

Vulnerability assessment of rural social-ecological system to climate change: a case study of Yunnan Province, China

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Abstract

Purpose – The purpose of this paper is to quantitatively measure the vulnerability level of the whole rural social-ecological system in Yunnan Province and to analyze the spatial differences of the vulnerability in different regions.

Design/methodology/approach – Based on the “exposure-sensitivity-adaptability” vulnerability assessment framework, this paper establishes the index system of rural social-ecological system vulnerability to climate change. Combined with the questionnaire survey and meteorological data, the entropy method was used to measure and analyze the vulnerability level and influencing factors of the overall rural social-ecological system in Yunnan Province. At the same time, the vulnerability level of social-ecological system in Yunnan Province is divided into five levels, and the spatial differences of vulnerability level of 16 states (cities) in Yunnan Province are analyzed.

Findings – The results show that: the social-ecological system has high exposure to climate change (0.809), strong sensitivity (0.729), moderate adaptability (0.297) and overall system vulnerability is at a medium level (0.373). Yunnan Province is divided into five levels of social-ecological system vulnerable areas. The areas of extreme, severe, moderate, mild and slight vulnerability account for 21.45%, 24.65%, 36.82%, 13.18% and 3.90% of the whole province, respectively. The geographical division and vulnerability division of Yunnan Province are basically consistent in space.

Originality/value – Comprehensive evaluation of the vulnerability of the social-ecological system of Yunnan Province to climate change is the scientific basis for the country to formulate countermeasures against climate change, and it is also the need to improve the adaptability of the social and economic system of the fragile area, reduce the vulnerability and realize the sustainable development of national social economy. The research results can provide a basis for decision-making of climate adaptation in Yunnan and other regions and provide methods and indicators for the assessment of social-ecological system vulnerability under the background of climate change.

Keywords Vulnerability, Adaptability, Climate change, Exposure, Sensitivity, Social-ecological system

Paper type Research paper



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1. Introduction

Climate change research is the first to spotlight on intense actions and long-term climate change, focusing on scenario analysis under different emission conditions. Researchers and policymakers pay more attention to emission reduction. Nevertheless, the effect of emission reduction will not be seen until at least several decades, and the contribution of adaptation to plummeting the risk of climate change can be realized on the regional scale (Pielke and Sarewitz, 2005). Hence, study lying on adaptation has involved extra concentration from researchers and policymakers. After the conference of the parties to the “United Nations Framework Convention on Climate Change” in 1995, there have been a lot of studies on how to improve the adaptability of climate change (Thomalla *et al.*, 2010). Effective adaptation requires two premises: one is to have information about what and how to adapt; the other is to have resources to implement adaptation strategies. The former is the research content of vulnerability, that is, it provides information about the exposure, sensitivity and adaptability of the social-ecological system to climate change. To enhance the ability to adapt to climate change, it is necessary to understand the current state of vulnerability. As a result, vulnerability and adaptability assessments have been carried out by the World Bank, the United Nations Development Programme, the United Nations Environment Programme and many non-governmental organizations.

Global climate change has brought extraordinary challenges to rural social-ecological systems. It has a great impact on rural ecosystems, human health, agricultural development, farmers' livelihoods and foodstuff manufacturing along with the use of natural resources (Adger *et al.*, 2005). With the increase of a series of uncontrollable extreme climate events (such as drought, flood, snow disaster, etc.), the vulnerability of human society and ecosystem to climate change is gradually exposed, that is, the vulnerable nature of social-ecological system to climate change disturbance and pressure, which shows that the system is developing in a direction that is not conducive to its own stability and human interests. Yunnan Province is an important ecological barrier and strategic channel in Southwest China, which plays a vital role in stabilizing and supporting national development. However, because of the special geographical environment and historical reasons, the gap between the development of Yunnan Province and that of the whole country is still widening, which needs further support from the state (Ding *et al.*, 2014). Under its important position, it is of great implication to the study regarding vulnerability and spatial pattern of social-ecological system in Yunnan Province for the sustainable development of Yunnan Province in the future.

As a hot spot and frontier in the study of global environmental change and regional sustainable development, many scholars have carried out a lot of research on vulnerability (Jia *et al.*, 2018; Amos *et al.*, 2015; Bardsley and Wiseman, 2012; Gunning *et al.*, 2005). The research perspective mainly focuses on the vulnerability of climate change system (Mcdowell *et al.*, 2016; Pandey and Bardsley, 2015; Ford and Smit, 2004; Mendoza Maria *et al.*, 2014) and the vulnerability of sustainable livelihoods (Below *et al.*, 2012; Preston *et al.*, 2011). Scholars at home and abroad have not yet reached an agreement on the vulnerability analysis framework and evaluation system. According to different research objects and purposes, the analysis framework and indicator system adopted are different. Many scholars have put forward vulnerability analysis framework based on different perspectives such as sustainable science and social geography. Turner *et al.* (2003) proposed an interactive vulnerability analysis framework for the coupled human-environment system and introduced the application process of the framework in combination with three cases. Lures *et al.* (2003) analyzed and measured the vulnerability and adaptability of different regions based on local scale. Some scholars choose to use the vulnerability framework of the International Panel of Climate Change (IPCC) to assess vulnerability from three aspects: exposure-sensitivity-adaptability. Ahsan and Warner (2014) measured the socioeconomic

vulnerability of the coastal areas in southwest Bangladesh. [Hahn et al. \(2009\)](#) used the IPCC's sustainable livelihood framework to separately measure the livelihood vulnerability of Mozambique. [Morzaria-Lina et al. \(2014\)](#) studied the social vulnerability of fishing communities in the Gulf of Mexico in Northern California to climate change. Some scholars made an evaluative analysis on the ecosystem vulnerability of climate change from the perspective of risk and sensitivity ([Sisira et al., 2018](#)). Some evaluated vulnerability of the social-ecological system of scenic spots from the compassion of the system to exterior intervention and the flexibility to risk ([Fedele et al., 2019](#)).

