmers have modified their planting schedule by cultivating early winter crops and using short-term crops to avoid storms and floods. Besides,

Table 6
Results of beta regression for the assessment of factors influencing households' vulnerability to climatic events ($n = 396$).

Variables	Coef.	S.E	Marginal effect	*p*-value	
Age (years)	−0.0151	0.0075	−0.0037	0.045	**
Agesquared	0.0001	0.0001	0.0000	0.095	*
Gender (1 if male)	0.1404	0.0247	0.0341	0.000	***
Family laborer (persons)	0.0257	0.0065	0.0063	0.000	***
Education (years)	−0.0086	0.0039	−0.0021	0.026	**
Income sources (number)	−0.0322	0.0121	−0.0079	0.008	***
Property (1000 USD)	0.0020	0.0012	0.0005	0.095	*
Farm size (ha)	−0.3347	0.1058	−0.0818	0.002	***
Farm size squared (ha^2)	0.1361	0.0559	0.0333	0.015	**
Off-farm income (1000 USD)	0.0273	0.0062	0.0067	0.000	***
Farmers' association (1 if yes)	−0.0326	0.0231	−0.0080	0.158	
Agricultural cooperative (1 if yes)	−0.1720	0.0302	−0.0422	0.000	***
Training (times)	−0.0264	0.0260	−0.0064	0.310	
Formal credit (1 if yes)	0.0818	0.0216	0.0200	0.000	***
Transportation (1 if yes)	−0.0494	0.0720	−0.0121	0.494	
Agricultural mechanization (1 if yes)	0.0141	0.0347	0.0034	0.686	
Irrigation (1 if yes)	0.1406	0.0343	0.0342	0.000	***
Heat waves (1 if yes)	0.0027	0.0052	0.0007	0.609	
Cold spells (1 if yes)	−0.0186	0.0062	−0.0045	0.003	***
Floods (times)	0.0140	0.0054	0.0034	0.010	***
Droughts (times)	0.0304	0.0053	0.0074	0.000	***
Climate information (1 if yes)	−0.0239	0.0290	−0.0059	0.410	
Dien Chau (1 if yes)	0.0521	0.0230	0.0128	0.024	**
Quynh Luu (1 if yes)	−0.0131	0.0242	−0.0032	0.588	
Constant	0.1069	0.2143			
Scale constant	4.8577	0.0708			
Diagnosis					
Number of observations	396				
Dependent variable: *LVI*					
L.R. χ^2 (*p*-value)	222.81 (0.000)				
Log likelihood	681.6777				

Note: ***, **, and * show statistical significance at 1%, 5%, and 10% levels, respectively.

mangrove forest plantation has been promoted by the local authorities (People Committee of Nghe An province, 2020; Vu et al., 2020).

In this study, property and off-farm income increased households' vulnerability to climatic stresses. This may be because the property of farmers included saving at the bank and productive assets (i.e. land, machines, and livestock). At the time the household surveys being conducted, climatic events and COVID-19 pandemic resulted in a dramatic drop of incomes from agricultural businesses, remittance flows, as well as the deposit interest rates, leading to huge losses for farmers (People Committee of Nghe An province, 2020). Moreover, many people experienced unemployment, thereby being relied on household's saving. According to Aryal et al. (2020), households who used their savings for climate risk adaptation had more capability to engage in additional employment. In the study area, climate stresses forced people to find other jobs to compensate for their losses, but the pandemic hampered the opportunities to engage in all sectors. Even though households could receive assistance from the local authorities, it was limited both in the amount received and the complicated process they had to undergo (People Committee of Nghe An province, 2020).

Farm size had a positive effect on households' vulnerability to climatic stresses. Given the small area of rice fields in Nghe An province (as shown in Table 3), holding more than one small plot located in different places might increase the production cost for rice producers (Nguyen and Leisz, 2021). Hence, holding extra farmland would increase households' vulnerability as they could not enjoy the benefit of increasing returns to scale. In several places, small and degraded water reservoirs, temporary dams, and dikes did not meet the requirements of agricultural production for all farmlands. Therefore, many farmers were not well-prepared for the adoption of flood or drought adaptation strategies (People Committee of Nghe An province, 2020).

