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Vulnerability of Farmer Households to Climate Change in Rocky Desertification Areas—A Case Study of Guizhou Province

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Abstract: Climate change significantly impacts the livelihoods of farmer households. Particularly vulnerable areas, both economically and environmentally, face significant threats from climate change. This study developed a framework to assess household-level vulnerability to climate change by integrating the Exposure-Sensitivity-Resilience Analysis (ESRA) and Sustainable Livelihoods Analysis (SLA) frameworks. Using Gui-Zhou Province as the study area, the study examined whether livelihood vulnerability differs among various types of farmer households in economically and environmentally vulnerable areas and identified the main factors contributing to vulnerability. Results indicate significant differences in livelihood vulnerability among the three household types, with pure agricultural households (PAH) being the most vulnerable due to high exposure, sensitivity, and low adaptive capacity. Further analysis revealed minor differences in sensitivity but significant differences in adaptive capacity among the three farmer categories. In terms of sensitivity, all three farmer household categories exhibit high sensitivity to water, housing, and agricultural production. Regarding adaptive capacity, significant differences in human and financial capital exist among the three household types, with off-farm households (OFH) possessing the highest adaptive capacity due to their substantial human and financial capital. Further research identified high exposure and low adaptive capacity as the primary causes of livelihood vulnerability, noting no significant difference in the main contributing factors among the three types of farmer households. Common factors contributing to the livelihood vulnerability of farmer households include agricultural cooperatives, labor capacity, temperature changes, drought frequency changes, precipitation changes, agricultural insurance, and losses in agricultural production. Overall, the proposed livelihood vulnerability framework offers guidance for analyzing the vulnerability of farmer households in areas with both economic and environmental vulnerabilities under climate change. Concurrently, tailored measures to reduce farmer households' livelihood vulnerability should be developed for different household types, considering the local climatic, geographic, and socioeconomic conditions.

Keywords: climate change; rocky desertification area; livelihood vulnerability; farmer households

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Citation: Liu, X.; Liu, S.; Wang, R.; Tang, H.; Zhang, F.; Jia, L.; Sun, X. Vulnerability of Farmer Households to Climate Change in Rocky Desertification Areas—A Case Study of Guizhou Province. *Land* **2024**, *13*, 582. https://doi.org/10.3390/land13050582

Academic Editor: Nir Krakauer

Received: 20 March 2024
Revised: 24 April 2024
Accepted: 25 April 2024
Published: 27 April 2024

1. Introduction

Climate change has persisted since ancient times; however, the current situation is distinguished by an unprecedented rate of change due to human activities [1]. From 2011 to 2020, the global surface mean temperature increased by 1.1 °C compared with the period between 1850 and 1900, as highlighted by Working Group I in the IPCC's 6th Assessment Report. Should the current trajectory continue, the earth will face a climate shock unprecedented in historical records. Numerous studies have shown that climate change is likely to intensify extreme precipitation events [2], increase energy security risks [3], reduce wind energy resources [4], enhance the spread of climate-sensitive infectious diseases [5], worsen marine pollution [6], and significantly increase ozone release [7]. Consequently, climate change significantly threatens human productivity, life, and health [8].

Agriculture, significantly impacted by climate change, particularly in crop production and food security, faces considerable challenges [9]. Farmers, as the primary economic agents and decision-makers in rural areas, are especially adversely affected by climate change [10]. Climate change disrupts natural ecosystems and hampers the development of agricultural communities dependent on natural resources for their livelihoods through mechanisms like 'ex ante' productivity loss, early response costs, physical capital depletion, and damage to human capital. This exacerbates the risks and vulnerabilities to farmers' livelihoods, posing serious challenges to resource degradation, food security, basic services, and social inequality in rural areas.

The concept of vulnerability originated in the study of natural disasters. The concept of vulnerability has been a powerful analytical tool for describing the state of vulnerability, powerlessness, and marginalization of physical and social systems and for guiding normative analyses of actions to enhance well-being through risk reduction [11]. Vulnerability assessment tools and methodologies find extensive application across diverse fields, including climate change, food security, disaster science, and human ecology [12–15]. The Intergovernmental Panel on Climate Change (IPCC) defines "vulnerability" as "the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extreme events" [16]. As global environmental changes and the impacts of human activities intensify, an increasing number of studies are integrating livelihood with vulnerability [17]. Livelihood research can help to understand the coping and adaptive capacity of groups when faced with external shocks, and its analysis of assets provides important knowledge for identifying key elements of people's daily living practices [18]. Vulnerability studies emphasize the exploration of ex-ante conditions, which compensates for the previous livelihood practices that focused on poverty measurement and ex-post interventions in poverty reduction policies [19]. As a result, livelihood vulnerability studies, which integrate the characteristics of "livelihood" and "vulnerability", not only concentrate on the impacts of external perturbations but also enhance the analysis of internal structural characteristics within livelihood systems.

The concept of livelihood vulnerability is extensively utilized in research exploring the impacts of climate change and extreme weather events, including droughts, floods, and typhoons, on rural households. For instance, Hahn et al. (2009) formulated the Livelihood Vulnerability Index (LVI) to evaluate the susceptibility of the Mabote and Moma Districts in Mozambique to climate change [20]. Das et al. (2020) assessed the livelihood vulnerability in the riparian communities of the Manikchak block within the Ganges plain, segmenting the area into three zones according to their proximity to the river. They discovered varying levels of vulnerability across these zones, with those closer to the river exhibiting higher vulnerability [21]. Okolie et al. (2023) utilized the Livelihood Vulnerability Index to assess the climate change vulnerability of smallholder farming households in Thaba Nchu, Mangaung District, Free State Province, South Africa [22]. Nguyen and Leisz (2021) conducted household surveys in two communities, Thai and Hmong, assessing their livelihood vulnerability using a composite index based on the IPCC framework [23]. Although prior research has significantly contributed to understanding farm households' livelihood vulnerability in the context of climate change, it has largely focused on the community level, with minimal exploration at the household level. Therefore, it is urgently required to conduct research on the microlevel of farmer households.

Owing to the complexity and diversity of climate types, the extensive range of impacts, the challenges in prediction, and the varied adaptability and strategic choices among individuals, the impact of climate change varies across different regions and populations [10]. Xu et al. (2020) discovered that vulnerability differences in the provinces of Inner Mongolia Autonomous Region (AOHAN), Qinghai Province (HYNH), Yunnan Province (YLNL), and Guangxi Zhuang Autonomous Region (NNQZ) were primarily attributed to exposure disparities, whereas differences in sensitivity and adaptive capacity were not significant [24]. Mabhuye (2024) investigated the effects of climatic and non-climatic factors on community vulnerability in selected villages within the western highlands of Tanzania, specifically in the Kasulu and Buhigwe districts of the Kigoma region [25]. Okolie et al. (2023) examined the vulnerability disparities among farmers in central, northern, and southern Tabane State, South Africa [22]. Although previous studies have contributed significantly to our understanding of climate change vulnerability, they have predominantly focused on inter-regional differences while neglecting intra-farmer differences. This represents a significant gap, necessitating further exploration of differences within farming households.