With the deepening of human understanding of vulnerability, the concept of vulnerability has gradually expanded to integrate nature, economy, society, humanities, environment and other comprehensive categories. The establishment of vulnerability index system not only focuses on climate and ecological factors but also pays more attention to local social, economic, political background and cultural traditions ([Adger et al., 2005](#); [Aryal et al., 2017](#); [Maikhuri et al., 2017](#); [Biggs, 2011](#)). Specific economically easily broken areas and susceptible groups have also received increasing attention. However, there are a small number of existing studies that have methodically assessed the vulnerability of the social-ecological system in micro rural areas to climate change, and case studies on the vulnerability of groups in dissimilar regions of Yunnan Province are even more lacking. In the long-term coexistence with natural ecosystems, Yunnan Province of China has formed a flexible knowledge and practice to cope with climate change, which plays a special role in vulnerability assessment, which provides space for this study.

In the future, climate change will continue for a long time. Under the pressure of climate change, it is urgent to explore whether the rural social-ecological system is vulnerable under the impact of climate change, how to take action to reduce the vulnerability of the system and adapt to the impact of climate change. Therefore, the comprehensive assessment of the vulnerability level of rural social-ecological system to climate change is of great significance to reduce the vulnerability of social-ecological system and improve its adaptability. It is the scientific basis for the country to formulate climate change response strategies, and it is the demand for realizing regional sustainable development.

On the basis of social-ecological system theory, this study establishes a "climate-livelihood" vulnerability analysis framework. According to this source, from the three dimensions of exposure, sensitivity and adaptability, the index system of social ecological system vulnerability is constructed by selecting explanatory indexes, respectively. The entropy process is used to determine the vulnerability index, exposure, sensitivity and adaptability of the social-ecological system in different regions of Yunnan Province and put forward appropriate suggestions.

2. Research framework and index selection

2.1 Research framework

The IPCC believes that vulnerability is the degree to which a system is susceptible but unable to deal with the various adverse effects of climate change. It depends on exposure, sensitivity and adaptability, and is a function of the characteristics, rate, intensity of the external climate change of a certain system, as well as the internal sensitivity and adaptability of the system ([Parry et al., 2007](#)). Based on the definition of vulnerability, the IPCC proposes an analysis framework of "exposure-sensitivity-adaptability." Exposure mainly refers to the characteristics and rate of climate change that disturbs the social-ecological system. Sensitivity is usually defined as the degree to which the system responds to climate change, such as the structure, components, basic functions of an ecosystem and the economic development basis of a social system under certain climate change conditions. Adaptability refers to the degree to which the

structure, activities and processes of the system can actively adjust in the face of potential and actual climate change.

The sustainable livelihood vulnerability analysis framework of Pandey *et al.* (2017) measured the vulnerability of the five major livelihood capitals of human capital, natural capital, physical capital, social capital and financial capital under climate change in the three dimensions of exposure, sensitivity and adaptability. The vulnerability analysis framework of regional human-ground coupling system by Turner *et al.* (2003) believes that under the pressure of global environmental changes, the adaptive flexibility of ecological system and the carrying capacity of human society are different, and the sensitivity and resilience performance of different subsystems are also different. The framework selects indicators according to different characteristics of each system and analyzes the vulnerability of human-environment coupling system. This study draws on the IPCC's "exposure-sensitivity-adaptability" vulnerability analysis framework, refers to the five livelihood indicators of human capital, natural capital, physical capital, social capital and financial capital of Pandey's sustainable livelihood vulnerability evaluation and integrates Turner's research thoughts on the vulnerability of the human-environment coupling system, which considers the sensitivity characteristics of ecological system and social system, respectively, finally constructing the "climate-livelihood" vulnerability analysis framework of social-ecological system (Figure 1). The integrated vulnerability analysis framework expands the specific index system of the IPCC's "exposure-sensitivity-adaptability" vulnerability framework, fills the vacancy of the sustainable livelihood vulnerability index system for climate change factors and at the same time makes up for the shortcomings of the human-environment coupling system vulnerability framework that is hard to measure. On the basis of "climate-livelihood" analysis framework, this paper constructs the vulnerability evaluation index system, so as to systematically and comprehensively assess the vulnerability level of the social-ecological system.

2.2 Index system construction

On the basis of "climate-livelihood" vulnerability analysis framework, combined with the research outcomes of well-known scholars and the particular circumstances of the study area

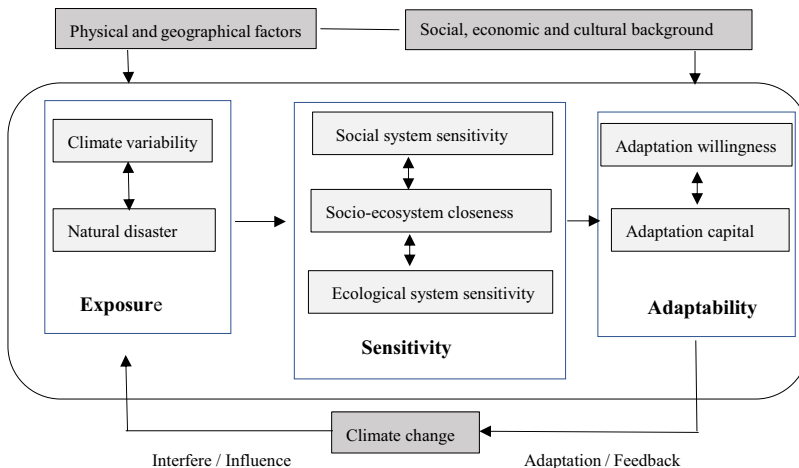


Figure 1. Analysis framework of "climate-livelihood" vulnerability of social-ecological system

Source: Created by the authors based on the research data

(Zhu *et al.*, 2018; Li and Ford, 2019; Armatas *et al.*, 2017; Binita *et al.*, 2015; Stefanie *et al.*, 2019; Zuniga-Upegui *et al.*, 2019; Shinn and Hall-Reinhard, 2019), this paper constructs an evaluation index system from three dimensions of exposure, sensitivity and adaptability (Table 1).