As expected, agricultural cooperatives reduced households' vulnerability to climatic stresses, suggesting that being a members of a cooperative may enhance households' adaptive capacity. Many studies have found that farmer groups provided farmers with access to credit, information, infrastructure, extension visits, and training courses (Leartlam et al., 2021; Sujakhu et al., 2019; ; Medugu et al., 2014; Ayodeji et al., 2017(Sadiq et al., 2019)). In 2020, there were 780 cooperatives in Nghe An, of which 419 cooperatives were highly effective in performing their activities (53.72%), 319 cooperatives were averagely efficient (40.80%), and 42 cooperatives were low efficient. After the transformation, the cooperatives have expanded their production and business, bringing the highest benefits to their members. Creating jobs and increasing incomes for farmers are the positive contributions of cooperatives in the process of agricultural development and new rural construction in Nghe An (Vietnam Cooperative Alliance (VCA), 2020). Cooperatives in the province support machines, equipment, and technical training to improve production techniques, management skills, and market development for their staff and participating farmers (; Hoang, 2020(Dobkowitz et al., 2020)).

Unlike expectations, formal credit increased households' vulnerability to climatic stresses. Previous studies revealed that many poor households could not pay interests on time, resulting in extra payments to the loan (Chainuvati and Athipanan, 2001; Hoang et al., 2020;). When the COVID-19 pandemic broke out in early 2020, it caused several problems on agricultural sectors and the national economy, particularly reducing the purchasing power and causing serious disruptions in the supply chains. During the pandemic, restricted transportation affected the quality of agricultural products and lowered the prices of all commodities, especially livestock and perishable items. Many people faced income losses and difficulties in paying the interest because their jobs were halted or slowed down (Nghe An's Department of Agriculture and Rural Development, 2021).

Irrigation harmed households' livelihoods, which might be a result of the abnormal incidence of extreme climatic stresses and the poor adaptive capacity of current infrastructure, which caused crop loss or crop failure in the study area. Many dams were constructed over 40 years ago, thereby, being seriously degraded. For example, Bara dam in Do Luong district of Nghe An was completely collapsed in 2020, resulting in a shortage of 50–70% of the water flows into the main canal of the North irrigation system of Nghe An (Raber et al., 2017; Sujakhu et al., 2019; Nghe An's Department of Agriculture and Rural Development, 2021; ;). During the driest periods from February to April, temperature increases, and severe drought events leads to water shortage for agriculture, forestry, and household use (Nghe An's Department of Agriculture and Rural Development, 2021).

Regarding the climatic stresses, floods and droughts that frequently happened in this province, either water deficiency or water abundance harmed households' livelihoods since they reduced crop production and induced food insecurity (MONRE, 2016; Pham, 2020; Reynaud and Nguyen, 2016; People Committee of Nghe An province, 2020). Floods damaged infrastructure and properties while causing injury or death for people, especially during the monsoon period (Reynaud and Nguyen, 2016; Casse et al., 2015). In terms of the agricultural sector, severe floods reduced land fertility and damaged crops on a large scale (Le, 2018; Sa-adthien et al., 2020). The prolonged drought may induce water shortage, which affects crops' growth and reduces agricultural output. Despite the efforts of creating the varieties of crops that can survive during prolonged droughts or inundations, such severe climatic stresses may cause food scarcity and negatively affect households' livelihoods and the development of the national economy (Le, 2018; Ray et al., 2018; Reynaud and Aubert, 2020; Nghiem, 2019). Households who engage in agricultural business often confront many difficulties due to the impacts of all those shocks. Several respondents lost their agricultural land, crops, and animals (Shahzad et al., 2021).

It was interesting that cold spells reduced households' vulnerability to climatic stresses. This may be because cold spells occurred only in winter and many farmers had practiced several measures to reduce losses caused by cold spells, such as changing plant schedules and practicing plastic cover for crops. Therefore, limited households reported their loss caused by this event. Instead, farmers observed that they could generate extra incomes in the winter (He et al., 2021; Nghiem, 2019). In the study area, the winter-spring rice crop lasts from January to May, the summer-autumn rice crop lasts from May to September. The autumn-winter crop starts from September, many farmers grow up-land crops to enhance their livelihoods (i.e. cucumbers, gourds, squash, corn, vegetables, kohlrabi, sweet potatoes, and potato). Farmers were also engaged in Acacia plantation, transporting, selling firewood, or working in wood processing factories to mitigate impacts of climate change (Vu et al., 2020).

Lastly, Dien Chau increased households' vulnerability to climatic stresses. Compared with Yen Thanh district, Dien Chau district was more exposed to climatic stresses because of its geographical variation of risks by being located in a low area and often affected by typhoons and coastal erosion (Nguyen and Hens, 2019; Le et al., 2017a; MONRE, 2016; Aryal et al., 2020; Alam et al., 2017). During the last 10 years, floods and droughts significantly impacted many communes in Dien Chau because of the increases in temperature and the abnormal rainfalls as compared to the past (People Committee of Nghe An province, 2020).