China exhibits a variety of climate types, with climate change and its adverse effects manifesting significant regional disparities. Regions that are environmentally and economically vulnerable face considerable threats from climate change, particularly smallholder farmers who rely extensively on natural ecosystems within these areas [24]. The rocky desertification region, a quintessentially fragile ecological area, is highly susceptible to meteorological disasters—drought, torrential rain, floods, hail, snowstorms, and freezing rain—and secondary disasters like pests and diseases, due to the combined influence of meteorological and geological conditions [26]. Guizhou Province, the epicenter of the rocky desertification region, has the largest expanse of rocky desertification land in China, exhibiting the greatest variety, depth, and severity of hazards. Concurrently, the region's economic vulnerability is evidenced by a per capita disposable income of 27,098 yuan in Guizhou Province in 2023, ranking it 30th among the 31 provinces and municipalities on the mainland. Consequently, this study investigates the impact of climate vulnerability on farmer households at the household level, with Guizhou Province serving as the focal area. The study posits the following hypotheses: (1) significant differences exist in livelihood vulnerability among different types of farm households; and (2) the primary factors contributing to vulnerability vary across different types of farm households.

2. Materials

2.1. Overview of the Study Area

Guizhou Province, located between 103°36′ and 109°35′ east longitude and 24°37′ and 29°13′ north latitude, borders Sichuan Province and Chongqing City to the north, Hunan Province to the east, Guangxi Zhuang Autonomous Region to the south, and Yunnan Province to the west. As shown in Figure 1, the terrain across the province varies significantly, with higher elevations in the west gradually sloping towards lower elevations in the east. Characterized by a subtropical humid monsoon climate, Guizhou has an average annual temperature of approximately 15 °C and receives annual rainfall ranging from 800 to 1700 mm. The region enjoys moderate light conditions and experiences simultaneous occurrences of rain and heat. Notably, the province has a distinct rainy season, primarily in the summer, featuring frequent cloudy days, limited sunshine, and year-round humidity levels exceeding 70%. The landforms within Guizhou are notably complex and diverse, with mountainous and hilly areas constituting approximately 90% of the region. Among these, karst landforms occupy about 70% of the total land area [27,28]. In Guizhou Province, which has a population of 38.56 million, 45.19% live in rural areas, primarily engaging in agriculture. This constitutes 3.5% of the country's rural populace. Guizhou's GDP in 2022 is projected to be 20,164.60 billion yuan, representing 1.67% of the national total economic output. This ranks it 22nd among the country's 31 provincial administrative regions. Its growth rate, at comparable prices, is 1.2%, below the national average of 3.0%. Pan and Zhao (2021) emphasize that Guizhou faces significant challenges related to poverty, with a substantial population of impoverished residents [29]. In 2010, the province had 15.21 million rural poor individuals, constituting 9.2% of the national total. With a poverty incidence rate of 45.1%, 2.62 times higher than the national average, it was recognized as the most deeply impoverished area in the country. By 2019, the number of rural poor had decreased to 530,000, with a poverty incidence of 1.5%, which still exceeded the national average of 0.6%. Regarding land usage, over 60% of the region's natural land area is forested, followed by cultivated land at 19.4%.

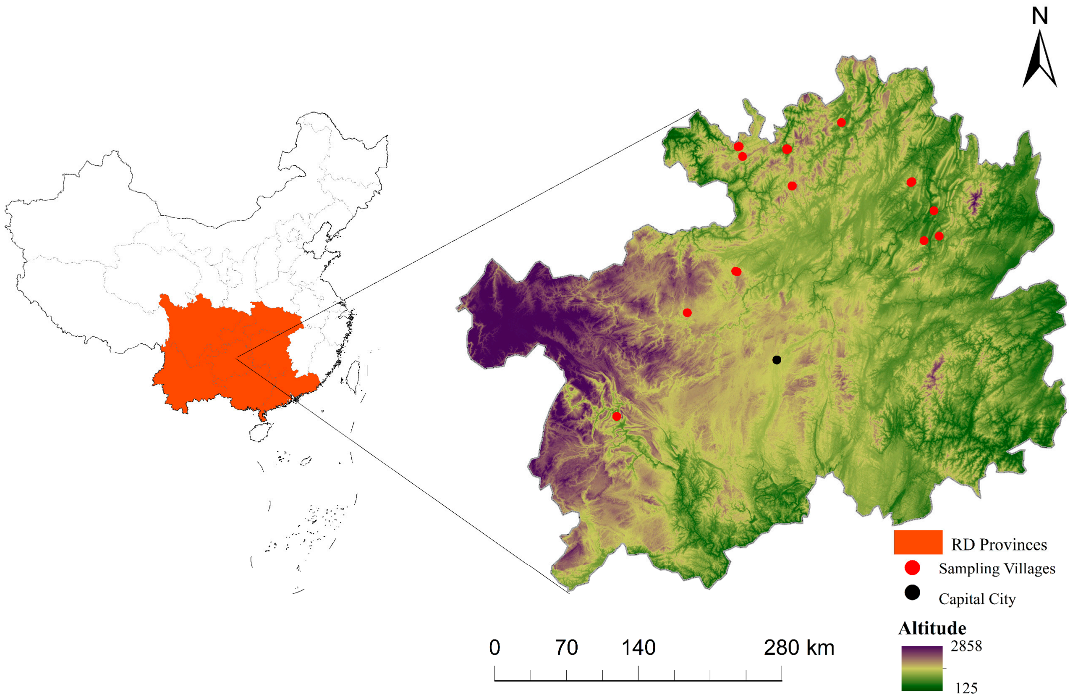

Figure 1. The distribution provinces of Rocky Desertification in China and Geographic location of the study site.

2.2. Sampling Method and Data Collection

In July 2023, a research group conducted a semi-structured questionnaire survey involving farmers and in-depth interviews with key figures across 21 administrative villages in nine districts and counties of Guizhou Province, including Zunyi, Xishui, Tongzi, Dejiang, and Jinsha. The questionnaire and interview outline were designed based on a literature review and previous preliminary survey findings. The research group first obtained permission from village cadres by explaining the investigation's purpose, which enabled them to conduct family visits. Subsequently, farmers within the villages were randomly selected to participate in household surveys. The research team distributed a total of 420 questionnaires, obtaining 400 valid responses, which resulted in an effective response rate of 95.2%. The primary subjects of the interviews were the heads of households.

The questionnaire encompasses demographic and socioeconomic characteristics of the household, such as age, education level, years of farming, labor force composition, income structure, health status, and family size. It also covers natural capital, encompassing cultivated area and grain yield, among others; physical capital, comprising housing quality, fixed assets, and food self-sufficiency; financial capital, which includes borrowing capacity, agricultural insurance, and pension insurance; and social capital, covering the ability to receive assistance from relatives, neighborhood relations, and access to information. Additionally, it addresses agricultural system disturbances, such as the intensity of natural disasters, perceptions of climate change, disaster situations, and attitudes towards climate change, along with agricultural production challenges, including aspects like crop planting and cultivated land area (as shown in Appendix A).