In vulnerability research, exposure generally refers to the degree of stress on the system. The exposure risk in Yunnan Province mainly comes from the interference of climate variability and natural disasters. Therefore, the index factors of climate variability and natural disasters are mainly considered to measure the exposure degree of the study area. Climate variation is the internal change of the characteristics of climate factors. This paper mainly selects two indicators, the mean square deviation of annual average temperature and mean square error of annual average rainfall, to evaluate the climate variability index. Natural disasters refer to extreme climate events, which are the external characteristics caused by the change of climate factors. It mainly includes three indicators: flood frequency, frequency of drought and frequency of heavy snow.

Sensitivity refers to the degree to which the system is changed or affected by interference. The sensitivity is determined by the properties of the system itself, and the relatively stable system is generally less sensitive. The sensitivity of the regional social-ecological system is closely related to the carrying capacity of rural resources and the environment, social factors and so on. It is different from the exposure index which is mostly natural factors. The difference in the sensitivity of the social-ecological system in rural areas of Yunnan Province is largely reflected in the differentiation of social development. Therefore, the sensitivity dimension of this paper mainly comes from the key factors of social subsystem, ecological subsystem and social-ecological system closeness. The social

First-level indicators	Secondary indicators	Third-level indicators
Exposure	Climate variability	Mean square deviation of annual average temperature Mean square error of annual average rainfall
	Natural disasters	Flood frequency Frequency of drought Frequency of heavy snow
Sensitivity	Social subsystem	Proportion of social support Effective irrigation rate of cultivated land Proportion of female-dominated households
	Ecological subsystem	Forest coverage Air quality excellence rate
	Social-ecological system closeness	Residential stickiness Extent of deforestation
Adaptability	Adaptation willingness	Proportion of households involved in ditch management Climate change perception
	Natural capital	Per capita cultivated land area Output value per mu of cultivated land
	Physical capital	Types of fixed assets Per capita housing area
	Human capital	Household labor force Education level of adult labor force
	Social capital	Social network support Proportion of families participating in cooperative organizations
	Financial capital	Annual household income Proportion of families receiving unpaid financial help

Table 1.
Social-ecological
system vulnerability
index system

subsystem mainly includes three specific indicators: the proportion of social support, the effective irrigation rate of cultivated land and the proportion of female-dominated households. The ecological subsystem mainly includes two indicators: forest coverage and air quality excellence rate. The social-ecological system closeness refers to the degree of dependence and interaction between the social and ecological system, which determines the system's ability to withstand climate change. The higher the nearness, the lower the sensitivity and the lower the vulnerability. The social-ecological system closeness is primarily assessed by two indicators: residential stickiness and the extent of deforestation.

Adaptability refers to the system's response to stress and its adjustment to the consequences of stress. Although both sensitivity and adaptability describe system attributes, the former focuses more on describing the stability of the system's status quo, whereas the latter more reflects the flexibility of the system after being hit. Consequently, the index of adaptability focuses more on describing the sustainability of the future development of the system. Because the adaptability criterion mainly emphasizes the adaptation of human society to risk, the indicators in this paper are all man-made processes associated with risk response. The dimension of adaptability in this paper is mainly evaluated by two indicators: adaptation willingness and adaptation capital. Adaptation willingness refers to the subjective expression of whether farmers are willing to actively adapt to climate change, including two parameters: climate change perception and the proportion of households actively participating in ditch management. Adaptation capital refers to the various types of capital that farmers need to adapt to climate change, including natural capital, human capital, physical capital, financial capital and social capital. The higher the adaptation capital, the stronger the adaptability to resist risks.

3. Material and methods

3.1 Study area

Yunnan is located in the southwestern border of China (21°8' N–29°15' N, 97°31' E–106°11' E) (Figure 2). Yunnan is a mountainous plateau terrain. The area with a middle altitude of 1,000–3,500 m accounts for 87.21% of the whole province's land area. Most areas of Yunnan Province are located in the middle altitude area. The climate of Yunnan basically belongs to subtropical plateau monsoon type. The three-dimensional climate features are remarkable, with numerous types, small annual temperature differences, large daily temperature differences, distinct dry and wet seasons and unusual vertical changes in temperature with the terrain. The annual average temperature is 15–16°C, and the frost-free period is 210–330 days. The annual precipitation is 800–1,200 mm, with abundant rainfall, but the spatial and temporal distribution is uneven. Because of the complexity and diversity of topography, geomorphology and geographical environment, the spatial and temporal distribution of light, heat, water, gas and other natural resources is uneven and greatly different. Coupled with human disturbance (deforestation and land reclamation, steep slope farming, mining and logging and other unreasonable use of resources), the problem of ecological degradation is serious, resulting in a decline in the productivity and recovery capacity of the system, and the ecological environment is very fragile.

In the province's 394,100 square kilometers of land area, mountains account for 94%, and only 6% are intermountain basins, which belong to low-latitude and high-altitude areas. The characteristics of many mountains, many ethnic minorities, a large number of poor people and diverse climate changes make Yunnan Province a region where ecologically fragile and economically backward coexist. Therefore, it is of great significance to study the vulnerability of social-ecological system in Yunnan Province, which can not only guide the direction of the restoration and reconstruction of the ecological environment, but also provide a basis for regional sustainable development.