5. Conclusions

This study aimed at evaluating the livelihoods of rice farming households in Nghe An province of Vietnam. The study employed the *LVI* to assess the extent of households' vulnerability to climatic stresses in the study area. The results showed that rice households were slightly vulnerable to climatic stresses, such as floods and droughts. Along with climatic hazards, the COVID-19 pandemic also impeded the livelihoods and social networks between farmers and other stakeholders (e.g. local authorities, scientists, and enterprises). Before the pandemic, many households had already implemented several adaptation strategies such as land use change or crop diversification to reduce their vulnerability. In addition, the beta regression was employed to measure the factors affecting households' vulnerability. The results indicated that climatic factors (i.e., cold spells, floods, and droughts), institutional factors (i.e. agricultural cooperative, formal credit, and irrigation), sociodemographic factors, and location factors were the major factors shaping the livelihoods of rice farming households.

The following recommendations are proposed based on the findings. First, in line with the national food security plans, rice production must be secured to ensure the stability of both domestic and international markets. Thus, there is a need for disaster relief (i.e. foods and financial support) and agricultural subsidies from local authorities and relevant actors, such as high-quality seeds, funds, technical training, and consultant services for prompt and effective responses. In the area where water is available during the growth phase, farmers are encouraged to cultivate stress-tolerant rice varieties, such as medium or short growth duration rice varieties. For instance, VT-NA6, Thien Uu 8, and VNR 20 should be cultivated in the summer-autumn crop, their potential yields range from 4.8 to 5.2 tons/ha. For winter-spring crop with more favorable weather, VT 505, VT 404, Nhi Uu 986, Thai Xuyen 111, and G97 may achieve the yields of up to 7.6 - 8.6 tons/ha. At the same time, modifying planting schedule is required to reduce water shortage in the dry season and avoid the shocks of storms and flash floods in the rainy season. In those areas where droughts and water shortages frequently occur, rice production becomes risky. Hence, adopting crop diversification is encouraged, such as growing short-term vegetables, melon, onion, eggplant, sesame, maize, and herbals. Integrating crops-livestock and/or aquatic production is an alternative option.

Second, this study highlights the role of cooperatives in connecting farmers and other stakeholders in the supply chain. The integration of scientific and technical knowledge with farmers' knowledge through cooperatives is crucial to support the effective operation of producing and marketing activities. Moreover, the "big field" model needs to be promoted by the cooperatives, local authorities, and enterprises in order to produce large quantities of high-quality products that meet domestic and export demand. Large-scale production also creates a favorable condition to apply integrated pest management, integrated crop management, and advanced climate-smart agriculture (i.e. alternate wet and dry, rain spray, and drip irrigation) to increase farmers' resilience to climate events towards crop diversification and water-secure production. Besides, cooperatives may provide the access to formal credit with favorable interest rates from the banks or other organizations to reduce the risks of livelihood diversification for farmers.

Third, the three districts experienced a high frequency of climatic stresses over the last five years. Therefore, upgrading and repairing damaged/degraded irrigation infrastructure needs to be paid more attentions to ensure the prevention of floods and droughts. Apart from hydropower reservoirs and pumping stations, all natural water resources from ponds, lakes, rivers, streams, and canals should be utilized to ensure adequate water supply for household consumption, livestock, and crop production in the dry season. In addition, it is importance to disseminate updated information about the situation of water sources and saltwater intrusion to raise people's awareness in economical use of water and take advantage of water collection and storage.

This study contributed to the literature on households' livelihoods and would be the material for policymakers in improving households' ability to survive under the impact of climatic stresses in the coastal area of Nghe An province. Additionally, the methodology employed in this study can be used for further research for the areas with similar socioeconomic and geographical characteristics. However, several limitations of this study should also be concerned for future research. First, the use of the *LVI* and several dummy variables may cause potential bias in the results. Thus, using other approaches and measurements are recommended for better analysis in further research. Second, this study was conducted using the data of the current situation of households, therefore, cannot provide medium- or long-term predictions. Lastly, to design appropriate climate adaptation strategies for improving the livelihoods of poor households, further research should be performed in different rural areas in Vietnam.

Declaration of Competing Interests

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

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Supplementary materials

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