3. Methods

3.1. Theoretical Framework

There are two main frameworks for analyzing vulnerability to climate change livelihoods: the Exposure-Sensitivity-Resilience Analysis (ESRA) framework and the Sustainable Livelihoods Analysis (SLA) framework [30]. The former comprehensively assesses the ability of systems to respond effectively to anticipated risks, namely, resilience [31]. The latter elucidates the structure of the core elements of a livelihood, their interactions, and interrelationships [32]. The SLA framework and the ESRS framework are integrated to develop a comprehensive framework for assessing household livelihood vulnerability (as shown in Figure 2). Based on existing research findings and the study area's characteristics, indicators are selected to construct the evaluation system. The assessment framework encompasses indicators across three components: exposure, sensitivity, and adaptive capacity.

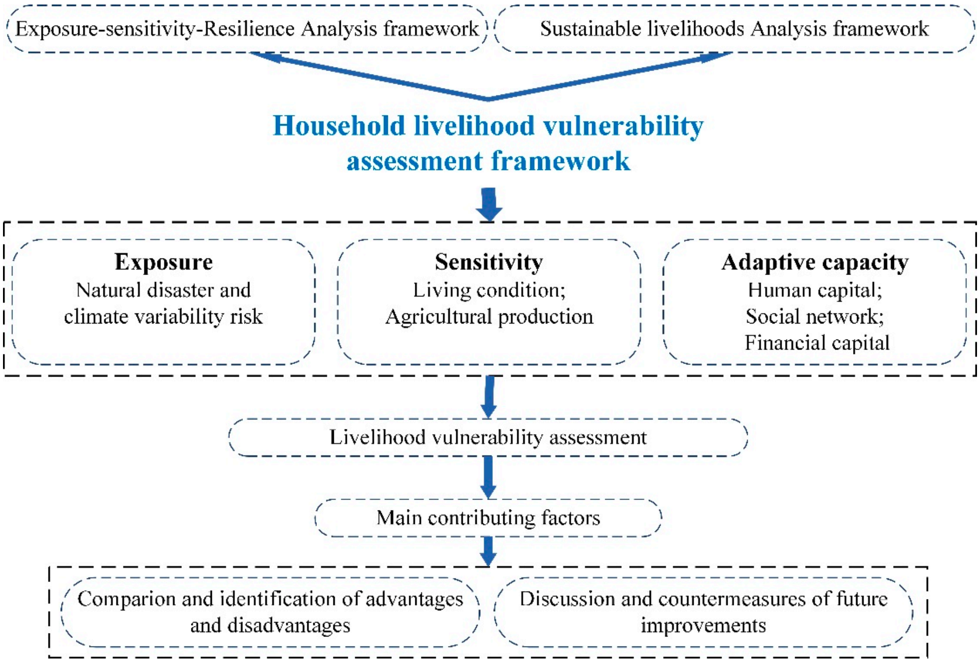

Figure 2. The framework of household livelihood vulnerability assessment to climate change.

The intensity and frequency of natural hazards, along with variations in temperature and precipitation, serve as metrics for assessing household-level exposure to climate change. Unlike previous studies, this research utilizes self-reported data from farmers instead of relying on meteorological observations to gauge extreme climate events. This latter approach is commonly employed to evaluate the effects of climate change on agricultural households across various communities and regions [20–23]. A distinctive characteristic of this assessment framework is its integration of the ESRA framework with the SLA. Drawing on the sustainable livelihood framework by Chambers and Conway (1992), this framework encompasses five types of household assets: natural, social, financial, physical, and human capitals [33]. Sensitivity examines the degree to which household livelihoods are affected by climate change [34]. Among the five types of capital, natural capital's contribution to vulnerability is primarily evident in sensitivity [35]. Furthermore, households' adaptive capacity is chiefly represented in social, financial, and human capital. Consequently, taking the local context into account, this study selected 12 indicators from these capitals to evaluate adaptive capacity [36,37].

3.2. Livelihood Vulnerability Indicators

The detailed vulnerability assessment index system is illustrated in Table 1. In this study, exposure is determined through a measure of risk to natural hazards and climate variability, which relies on farmers' perceptions of extreme weather events as well as climate change and consists of six subcomponents. The sensitivity component consists mainly of various household resource indicators and agricultural production conditions. The livelihoods of farmers in rocky desertification areas are largely affected by the availability of resources, and the spatial and temporal variability of precipitation in rocky desertification areas, as well as the scarcity of land resources and severe soil erosion, have led to the inclusion of indicators representative of farmers' access to water resources and the conditions of agricultural production. Eight indicators were selected to evaluate the sensitivity of farmer households. Adaptive capacity is gauged through three capital types: human capital encompasses household members' health status, education level, labor capacity, and professional skills; social capital pertains to the social resources that facilitate achieving livelihood goals; and financial capital denotes the financial resources available for achieving livelihood objectives, primarily mobilizable and usable funds. This study considers annual household income, income sources, borrowing capacity, and agricultural insurance.

Table 1. Index system of household livelihood vulnerability evaluation in Guizhou Province.

Dimension Level	Subcomponent	Indicator	Meaning of Indicator
Exposure	Natural disaster and climate variability risk	Precipitation change (E1)	Farmers' perception of precipitation changes: increase = 1, invariability = 2, decrease = 3
		Temperature change (E2)	Farmers' perception of temperature changes: increase = 1, invariability = 2, decrease = 3
		Drought frequency change (E3)	Farmers' perception of drought frequency changes: increase = 1, invariability = 2, decrease = 3
		Flood frequency change (E4)	Farmers' perception of changes in the frequency of floods: increase = 1, invariability = 2, decrease = 3
		Number of disasters (E5)	Number of types of disasters suffered by farmers
		Disaster loss (E6)	Agricultural production losses in the last three years: 0 = no; 1 = yes
Sensitivity	Living condition	Food source (S1)	Depend mainly subsistence production of food: 0 = no; 1 = yes
		Water shortage(S2)	Number of months with water shortage for domestic use: 0 = no; 1 = yes
		House with breakage (S3)	The house is in a dilapidated state: 0 = no; 1 = yes
		Household status (S4)	National certified poor families: 0 = no; 1 = yes
	Agricultural production	Crop biodiversity (S5)	Average crop diversity index (1/1 + number of crop species)
		Farmland area (S6)	Farmland area of farmers households
		Farmland irrigation condition (S7)	Farmland irrigation condition of farmers households: very good = 1, good = 2, neutral = 3, bad = 4, very bad = 5
		Farmland quality (S8)	Farmland quality of farmers households: high = 1, common = 2, inferior = 3
Adaptive capacity	Human capital	Health level (A1)	The health level of the household head: unhealthy = 1, neutral = 2, healthy = 3
		Education level (A2)	Level of education of the head of household
		Labor capacity (A3)	Population of labor forces in a household
		Agricultural training (A4)	The household labor force was trained in agriculture: 0 = no; 1 = yes
	Social network	Information acquisition (A5)	The number of channels through which households access information
		Cooperative organization (A6)	Whether households participate in agricultural cooperatives: 0 = no; 1 = yes
		Social relation (A7)	The households get help from relatives and friends: difficult = 1, neutral = 2, easy = 3
		Government assistance (A8)	Whether the households receive government agricultural assistance: 0 = no; 1 = yes
	Finance capital	Income source (A9)	Number of sources of household income
		Economic capability (A10)	Annual household income
		Agricultural insurance (A11)	Whether the households purchase farm insurance: 0 = no; 1 = yes
		Borrowing capacity (A12)	Attitudes of households towards obtaining loans: very difficult = 1, difficult = 2, neutral = 3, easy = 4, very easy = 5