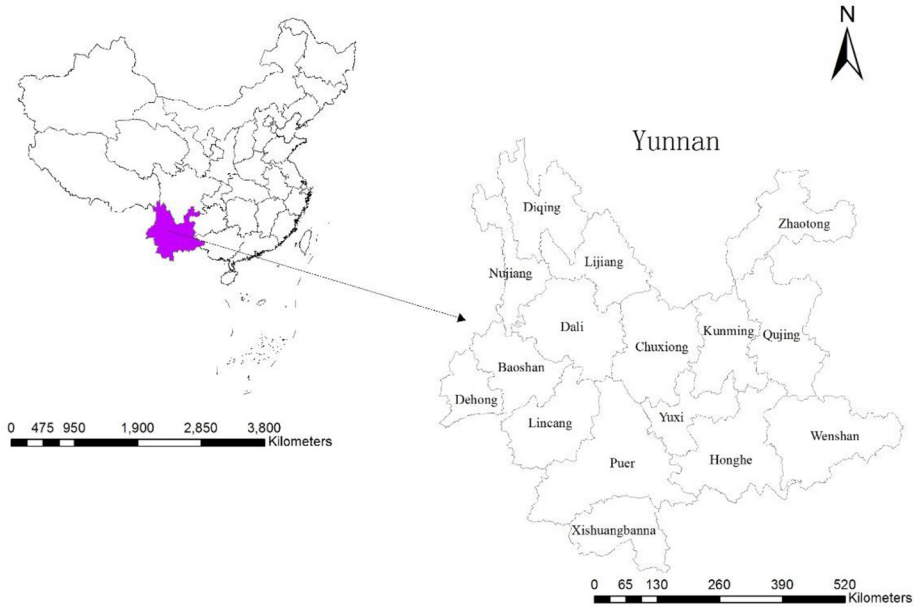


Figure 2.
Geographical location
of the study area

Source: Created by authors using ArcGIS software

3.2 Research method

There are many research methods on vulnerability. Entropy technique is an impartially biased multi-index comprehensive evaluation method. It determines the weight of the index according to the degree of connection of each index or the amount of information provided by each index. It can impartially and exactly assess the research object, so it is adopted by many scholars (Li and Jin, 2019; Jena and Pradhan, 2020; Perera *et al.*, 2019; Zhang, 2019). This paper first uses the entropy technique to acquire the assessment values of the three criteria layers of exposure, sensitivity and adaptability and then uses formula (7) to obtain the vulnerability index. The exact steps are as follows:

- Standardization of indicators: To eliminate the influence of different index dimensions, this study uses extreme value method to standardize the data of each index:

$$\text{Standardization of positive indicators : } Z_{ij} = \frac{X_{ij} - X_{jmin}}{X_{jmax} - X_{jmin}} \quad (1)$$

$$\text{Standardization of negative indicators : } Z_{ij} = \frac{X_{jmax} - X_{ij}}{X_{jmax} - X_{jmin}} \quad (2)$$

Among them, X_{ij} is the original value of the j th index in the i th functional subset, X_{jmax} is the maximum value of the j th index and X_{jmin} is the minimum value of the j th index.

- Determine the weight of each indicator: In this paper, the entropy method is used to calculate the index weight. The specific steps are as follows:
Calculate the index value proportion of the i th functional subset under the j th index:

$$P_{ij} = Z_{ij} / \sum_{i=1}^n Z_{ij} \quad (3)$$

Calculate the entropy value of the j th index : $e_j = -1/\ln n \sum_{i=1}^n P_{ij} \ln P_{ij}$ (4)

Calculate the weight of the j th index : $W_j = (1 - e_j) / \sum_{j=1}^n (1 - e_j)$ (5)

- Calculate exposure, sensitivity and adaptability values:

$$E = \sum_{i=1}^5 E_i W_i \quad S = \sum_{k=1}^7 S_k W_k \quad A = \sum_{j=1}^{12} A_j W_j \quad (6)$$

Among them, E , S and A are exposure, sensitivity and adaptability values, respectively; E_i , S_k and A_j are the standardized scores of the i th index of exposure, the k th index of sensitivity and the j th index of adaptability, respectively; W_i , W_k and W_j are the weights of the i th index, the k th index and the j th index, respectively.

- Calculate the “climate-livelihood” vulnerability index (Hahn *et al.*, 2009):

$$VI = (E - A) * S \quad (7)$$

In the formula, $VI \in [-1, 1]$, -1 means the least fragile, 1 means the most fragile and 0 means not fragile. The larger the VI value, the stronger the vulnerability.

3.3 Data sources

Data sources comprise government statistics besides questionnaire surveys. The government statistical data come from the pertinent statistical data from 2015 to 2019, such as Yunnan Statistics Bureau, Agriculture Bureau, Forestry Bureau, Environmental Protection Bureau, Meteorological Bureau, Forestry Ecological Status Bulletin of Yunnan Province and Forest Resources Situation Circular of Yunnan Province, as well as chronological records of the village where the survey site is located.

The data of questionnaire survey come from a sample household survey of rural households in various regions of Yunnan Province in 2019. A total of 480 rural households were selected in this paper. The climate change situation of the chosen regions has convinced differences, and each has its typical representativeness. It is possible to examine the relevant experience, compassion and flexibility status of social-ecological systems in different regions under climate change and then analyze the impact of various indicators on vulnerability.