3.3. Classification of Farmer Households

The livelihood vulnerability of farmer households is directly influenced by their respective production methods, as highlighted by Liu et al. (2018) [38]. To analyze this impact, it is essential to classify farmers' households based on their respective production methods. Previous studies have predominantly focused on categorizing farmers' households according to the level of diversification in their livelihoods, mainly by considering the proportion of non-agricultural income in the total household income [38]. Building on the categorization frameworks established in prior research [39–41], this study identifies three main types of farmers' households: pure agricultural households (PAH), mixed income households (MIH), and off-farm households (OFH). Pure agricultural households are defined as those with a non-agricultural income proportion of less than 15% in their total household income, while mixed income households have a non-agricultural income proportion of more than 15% but less than 85%, and off-farm households have a non-agricultural income proportion exceeding 85%. Among the sampled households, pure agricultural households comprised 41.8%, mixed-income households constituted 16.5%, and off-farm households represented 46.8%.

3.4. Data Analysis

3.4.1. Composite Livelihood Vulnerability Index (CLVI) Calculation

This study adopts the Composite Livelihood Vulnerability Index (CLVI) used by Nguyen et al. (2021), evaluating vulnerability based on the relationship between exposure, sensitivity, adaptive capacity, and vulnerability within the ESRA framework [23]. The calculation process is as follows.

As each indicator is measured on distinct scales, the original data for each indicator is normalized using Formulas (1) and (2):

$$C_h = \frac{B_h - minB_h}{maxB_h - minB_h} \tag{1}$$

$$C_h = \frac{maxB_h - B_h}{maxB_h - minB_h} \tag{2}$$

where C_h represents the normalized value of the original indicator data, B_h represents the original value of the indicator data, and $maxB_h$ and $minB_h$ denotes the maximum and minimum values of the indicator for the entire study population, respectively.

After the indicators have been normalized, the subsequent formula is employed to compute the subcomponent scores following standardization:

$$D_h = \frac{\sum_{i=1}^{n} C_{hi}}{n} \tag{3}$$

where D_h represents the score of one of the subcomponents of the household, C_{hi} is an indicator related to the subcomponent, and n is the number of sub-indicators contained in each main indicator.

After that, the three components of vulnerability are calculated using the following formula:

$$ESA_h = \sum_{i=1}^{n} S_i D_{hi} \tag{4}$$

where ESA_h is one of the three components of vulnerability; D_{hi} is the subcomponent; S_i is the weight of each subcomponent in the three components (that is, the ratio of the number of indicators of the subcomponent to the number of indicators of the vulnerability component containing the subcomponent); and n is the number of subcomponents in the components of vulnerability.

Finally, the three components are combined by the following formula:

$$LVI_h = (E + S) - A \tag{5}$$

where LVI_h is the comprehensive livelihood vulnerability index at the household level; E represents the exposure score of the household; S represents the sensitivity score of the household; and A represents the household's Adaptive capacity score.

3.4.2. Obstacle Degree Model

The obstacle degree model is capable of calculating the degree of obstacle for each evaluation indicator within a comprehensive assessment, thereby identifying the key factors that limit further development. It helps to clarify the factors that have a major impact on the evaluation results and to make clear the extent of influence of key constraining factors. This provides a scientific basis for the formulation of scientific and reasonable policies [39]. Therefore, the obstacle degree model is introduced to measure the main factors affecting the vulnerability of farmer households' livelihoods to climate change. On this basis, the main factors affecting the livelihood vulnerability of different types of farmers are determined to provide a basis for formulating scientific and reasonable policies and measures. The formula is as follows:

$$V_i = 1 - D_i \quad (6)$$

$$W_i = \frac{P_i * V_i}{\sum_{i=1}^{n} P_i * V_i} \quad (7)$$

where W_i denotes the impact of indicators on livelihood vulnerability; D_i is the normalized value of the indicator; V_i signifies the deviation of the indicator, namely, the difference between the indicator's normalized value and 100%; and P_i is the indicator weight, which represents the influence degree of a certain indicator in the index system on the research goal. In this study, the weight of each single index is the same. Therefore, P_i is 1; n represents the number of indicators.

3.4.3. One-Way Analysis of Variance (ANOVA)

A one-way ANOVA can tell us whether the sample provides sufficient evidence to conclude that there is a difference in the population means among the groups [23]. One-way analysis of variance (ANOVA) and the Duncan test were used to test the significant differences in sub-indicators, main indicators, three influencing factors, and the comprehensive livelihood vulnerability index among PAH, MIH, and OFH.

4. Results

The evaluation system for the vulnerability of livelihoods in three types of farming households includes scores for various indicators, scores for sub-components, scores for the three main components, and vulnerability scores, as shown in Table 2. The p-value indicates the level of significance of the differences, where a, b, c and ab denote different levels of significance. Identical letter markings signify non-significant differences, whereas different letter markings indicate significant differences.

Table 2. Analysis results of household livelihood vulnerability of farmers households.

Indicators	Pure Agriculture Households (n = 147)	Mixed Income Households (n = 66)	Off-Farm Households (187)	p-Value	Average (n = 400)
Exposure	0.74 ± 0.12 a	0.68 ± 0.17 b	0.70 ± 0.15 ab	0.001	0.71 ± 0.15
Natural disaster and climate variability risk	0.74 ± 0.12 a	0.68 ± 0.17 b	0.70 ± 0.15 ab	0.001	0.71 ± 0.15
Precipitation change (E1)	0.89 ± 0.27 a	0.72 ± 0.41 c	0.8 ± 0.34 b	0.002	0.82 ± 0.33
Temperature change (E2)	0.96 ± 0.14	0.92 ± 0.18	0.94 ± 0.19	0.246	0.95 ± 0.17
Drought frequency change (E3)	0.91 ± 0.23	0.89 ± 0.23	0.9 ± 0.2	0.727	0.9 ± 0.22
Flood frequency change (E4)	0.51 ± 0.14	0.52 ± 0.17	0.51 ± 0.16	0.971	0.51 ± 0.15
Number of disasters (E5)	0.32 ± 0.18 a	0.28 ± 0.18 b	0.27 ± 0.20 b	0.063	0.29 ± 0.19
Disaster loss (E6)	0.84 ± 0.37	0.79 ± 0.41	0.77 ± 0.43	0.013	0.8 ± 0.4
Sensitivity	0.33 ± 0.13 a	0.33 ± 0.13 a	0.29 ± 0.13 b	0.009	0.3 ± 0.13
Living condition	0.31 ± 0.24 a	0.32 ± 0.24 a	0.24 ± 0.21 b	0.005	0.28 ± 0.23
Food source (S7)	0.18 ± 0.39 a	0.2 ± 0.4 a	0.1 ± 0.3 b	0.051	0.15 ± 0.35
Water shortage(S8)	0.36 ± 0.48	0.33 ± 0.48	0.35 ± 0.48	0.889	0.35 ± 0.48
House with breakage (S9)	0.47 ± 0.5 ab	0.52 ± 0.5 a	0.37 ± 0.49 b	0.061	0.43 ± 0.5
Household status (S10)	0.21 ± 0.41 ab	0.23 ± 0.42 a	0.13 ± 0.34 b	0.095	0.18 ± 0.38
Agricultural production	0.35 ± 0.10	0.34 ± 0.12	0.34 ± 0.10	0.751	0.35 ± 0.10
Crop biodiversity (S11)	0.22 ± 0.13	0.24 ± 0.16	0.23 ± 0.13	0.769	0.23 ± 0.13
Farmland area (S12)	0.12 ± 0.13 a	0.11 ± 0.11 a	0.08 ± 0.09 b	0.009	0.10 ± 0.11
Farmland irrigation condition (S13)	0.53 ± 0.18	0.51 ± 0.18	0.52 ± 0.2	0.804	0.52 ± 0.19
Farmland quality (S14)	0.53 ± 0.31	0.52 ± 0.35	0.54 ± 0.29	0.854	0.53 ± 0.31
Adaptive capacity	0.35 ± 0.11 b	0.4 ± 0.11 a	0.42 ± 0.12 a	0	0.39 ± 0.12
Human capital	0.34 ± 0.16 b	0.41 ± 0.14 a	0.38 ± 0.15 a	0	0.37 ± 0.15
Health level (A15)	0.73 ± 0.28 b	0.85 ± 0.23 a	0.75 ± 0.3 b	0.012	0.76 ± 0.28
Education level (A16)	0.22 ± 0.22 b	0.38 ± 0.29 a	0.32 ± 0.28 a	0	0.3 ± 0.27
Labor capacity (A17)	0.2 ± 0.11 c	0.29 ± 0.13 b	0.32 ± 0.14 a	0	0.27 ± 0.14
Agricultural training (A18)	0.2 ± 0.4	0.12 ± 0.33	0.12 ± 0.33	0.135	0.15 ± 0.18
Social network	0.48 ± 0.17	0.47 ± 0.19	0.48 ± 0.21	0.984	0.48 ± 0.2

Table 2. *Cont.*

Indicators	Pure Agriculture Households (n = 147)	Mixed Income Households (n = 66)	Off-Farm Households (187)	*p*-Value	Average (n = 400)
Information acquisition (A19)	0.57 ± 0.36	0.54 ± 0.36	0.55 ± 0.35	0.196	0.29 ± 0.26
Cooperative organization (A20)	0.01 ± 0.12	0 ± 0	0.03 ± 0.18	0.095	0.02 ± 0.14
Social relation (A21)	0.75 ± 0.34	0.75 ± 0.32	0.74 ± 0.36	0.973	0.75 ± 0.34
Government assistance (A22)	0.59 ± 0.49	0.61 ± 0.49	0.59 ± 0.49	0.954	0.59 ± 0.49
Finance capital	0.24 ± 0.15 c	0.32 ± 0.15 b	0.41 ± 0.19 a	0	0.33 ± 0.18
Income source (A23)	0.19 ± 0.09 c	0.33 ± 0.13 b	0.42 ± 0.17 a	0	0.32 ± 0.18
Economic capability (A24)	0.1 ± 0.23 c	0.28 ± 0.25 b	0.53 ± 0.31 a	0	0.33 ± 0.33
Agricultural insurance (A25)	0.17 ± 0.38	0.15 ± 0.36	0.17 ± 0.38	0.937	0.17 ± 0.37
Lending capacity (A26)	0.5 ± 0.34	0.53 ± 0.31	0.52 ± 0.36	0.763	0.51 ± 0.35
Vulnerability	0.72 ± 0.22 a	0.61 ± 0.25 b	0.57 ± 0.25 b	0	0.63 ± 0.25

Note: a, b, c and ab denote different levels of significance. Identical letter markings signify non-significant differences, whereas different letter markings indicate significant differences.

4.1. Livelihood Vulnerability Assessment

The vulnerability of each type of farm household to livelihood threats is determined by three components: exposure, sensitivity, and adaptive capacity, as depicted in Figure 3. PGH was identified as the most vulnerable, followed by MIH and OFH households, with statistical significance ($p < 0.001$). Differences were observed in the vulnerability components across the three household types. Notably, the largest disparities were in adaptive capacity, with OFH achieving the highest score (0.42), followed by MIH (0.4), and PAH (0.35) ranking last. Exposure scores varied between 0.68 and 0.74, with PGH recording the highest score. Sensitivity scores exhibited minor differences.

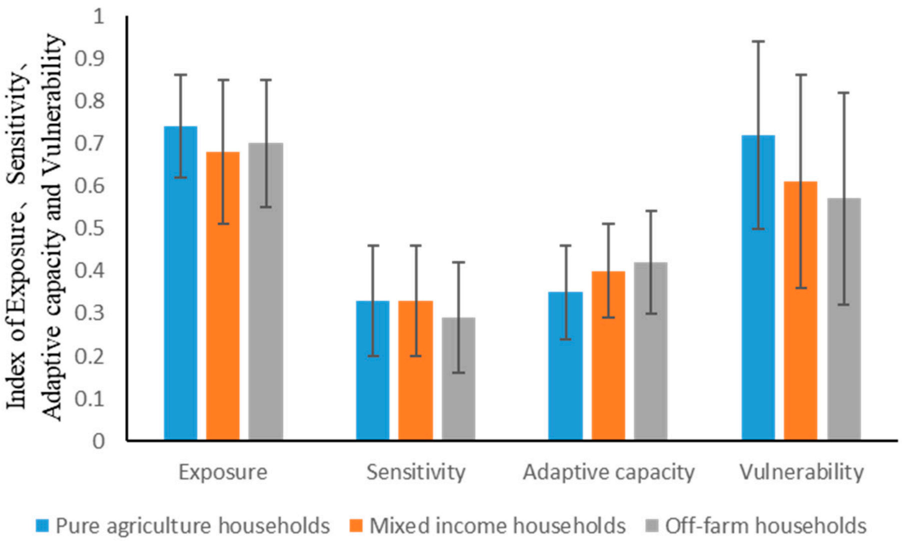

Figure 3. Analysis of household livelihood vulnerability index of different types of farmer households.

4.2. Exposure Assessment

Exposure levels for different types of household risk responses to natural disasters and climate variability are shown in Table 2. In terms of overall exposure, PAH experienced the highest level of exposure, while MIH experienced the lowest. Disparities in precipitation variability and disaster losses were the primary reasons for these differences. Variation in exposure to natural hazards and climate variability was observed among different types of households. PAH experienced the highest impact from precipitation variability (0.89), followed by OFH (0.8) and MIH (0.72). Moreover, PAH was the most affected farmer household in terms of disasters, as indicated by its exposure to a wider range of disaster types (0.32) and its higher vulnerability to losses from disasters (0.84). There was no significant difference in the frequency of drought and waterlogging, and all three scores are high.