4. Results

4.1 Vulnerability of social-ecological system to climate change in Yunnan Province

4.1.1 Overall level of vulnerability. According to the overall vulnerability assessment results (Table 2), the social-ecological system has high exposure to climate change (0.809), strong

First-level indicators	Mean value	Secondary indicators	Mean value	Third-level indicators	Mean value
Exposure	0.809	Climate variability	0.291	Mean square deviation of annual average temperature (0.2042)	0.159
				Mean square error of annual average rainfall (0.1621)	0.132
		Natural disasters	0.518	Flood frequency (0.1744)	0.164
				Frequency of drought (0.2838)	0.206
Sensitivity	0.729	Social subsystem	0.347	Frequency of heavy snow (0.1755)	0.148
				Proportion of social support (0.1123)	0.131
				Effective irrigation rate of cultivated land (0.0845)	0.068
		Ecological subsystem	0.150	Proportion of female-dominated households (0.1308)	0.148
				Forest coverage (0.1344)	0.082
				Air quality excellence rate (0.1258)	0.068
Adaptability	0.297	Social-ecological system closeness	0.232	Residential stickiness (0.1842)	0.145
				Extent of deforestation (0.2280)	0.087
		Adaptation willingness	0.072	Proportion of households involved in ditch management (0.0645)	0.030
				Climate change perception (0.0581)	0.042
		Natural capital	0.019	Per capita cultivated land area (0.1021)	0.015
				Output value per mu of cultivated land (0.0636)	0.004
				Physical capital	0.044
Human capital	0.048	Per capita housing area (0.1021)	0.023		
		Household labor force (0.0956)	0.032		
Human capital	0.047	Education level of adult labor force (0.1214)	0.016		
		Social network support (0.0687)	0.042		
		Proportion of families participating in cooperative organizations (0.1123)	0.005		
Financial capital	0.067	Annual household income (0.0603)	0.036		
		Proportion of families receiving unpaid financial help (0.0665)	0.031		
Vulnerability	0.373				

Table 2.
Evaluation results of
social-ecological
system vulnerability

Note: Numbers in brackets are index weights
Source: Compiled from research data result

sensitivity (0.729) and moderate adaptability (0.297). The overall level of social-ecological system vulnerability is moderate (0.373).

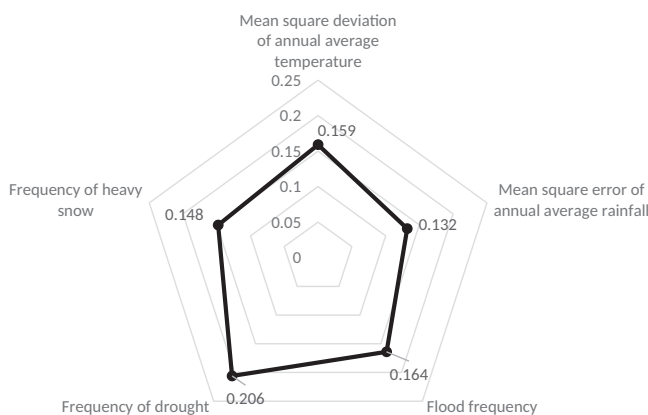
For the secondary indicators, according to the research results and the actual situation of Yunnan Province, it is generally considered that if the exposure is greater than 0.5, it is relatively high; if the sensitivity is greater than 0.1, it is relatively high; if the adaptation capital is less than 0.3, it is relatively low. The social-ecological system exposure in Yunnan Province is relatively high. In the past five years, although the rate of climate variability is not significant (0.291), natural disasters are significant (0.518), which has increased the vulnerability of the region to climate change to a certain extent. Yunnan, located in the southwest border of the motherland, is a combination of frontier, nationality, mountainous area and poverty. The ecological foundation is relatively weak, making the local ecological sensitivity higher (0.150), and the closeness between the social-ecological system is poor,

with the sensitivity of 0.232. To a large extent, the traditional natural resource management has failed to form a good interaction between social systems and ecosystems. It has not only failed to make rational use of local natural resources but also increased the sensitivity of the region to climate change. At the same time, because the local social public service supply is not very sound, the sensitivity of social system is strong (0.347), and the adaptation capital is low (0.225), which increases the vulnerability of social-ecological system to climate change to a certain extent. The impact way and amount of the exact indicators regarding the vulnerability of the social-ecological system of Yunnan Province will be carried out in the study regarding influencing factors of vulnerability

4.1.2 Analysis of the influencing factors of vulnerability.

4.1.2.1 Exposure assessment results. The social-ecological system exposure of Yunnan Province is 0.809, which is at a relatively high level. In recent five years, the distinction intensity of annual average rainfall is 0.132. In a short period of time, the variability level of climate factors in Yunnan Province is not high (0.291). However, the natural disasters caused by climate variation are significant (0.518), and extreme climate events such as flood, drought and heavy snow occur every year. Climate change, variability and extreme climate events have the most serious impact on the farming besides forestry production of the social-ecological system. In the spring of 2020, Yunnan suffered the worst drought in nearly 10 years, and 4.6 million mu of crops were affected. The higher the social-ecological system's exposure to climate change, the greater the vulnerability of Yunnan's livelihoods. While other conditions remain unchanged, for every 0.1 increase in climate change exposure, the vulnerability of livelihoods will amplify by 0.073. The assessment chart regarding the index values of the social-ecological system's exposure to climate change is shown in Figure 3.

4.1.2.2 Sensitivity assessment results. The social-ecosystem sensitivity level of Yunnan Province is relatively high (0.729). According to Table 2, the sensitivity of the social subsystem is 0.347. The effective irrigation rate of cultivated land is 0.068. The proportion of social support (0.131) and the proportion of female-dominant households (0.148) have higher index values, which have a greater impact on sensitivity. It is manifested in the serious aging of the social population, and the proportion of elderly over 60 years old is as high as 12.4%. In addition, part of the male labor force goes out to work, and almost half of the households are dominated by women. As a vulnerable group, women have to bear the



Source: Created by authors based on the research data

Figure 3. Comparison chart of each index value of exposure

burden of caring for the elderly and children when carrying out production activities such as planting and breeding, which leads to the lack of local human capital to cope with climate change and increase vulnerability. The ecological subsystem has a low sensitivity of 0.150. The index values of forest coverage rate and air quality excellence rate are 0.082 and 0.068, respectively. On the one hand, the forest coverage rate and air quality excellence rate of Yunnan Province are higher, which makes it more resistant to climate change and less sensitive. On the other hand, the local ecosystem is well managed and protected, which makes it more resilient when impacted by extreme climate events. In addition, when encountering extreme weather events such as drought, local farmers will flexibly adjust planting types and varieties such as changing paddy fields to dry fields and plant corn instead of rice, stabilize food production under the impact of climate change, maintain livelihoods and reduce vulnerability risks. The closeness of the social-ecological system is general, with a sensitivity of 0.232. Human activities are less destructive to the ecological environment and have a stronger sense of belonging. The degree of deforestation is only 0.087, and the residential viscosity is 0.145, which can effectively reduce the vulnerability of the social-ecological system. On the whole, for every 0.1 decrease in sensitivity, the vulnerability decreases by 0.051. The assessment chart of the index values of the social-ecological system's sensitivity to climate change is shown in Figure 4.