4.3. Sensitivity Assessment

4.3.1. Differences in Sensitivity at the Subcomponent Level

This study considered sensitivity as comprising two subcomponents: living conditions and agricultural production. Eight specific indicators were used for the assessment. The overall sensitivity score of OFH was the lowest, whereas PAH and MIH were higher. Specifically, as shown in Figure 4, the three types of households exhibit differences across the various subcomponents. Regarding living conditions, PAH and MIH were closely aligned and significantly different from OFH ($p < 0.001$). As for agricultural production, there were no significant differences among the three.

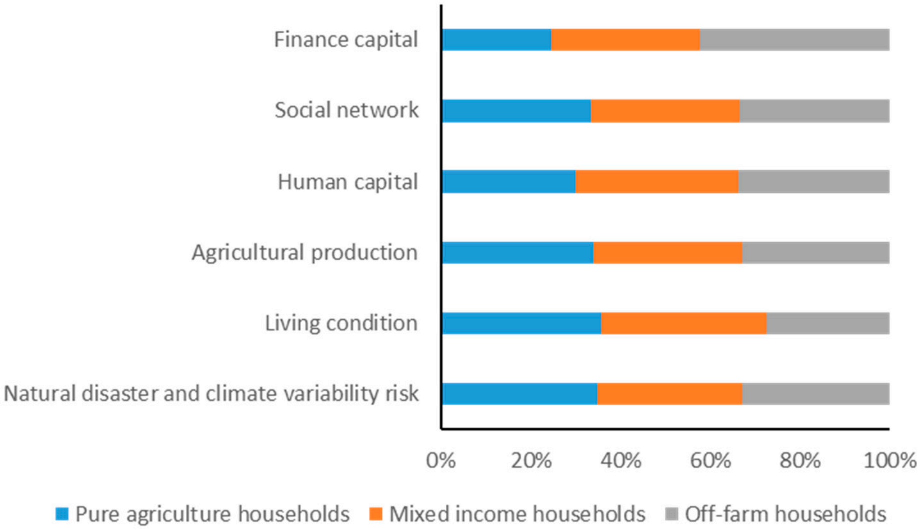

Figure 4. Analysis chart of subcomponents of three types of farmer households.

4.3.2. Differences in Sensitivity at the Factor Level

To further analyze the variations in sensitivity among the three types of households, it is necessary to examine the differences in their factor levels. Significant differences existed in the scores of the three types of households regarding living conditions. Generally, housing situation received higher scores compared with the other factors, while food source and household status received the lowest scores. Despite the presence of piped water in nearly all households, the uneven spatial and temporal distribution of precipitation, coupled with limited surface water storage capacity, contributes to infrequent water shortages. MIH achieved the highest scores in food source, housing situation, and household status, showing a significant difference from the other two household categories ($p < 0.1$). Regarding agricultural production, all three household categories reported inadequate irrigation, subpar farmland quality, and small farmland area, with OFH obtaining the lowest score in farmland area. The difference in crop diversity index among the three household categories was minimal.

4.4. Adaptive Capacity Assessment of the Three Types of Households

4.4.1. Differences in Adaptive Capacity at the Subcomponent Level

Drawing on sustainable livelihood's framework and the concept of adaptive capacity, this study classified adaptive capacity into three primary components: human capital, social network, and financial capital. Overall, adaptive capacity showed greater variation among the three household types compared with exposure and sensitivity, with OFH scoring the highest (0.42) and PGH the lowest (0.35). Regarding human capital, MIH exhibited the highest score (0.41), followed by OFH (0.38), and finally PAH (0.34). The disparities in social networks among the three household types were minimal, with PAH and OFH receiving the highest scores (0.48) and MIH obtaining the lowest score (0.47), indicating limited variations in cooperative organizations and social connections among the three household types. Financial capital exhibited the most significant variation among the components of adaptive capacity, demonstrating notable differences among the three family types ($p < 0.001$), with OFH achieving the highest score (0.41), followed by MIH (0.32), and finally PAH (0.24).

4.4.2. Differences in Adaptive Capacity at the Subcomponent Level

To gain a better understanding of the variations in adaptive capacity among the three types of families, it is necessary to analyze the factors. Health level scored the highest, and agricultural training scored the lowest among the factors related to human capital. Significant differences ($p < 0.05$) existed among the three types of households regarding health, education, and labor capacity. MIH scored the highest in health and education, while OFH scored the highest in labor capacity. The disparity in agricultural training among the three categories was minimal and insignificant (0.15). Regarding social networks, all three types of households exhibited strong social connections, access to information, and government assistance, but the number of cooperative organizations was limited. The variation in financial capital among the three types of households was extremely significant ($p < 0.001$). In general, agricultural insurance received a low score, whereas it performed well in terms of borrowing capacity. With respect to income source, OFH achieved the highest score (0.42), followed by MIH (0.33) and PAH (0.19) in last place. Regarding financial capability, OFH surpasses the other two categories of households significantly (0.53).

4.5. Vulnerability Impact Factors of the Three Types of Households

The barrier degree model was utilized to calculate the contribution of each dimensional factor to the vulnerability of farm household livelihoods. Because of the large number of indicators, the top nine most significant contributors were selected. Among them, agricultural cooperative organization, labor capacity, temperature change, change in the frequency of drought, change in precipitation, insurance, and loss of agricultural production were the common contributors affecting the vulnerability of farm households' livelihoods (as shown in Table 3).

Table 3. Major obstacle degree factors.

Type of Household	**Off-Farm Households**		**Mixed Income Households**		**Pure Agriculture Households**	
Factor ranking	Factor	Obstacle degree	Factor	Obstacle degree	Factor	Obstacle degree
1	Cooperative organization (A20)	7.20%	Cooperative organization (A20)	7.20%	Cooperative organization (A20)	6.68%
2	Temperature change (E2)	6.98%	Agricultural training (A18)	6.64%	Temperature change (E2)	6.47%
3	Drought frequency change (E3)	6.72%	Temperature change (E2)	6.36%	Drought frequency change (E3)	6.15%
4	Agricultural training (A18)	6.66%	Drought frequency change (E3)	6.31%	Economic capability (A24)	6.06%
5	Agricultural insurance (A25)	6.20%	Agricultural insurance (A25)	6.09%	Precipitation change (E1)	5.97%
6	Precipitation change (E1)	5.90%	Disaster loss (E6)	5.66%	Disaster loss (E6)	5.67%
7	Disaster loss (E6)	5.68%	Precipitation change (E1)	5.17%	Agricultural insurance (A25)	5.58%
8	Labor capacity (A17)	5.07%	Economic capability (A24)	5.17%	Income source (A23)	5.47%
9	Education level (A16)	5.06%	Labor capacity (A17)	5.13%	Labor capacity (A17)	5.39%

Precipitation change, drought frequency change, temperature change, and disaster losses contributed 25.28%, 23.82%, and 24.27% to the three categories of farmers, all exceeding 20%. Our survey found that 83% of the farmers believed that the frequency of drought has increased in recent years. Furthermore, 74% of farmers reported a decrease in precipitation, while 90% emphasized an increase in temperature during the same period. Conversely, the frequency of floods is perceived as stable. Over the past few years, 80% of farmers have experienced losses in agricultural production due to disasters. More than 80% of affected farmer households were particularly impacted by the drought. The three barrier factors of agricultural insurance, cooperative organization, and labor capacity contributed 18.43%, 18.40%, and 17.65% to the three categories of farm households, respectively. Surprisingly, only 8 out of 400 households reported being part of rural cooperatives. When asked about their involvement in cooperatives, all respondents unanimously claimed that there had never been a cooperative in their communities. Furthermore, our finding indicated that farmers' willingness to purchase agricultural insurance is low, with only 16% of the farmers in the study sample doing so. A labor shortage has hindered rural development. In addition to the previously mentioned seven common obstacles, the level of education (5.06%) and agricultural training (6.66%) also significantly contributed to the vulnerability of OFH. Meanwhile, for MIH, agricultural training (6.64%) and economic capacity (5.17%) played comparable roles, while sources of income (5.47%) and economic empowerment (6.06%) significantly contributed to PAH.