4.1.2.3 Adaptability assessment results. As for adaptability, it is generally considered that if the value of adaptation willingness is greater than 0.02, the value of the index is higher. On the whole adaptability of Yunnan Province is 0.297, which is generally lower level. Because of the high perception of climate change in Yunnan Province (0.042), the initiative of local villagers to participate in the maintenance of village ditches is strong (0.030), and the local willingness to adapt is higher (0.072), which provides an action basis for effective adaptation and response to climate change. However, all kinds of adaptation capital in Yunnan Province are relatively low, which greatly limits the adaptability and increases the livelihood vulnerability of Yunnan Province to climate change. The index values of natural capital, physical capital, human capital, social capital and financial capital are 0.019, 0.044, 0.048, 0.047 and 0.067, respectively. Among them, natural capital is the lowest. Through the investigation, it is found that the arable land resources available to farmers are relatively small, which is closely related to the land distribution system. In

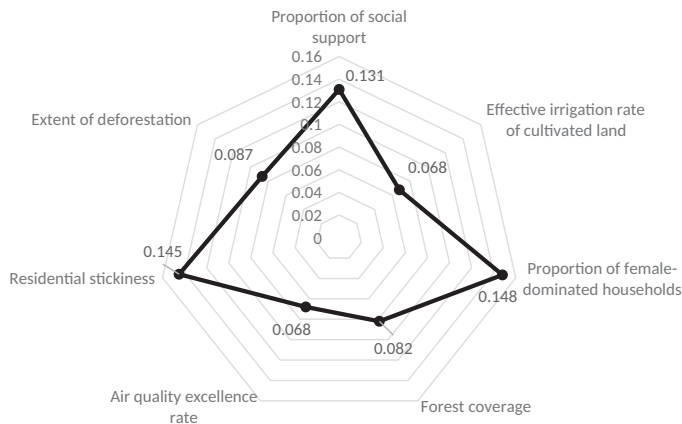


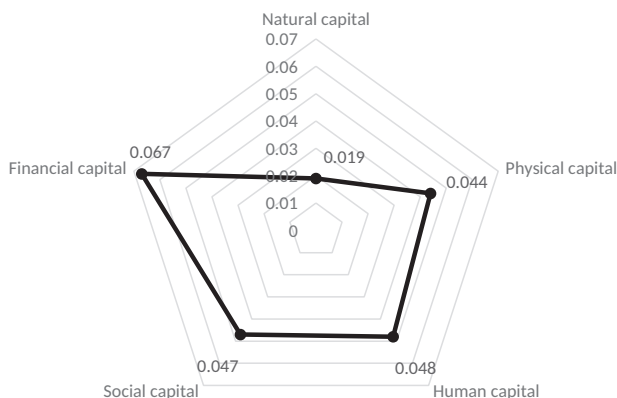
Figure 4.
Comparison chart of
each index value of
sensitivity

Source: Created by the authors based on the research data

addition, because of the limitation of terrain and soil conditions, the output value of cultivated land per mu is relatively low. When extreme weather events occur, farmers' livelihoods are severely affected by climate change, and their vulnerability is low. As for social capital, the proportion of households participating in cooperatives is very small (0.005), and its role in climate change response is limited. Rural cooperatives can reduce farmers' production costs and disaster risks, but most of the cooperative systems are not yet complete. In addition, human capital is also relatively low. The family's average labor capacity is 0.032, and the family's population structure is dominated by the elderly and children, with limited labor capacity. The education level of the head of the household is low (0.016). As rural areas in Yunnan Province are generally located in remote mountainous areas, the number of local primary and secondary schools is small, the conditions are simple and the number and quality of teachers are insufficient, which severely restricts the level of education. The low level of education is one of the important factors that restrain the improvement of human capital. Among the five types of capital, the financial capital is relatively high. Because of the local good social network, residents with common beliefs carry forward the local mutual help mechanism. Free assistance from relatives and friends can help to reduce the cost of climate change adaptation, thereby reducing vulnerability. Generally, for every 0.1 increase in adaptability, the vulnerability will decrease by 0.073. The comparison chart of the five types of adaptation capital is shown in Figure 5.

4.2 Spatial difference analysis of vulnerability

The previous research principally analyzes the general vulnerability level of Yunnan Province. To estimate the reliability of the area, this research takes the municipal administrative region as the assessment element, studies and analyzes the social-ecological system vulnerability of different regions in Yunnan Province (Table 3). By analyzing the susceptibility category of different regions in Yunnan Province, we can propose social-ecological system re-establishment and maintenance countermeasures for different vulnerability degree and characteristics, which can make available a scientific basis for the country and the world to formulate policies related to climate change. According to Table 3, Zhaotong has the highest vulnerability (0.613), and Yuxi has the lowest vulnerability (0.194).



Source: Created by the authors based on the research data

Figure 5. Comparison chart of five kinds of adaptation capital

Table 3.
Vulnerability values
of social-ecological
systems in different
regions of Yunnan
Province

Study area	Exposure	Sensitivity	Adaptability	Vulnerability
Kunming	0.784	0.692	0.325	0.318
Qujing	0.883	0.815	0.242	0.522
Yuxi	0.667	0.608	0.348	0.194
Zhaotong	0.946	0.853	0.227	0.613
Chuxiong	0.797	0.703	0.314	0.340
Honghe	0.845	0.773	0.272	0.443
Wenshan	0.914	0.826	0.231	0.564
Puer	0.809	0.718	0.318	0.353
Dali	0.841	0.783	0.286	0.435
Baoshan	0.826	0.776	0.301	0.407
Dehong	0.742	0.654	0.315	0.279
Lijiang	0.713	0.628	0.341	0.234
Nujiang	0.867	0.801	0.248	0.496
Diqing	0.766	0.683	0.321	0.304
Lincang	0.838	0.741	0.313	0.389
Xishuangbanna	0.698	0.613	0.344	0.217

Source: Compiled from research data result

The social-ecological system vulnerability of eight regions is higher than the overall average level of Yunnan Province (0.373).

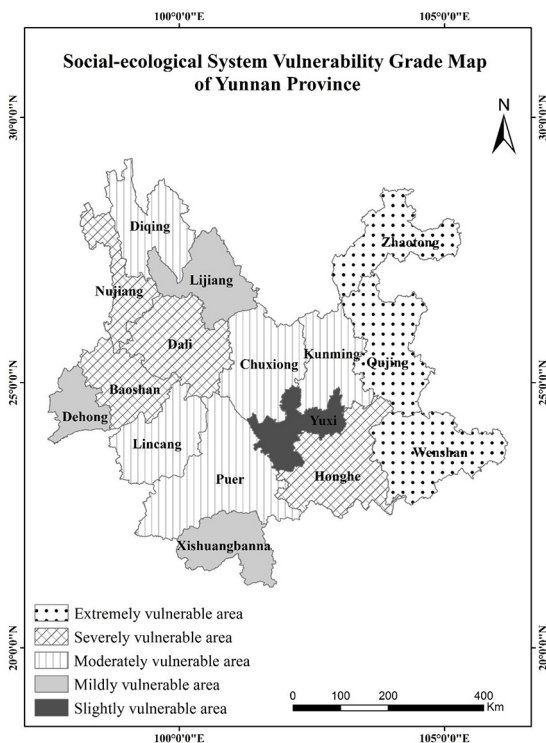
According to the beyond computational results, on the basis of related study and collective along with the authentic state of the study area, the social-ecological system vulnerability of Yunnan Province is divided into five levels: extremely vulnerable, severely vulnerable, moderately vulnerable, mildly vulnerable and slightly vulnerable. If $VI > 0.50$, it is extremely vulnerable, $0.40 < VI < 0.50$ is severely vulnerable, $0.30 < VI < 0.40$ is moderately vulnerable, $0.20 < VI < 0.30$ is mildly vulnerable and $VI < 0.20$ is slightly vulnerable. The detailed dissection results are shown in [Table 4](#) and [Figure 6](#).

4.2.1 Extremely vulnerable area. The distinctiveness of the social-ecological system of this level are: the social-ecological system is extremely delicate, the system is under great pressure, the stability is extremely weak and the resilience is extremely weak or even irreversible. The results of the study show ([Table 4](#) and [Figure 6](#)) that extremely vulnerable areas are mainly distributed in Zhaotong in the northeast of Yunnan, Qujing in the east and Wenshan in the southeast. The total area is 84,164 km², accounting for 21.45% of the total area of the province. As part of the area is located in the hot and dry valley of the Jinsha River, the climate is arid, the water and heat are extremely unbalanced, the population density is high, the forest coverage rate is low and the ecological damage caused by people is serious, so it is difficult to recover vegetation. The per capita gross domestic product is at a

Table 4.
Classification and
area of social-
ecological system
vulnerability in
Yunnan Province

Grades	Regions	Areas (km ²)	Area proportion (%)
Extremely vulnerable	Zhaotong, Wenshan, Qujing	84,164	21.45
Severely vulnerable	Nujiang, Honghe, Dali, Baoshan	96,730	24.65
Moderately vulnerable	Lincang, Puer, Chuxiong, Kunming, Diqing	144,455	36.82
Mildly vulnerable	Dehong, Lijiang, Xishuangbanna	51,708	13.18
Slightly vulnerable	Yuxi	15,285	3.90

Source: Compiled from research data result



Source: Created by authors based on the research data using ArcGIS software

Figure 6. Schematic diagram of the classification of social-ecological system vulnerability in Yunnan Province

low level, and the overall economy of urban and rural residents is not rich. This area is mainly based on agriculture, the soil fertility is low and the grain yield per mu is little. Therefore, it leads to higher exposure and sensitivity, as well as lower adaptability.

4.2.2 Severely vulnerable area. The social-ecological system distinctiveness of this level is as follows: social-ecological system vulnerability is strong; the system has great changes, strong instability and weak coping ability. The severely vulnerable areas are mainly distributed in Honghe in southern Yunnan and Dali, Nujiang and Baoshan areas in the west. The total area is 96,730 km², accounting for 24.65% of the total area of the province. The geological environment of this type of area is extremely complex, and most of the areas belong to the strong geological activity zone. Geological disasters such as landslides and mudslides occur frequently. At the same time, the forest coverage rate is generally low, people’s living standard is not high and the ecological environment is greatly disturbed. The per capita arable land area is at a medium level, the overall economy of urban and rural residents is still not rich and the closeness of the social-ecological system is low, which is also an important reason for the fragile social-ecological system.