5. Discussion

5.1. Exposure and Sensitivity

Small-scale farmers in developing countries are facing escalating weather-related risks due to the intensifying impact of climate change [42,43]. Our research findings support this trend, highlighting the pressing and unavoidable nature of the impact of climate change-induced disasters on rural households. Natural disasters are the most immediate and severe manifestations of the effects of climate change on farmers. In Guizhou, a variety of natural disasters such as drought, low temperatures, hail, wind, and heavy rain have significant impacts on agricultural activities [44]. Particularly, drought disasters are increasingly widespread and severe as a result of rising temperatures and declining precipitation levels [32]. Despite the high risk associated with these disasters, the actual losses incurred often stem from both increased risk and inadequate mitigation measures [45]. The insufficient development of water conservation infrastructure emerges as a key factor contributing to the prevalence of drought disasters. Limited social and economic resources hinder investments in improving water infrastructure. Our analysis highlighted differences in the impacts of climate change on different types of farmers. PAH was more vulnerable to a wider range of disasters and was more likely to incur significant losses as a result. Furthermore, PAH was more significantly affected by the decrease in precipitation compared with the other two types of farmers, possibly due to its heavier reliance on agricultural production compared with the extreme reliance of MIH and OFH on favorable climatic conditions.

Quasi-poverty alleviation has successfully lifted 98.99 million rural residents out of poverty, achieving the challenging goal of eradicating absolute poverty [46] and significantly reducing farmers' vulnerability. Adequate housing and water security are crucial components of the "two assurances and three guarantees". Thus, throughout the poverty alleviation project, the government invested significantly in improving farmers' housing and water supply systems, ultimately achieving comprehensive upgrades to water supply and hazardous housing for all households [47], findings that align with our field research. However, rural houses are prone to damage due to the unique environmental factors in rural areas, including high humidity, large temperature variations, and prolonged exposure to wind and sun. Additionally, unlike PAH and MIH, OFH tends to carry out their own home repairs instead of relying on government intervention. Moreover, despite access to running water in every household, the uneven spatial and temporal distribution of precipitation in karst areas, combined with limited surface water storage capacity, can result in regional water shortages. The land resources in Guizhou Province are defined by numerous hills and limited wetlands, which are comparable to plains and basins in other regions. Furthermore, arable land such as hills is prone to soil erosion, slow soil formation, shallow soil layers, poor soil quality, and susceptibility to disruption of the land cover system. In conclusion, reducing sensitivity in terms of livelihood scenarios relies mainly on measures taken by farmers themselves, while enhancing agricultural production capacity requires more government measures.

5.2. Strengthening Adaptation to Climate Change

Mitigation and adaptation are the primary strategies for addressing climate change, and they complement each other, playing an indispensable role in this effort. Adaptation involves implementing measures to maximize favorable factors and minimize unfavorable ones, thereby mitigating the adverse impacts and potential risks associated with climate change [48]. Hence, smallholder farmers can enhance their adaptive capacity and diminish their vulnerability by augmenting their financial resources from diverse channels to attain sustainable livelihoods [49]. The results indicate a notable disparity in the adaptive capacity to climate change among the three farmer categories, stemming from variations in the subcomponents of adaptive capacity.

First, human capital is pivotal, and the size of the labor force significantly influences livelihood choices [50]. Households possessing a larger labor force often opt for favorable livelihood strategies [51]. OFH exhibited a higher labor capacity in comparison to PAH and MIH. Agricultural training was one of the main reasons for the vulnerability of OFH and MIH. The education level significantly contributed to OFH's vulnerability. Achieving comprehensive poverty alleviation requires that education be as prioritized as health [52]. Enhancing the labor force's education can significantly minimize input waste and, consequently, boost agricultural productivity [53]. Consequently, higher education levels lead to increased income for farmers from agricultural production [54]. Ahmed et al. (2021) emphasized that ensuring universal education, especially for middle-aged and old-aged farmers, may improve the implementation and adoption of different climate change adaptation strategies in their farming systems [55]. Participation in relevant agricultural training influences farmers' behavioral decisions [56], underscoring the importance of professional training for farmers.

Second, enhancing social capital through cultural and institutional development is a potent strategy to bolster adaptive capacity. In our survey of 400 farming households, merely 8 farmers were members of agricultural cooperatives. The current state of cooperative development in Guizhou Province exhibits slow progress, limited agricultural reach, and a low level of development. Numerous factors contribute to this outcome, including limited awareness and understanding of cooperatives among farmers [57] on a subjective level, and on an objective level, fragmented arable land distribution hinders large-scale, intensive operations, coupled with the region's low socio-economic development, which constrains funding for cooperative development. And participation in cooperatives is an effective tool to narrow the gap between small farmers and modern agriculture [58]. Through the organization of dispersed farmers, cooperatives enhance land management scale and efficiency, augment agricultural mechanization, provide better farmland water conservation facilities, upgrade the regional agricultural service system, and achieve production standardization and specialization [59]. Consequently, engaging in farmers' cooperatives and adopting agricultural technologies not only markedly boosts the income of low-income farmers [60] but also substantially enhances their capacity to manage risks.

Third, enhancing farmers' financial capital necessitates increasing their overall income, diversifying their income sources, and reinforcing the role of agricultural insurance. Elevating the total income of farm households enables a broader selection of adaptation strategies for farmers. Diversifying income sources contributes to the stability of farmers' livelihoods and augments their financial capital. Farmers demonstrate a minimal willingness to purchase agricultural insurance. Firstly, the lack of clarity among farmers regarding the terms and premium rates of agricultural insurance empowers companies with interpretative authority. Secondly, agricultural insurance companies leverage their interpretative authority. Compensation claims from farmers are often rejected due to ineligibility, or they are required to submit extensive documentation. Consequently, this cumbersome process dissuades many farmers from pursuing compensation.

5.3. Recommendations for Climate Change Adaptation Behavior

Therefore, to reduce the vulnerability of farmers, the focus should be on reducing exposure and increasing adaptive capacity. In 2022, the Ministry of Ecology and Environment and 17 other departments jointly issued the National Climate Change Adaptation Strategy 2035, emphasizing the implementation of a national strategy to actively respond to climate change [48]. This strategy underscores the equal importance of mitigation and adaptation and promotes the modernization of the governance system and capacity for climate change adaptation. Proactive adaptation and scientific adaptation are emphasized in its basic principles. Therefore, farmers should also proactively adopt scientific measures to adapt to climate change. (1) Farmers can adopt crops more resilient to climate change, such as substituting corn with sorghum. (2) The formation of agricultural cooperatives presents a viable option. Policies like reforesting farmland, transforming sloping land, and land relocation for poverty alleviation have unified populations and farmland, creating conducive conditions for cooperative formation. (3) Diversifying income sources, including renting out underutilized or remote land, can enhance revenue.

6. Conclusions

This study developed a framework to assess farmer household livelihoods' vulnerability to climate change, drawing on the ESA and SLA frameworks. Expanding upon prior research, this paper employs farmers' self-reported experiences of climate change and disasters to gauge exposure as well as identify living conditions and agricultural production as key indicators of household livelihood sensitivity. Additionally, it uses human, social, and financial capital to assess adaptive capacity. The framework's relevance stems from its use of indicators that reflect local realities.

In the environmentally and economically vulnerable regions examined, differences in livelihood vulnerability among farmer household types primarily stem from varying degrees of exposure and adaptive capacity, with sensitivity differences being less pronounced. Notably, the adaptive capacities among household types significantly vary, warranting consideration in devising climate change adaptation strategies. Overall, farmer households' vulnerability ranks in descending order: PAH, MIH, and OFH. Sensitivity scores differed marginally. PAH, despite having the highest exposure and sensitivity to climate change, had the lowest adaptive capacity, rendering it the most vulnerable. Although MIH had a higher sensitivity, its lower exposure and greater adaptive capacity lessened its overall vulnerability. OFH, with its lower exposure, reduced sensitivity, and high adaptive capacity, emerged as the least vulnerable among the farmer households. Subsequent research indicated that high exposure and low adaptive capacity primarily drive livelihood vulnerability, with no significant variation in these factors across the three farm household types. Common factors contributing to farmer households' livelihood vulnerability included agricultural cooperatives, labor capacity, temperature fluctuations, drought frequency, precipitation changes, agricultural insurance, and production losses. Beyond these seven factors, education (5.06%) and agricultural training (6.66%) also significantly influenced OFH's vulnerability. For MIH, agricultural training (6.64%) and economic capacity (5.17%) similarly contributed to vulnerability. Income sources (5.47%) and economic empowerment (6.06%) significantly affected PAH's vulnerability. Proposed responses aim to mitigate the livelihood vulnerability of farm households. This study offers a framework for assessing climate change vulnerability, encouraging future research on its varied impacts across farm household types, and potentially enhancing sustainable livelihoods in climate-threatened regions.

Although this study has made certain contributions to the literature, it also has its limitations. For instance, the survey data on income and the data on the intensity of natural disasters may contain measurement errors, as these variables are constructed based on memory. Future research should pay more attention to how various levels can mitigate and adapt to the impacts of climate change. At the same time, attention should be given to the changes in central and local policies and the effects these changes have brought about.

Author Contributions: Conceptualization, S.L., R.W. and L.J.; methodology, L.J., X.S., H.T., F.Z. and R.W.; software, F.Z., X.S., H.T., L.J. and R.W.; data curation, X.S., R.W., F.Z. and L.J.; resources, R.W., H.T. and L.J.; writing—original draft, X.L.; writing—review and editing, R.W., H.T., X.S., F.Z., L.J. and S.L.; supervision, S.L.; funding acquisition, S.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China (42171175); Natural Science Foundation of Chongqing (CSTB2022NSCQ-MSX0753); Innovation Research 2035 Pilot Plan of Southwest University (SWUPilotPlan031); and Special Fund for the Youth Team of Southwest University (SWU-XJPY202307).

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author. The data are not publicly available due to all data were obtained from funded field surveys conducted by the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Farmer household Survey questionnaire

1. Gender.

   A. male B. female

2. Age.

   A. 18–22 B. 23–44 C. 45–59 D. 60–74 E. Over 75

3. Physical condition.

   A. Unhealthy B. Neutral C. Healthy

4. What kind of work are you doing?

   A. Farming B. Farming + odd jobs C. Helping in a cooperative D. Others (specify) ____

5. Your level of education.

   A. Illiterate B. Primary school graduate C. Junior high school graduate D. Senior high school/technical secondary school graduate E. Junior college/ordinary college graduate and above

6. Which of the following jobs are performed by household members?

   A. Machinery maintenance B. Building trades C. Electrician D. Medical Treatment and Public Health E. None F. Others (specify) ____

7. Total household size: ____
8. The number of people in the household engaged in agriculture: ____
9. The number of people in the household who have jobs: ____
10. Gross annual household income.

    A. 0–20 thousand RMB B. 20–40 thousand RMB C. 40–60 thousand RMB D. 60–80 thousand RMB E. More than 80 thousand RMB

11. Annual agricultural income of the household (including crop and livestock farming): RMB.
12. The household's annual non-farm income: RMB.
13. Whether the house has been damaged by bad weather?

    A. Yes B. No

14. Size of farm (acre): ____
15. Irrigation conditions of cultivated land.

    A. Very poor B. Poor C. Average D. Good E. Very good

16. Quality of cultivated land.

    A. Good B. Average C. Poor

17. Corn acreage (acre): ____
18. Rice acreage (acre): ____
19. Wheat acreage (acre): ____
20. Potato acreage (acre): ____
21. Other crops planted area (specify, acre): ____
22. Whether the household has joined a cooperative or cooperation with a agro-processing enterprise?

    A. Yes B. No

23. What is your radio listening frequency?

    A. Often B. Sometimes C. Never

24. How often do you watch the news?

    A. Often B. Sometimes C. Never

25. How often do you surf the internet?

    A. Often B. Sometimes C. Never

26. Does the farm have agricultural insurance?

    A. Yes B. No

27. Number of times household members have attended agricultural training: ____
28. Will friends and relatives be able to help if the family needs it?

    A. Often B. Occasionally C. Rarely

29. How difficult is it to get a loan?

    A. Difficult B. Relatively difficult C. General D. Relatively easy E. Very easy

30. What kind of subsidies do you get from the government?

    A. Arable land protection subsidies B. Grain subsidies C. Agricultural machinery subsidies D. Soybean and corn rotation subsidies E. Subsidies for converting farmland to forest/grass

31. Whether the household is poor household/ receive minimum living standard guarantee /enjoy five guarantees? (A. Yes B. No)
32. How do you think the following climate events have changed in recent years?

	Precipitation	Air Temperature	Drought Frequency	Landslide Frequency	Debris flow Frequency	Flood Frequency
Increase (Rise)						
No changes						
Decrease						
Not clear						

33. Whether crops have suffered disasters in the past three years? (A. Yes B. No)
34. Types of disasters suffered: ____
35. Damage caused by disasters (RMB): ____
36. Has there ever been a lack of water in the house?

    A. Yes B. No

37. Duration of water shortage in a year (weeks): ____

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