4.2.3 Moderately vulnerable area. The distinctiveness of the social-ecological system at this level are: the social-ecological system is highly vulnerable, and system disorders have already occurred; the system pressure approaches the threshold value, the volatility

becomes stronger and the recovery ability decreases. The moderately vulnerable areas are mainly distributed in Kunming in central Yunnan, Chuxiong in the west, Diqing in the northwest and Lincang and Puer in the southwest. The total area is 144,455 km², accounting for 36.82% of the total area of the province. It can be seen that the overall vulnerability of Yunnan Province is moderate and severe. The climate in this region is relatively humid, the vegetation coverage rate is high and the per capita water resources are relatively high, which is higher than that of the extremely vulnerable and severely vulnerable areas. However, the problems of low per capita cultivated land, low grain yield per unit area and low education level of residents are still prominent.

4.2.4 Mildly vulnerable area. The distinctiveness of the social-ecological system at this level are: the vulnerability of social-ecological system is low and there are potential problems; the internal and external changes of the system are small, moderately stable and have strong modification capabilities. The mildly vulnerable areas are mainly distributed in Dehong in western Yunnan, Lijiang in the northwest and Xishuangbanna in the southwest. The total area is 51,708 km², accounting for 13.18% of the total area of the province. This type of area has less rainfall and higher population density, which has a certain pressure on the ecological environment but has a better recovery capacity.

4.2.5 Slightly vulnerable area. The social-ecological system distinctiveness of this level is as follows: the vulnerability of social-ecological system is low, the internal and external changes of the system are small and stable and the regulation capability is strong. The slightly vulnerable areas are mainly disseminated in Yuxi in central Yunnan. The total area is 15,285 km², accounting for 3.90% of the total area of the province. This type of area is better for the operation and maintenance of the social-ecological system. The social-ecological system is less sensitive and more resilient to climate change, thereby reducing the vulnerability of livelihoods. In addition, the adaptation capitals of these regions are relatively high. These adaptation capitals play an important role in the practice of climate change adaptation. The more adaptation capital, the less vulnerable to climate change.

5. Discussion

The research on regional vulnerability has been continuously deepened at home and abroad (Thiault *et al.*, 2017). The evaluation of vulnerability is also constantly developing, and new evaluation methods are constantly being explored and are gradually used by the majority of scholars at home and abroad, such as regression analysis (Barreteau *et al.*, 2020), analytic hierarchy process (Hagenlocher *et al.*, 2018), artificial neural network (Naylor *et al.*, 2019), fuzzy evaluation (Frazier *et al.*, 2014) and so on. Each evaluation method has its advantages and disadvantages. According to the real situation of the study area, this paper selects the entropy method as the evaluation method of the rural social-ecological system in Yunnan Province. The cause is that the entropy technique can intensely imitate the utility value of the index information entropy value and thus determine the weight. This approach is consistent with the vulnerability assessment method. In addition, the entropy method is an objective weighting method, so the weights of indicators derived from it are more intention, with moderately high reliability and accuracy (Winkler *et al.*, 2018). Taking Yunnan Province as an example, this paper not only evaluates the overall vulnerability of the social-ecological system of Yunnan Province from the perspective of vulnerability but also analyzes the spatial differences in the vulnerability of 16 states (cities) in Yunnan Province. The assessment results are basically reliable with the actual geological environment of Yunnan Province. It shows that the research results have very high reliability.

Though this study holds convinced limitations. Constructing an entire assessment index system is the basis for the vulnerability assessment of the rural social-ecological system.

Starting from the regional scale, this paper selects typical cases and observes it as a social-ecological system. On the Basis of “climate-livelihood” vulnerability analysis framework, an inclusive vulnerability evaluation index system composed of 24 indicators is constructed. Because of the complexity of the factors that affect system vulnerability and their interrelationships, as well as the limitations in understanding the connotation of vulnerability, additional explorations will be made in index selection, theoretical cognition, mechanism analysis and so on to construct a more scientific and reasonable rural social-ecological system vulnerability assessment index system, focusing on the relationship between the components of vulnerability. In addition, limited by the availability of data, this paper only assesses the vulnerability of rural social-ecological systems in Yunnan Province from a single time and space. Though the vulnerability of the study area is the result of time accumulation, its vulnerability will also evolve over time. Future research also needs to pay attention to the dynamic changes and evolutionary laws of vulnerability. Research on adaptation strategies needs to combine dynamic changes in vulnerability and dynamically adjust plans and actions based on the feedback results of practice to improve the regional adaptability to climate change.

6. Conclusions

The entropy technique is used to assess the vulnerability of the social-ecological system in Yunnan Province. First, make an overall assessment of the vulnerability of the social-ecological system in Yunnan Province. Second, it is divided into five major levels according to the size of vulnerability. The valuation results are steady along with the distinctiveness of the ecological environment besides social economy of each region, which proves the feasibility of the evaluation method. This method can be used to evaluate the vulnerability of social-ecological systems in other regions.

On the whole, the vulnerability of the social-ecological system in Yunnan Province is at a medium level. First, irregular temperature and rainfall climatic factors, intense natural disasters such as droughts and floods frequently occur, which threaten the production and life of rural communities and show the way to higher exposure to climate change. Second, the social-ecological system compassion is strong. The effective irrigation rate of cultivated land, the proportion of social support and the proportion of female-dominant households are important factors that affect the sensitivity of the social-ecological system. Finally, the adaptability of the social-ecological system in Yunnan Province is general, and the participation in drain management is not high. Natural capital, physical capital and social capital are important factors that confine adaptability.

Dividing Yunnan Province into five levels of social-ecological system vulnerable areas will be able to provide supremacy instructions for the reinstatement and building of the social-ecological system. The extremely vulnerable areas and the severely vulnerable areas should be treated with priority. Strengthen supervision and governance in moderately vulnerable areas. Mildly vulnerable areas and slightly vulnerable areas should spotlight on strengthening and take matching measures to restore the social-ecological system. In short, only by continuously strengthening regional ecological construction, improving the level of adaptability, scientifically and rationally planning and effectively reducing exposure can we maintain and promote the stability and sustainable development of the social-ecological system in Yunnan Province.

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