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Increasing Vulnerability of Village Heritage: Evidence from 123 Villages in Aba Prefecture, Sichuan, China

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Abstract: As the threat of global risks has increased, the study of village heritage has begun to move away from the interpretation of traditional values or the presentation of historical wisdom to focus on the vulnerability of villages. Taking Chinese traditional villages (a type of vernacular heritage) as the target, this study clarifies the connotation of village vulnerability and its generation pattern. Drawing on the framework of "exposure-sensitivity-adaptive capacity", a set of vulnerability evaluation index systems integrating the characteristics of village heritage is proposed. By utilizing vulnerability index and obstacle degree models, we analyze the spatial differentiation and evolutionary characteristics of vulnerability in 123 traditional villages within Aba Prefecture, Sichuan Province, southwestern China, while also exploring the main factors influencing vulnerability evolution at different spatial scales. The results reveal an "east high, west low" spatial pattern and a clustered distribution of vulnerability in traditional villages across the region. From 2012 to 2019, the vulnerability levels fluctuated and intensified, with decreasing individual differences. The evolutionary characteristics of exposure, sensitivity, and adaptive capacity also displayed significant variations. Persistent and stable influences on village vulnerability were identified from factors such as land use scale, population density, gross domestic product, and land fragmentation. Based on these findings, strategic recommendations for village classification, protection, and development are proposed.

Keywords: traditional villages; vulnerability assessment; spatial characteristics; human settlement environment; Southwestern China

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1. Introduction

The "extreme vulnerability of built vernacular heritage" has become an international consensus, and village heritage has received widespread attention [1]. Since the early 20th century, rural areas in China have experienced various social movements and institutional changes, including turbulence, revolutionary transformation, social reform, urbanization, and new rural construction [2]. These dynamic changes have continuously impacted the construction and destruction of rural settlements. In the current era, Chinese rural areas face numerous challenges such as non-agricultural industrialization, an aging population, abandoned construction land, soil and water pollution, and multidimensional poverty [3]. These challenges contribute to the spatial vulnerability characteristics observed in rural areas of China, with higher vulnerability in the southwest and lower vulnerability in the northeast [4]. Chinese traditional villages, characterized by their "vernacular heritage" attributes, have garnered significant attention for their historical, cultural, social, and artistic values [5,6]. While sharing common issues with rural areas, traditional villages also face unique challenges related to cultural landscape changes [7], regional characteristic decline, and weak cultural identity [8,9], reflecting multiple dimensions of vulnerability and their association with "heritage".

From 2012 to 2019, a total of 6819 villages were included in China's national traditional village protection list, with additional provincial and municipal protection lists established.

Due to the complex mountainous environment, the concentration of ethnic minorities, and slow economic development [10,11], Southwest China has gathered about one-third of the number of national traditional villages [12] and has become a superimposed region with high rural vulnerability and a concentration of traditional villages in the country. However, research on traditional villages in this region has primarily focused on the heritage characteristics of typical ethnic minority villages [13,14] or historical traditional wisdom [15,16]. Analyses of village protection and development levels [17], as well as influencing factors [18], have largely been limited to macroscopic scales, such as regional or provincial levels, lacking direct guidance or inspiration for village management departments at the municipal or county level. Additionally, frequent earthquakes, mudslides, and landslides in this region exacerbate environmental exposure and affect village vulnerability levels [19].

At present, vulnerability research has shifted from specific natural or disaster vulnerability to comprehensive vulnerability of social-ecological systems and coupled human-environment interaction systems [20,21]. Research on village or community vulnerability mainly focuses on macroscopic spatial classification and identification of vulnerability, or micro-level assessment of architectural performance. The former analyzes the overall vulnerability level of villages using vulnerability quantification models and investigates influencing factors, with two tendencies observed in village system evaluation [22–24] and external disturbance evaluation [25–27]. Research has mainly focused on developing countries in Southeast Asia, South Asia, Africa [28,29], or regions such as coastal, mountainous, and island areas [30,31]. The latter mainly simulates and analyzes the vulnerability of important historical buildings in terms of structure, materials, and other performance parameters [32–34]. In 2016, vulnerability was introduced into the research of traditional villages [35], with studies focusing on traditional village landscapes, historical environments, and cultural landscapes gaining attention. However, these studies have mainly concentrated in central and eastern regions, such as Hunan [36], Henan [37], and Zhejiang [38], and have primarily focused on a few representative villages or geological disasters (external disturbance) as the main point of analysis. While these research achievements have provided a foundation for understanding and evaluating the vulnerability of traditional villages, they lack targeted interpretations of traditional village vulnerability connotations. Performance indicators of key historical buildings are not suitable for evaluating the overall vulnerability of villages, and evaluation indicators insufficiently reflect the “heritage” attributes of villages.

Therefore, this study analyzes the pattern of vulnerability generation from the village perspective, which will helps to reflect on the over-promotion of village heritage value or traditional wisdom, thus triggering scholars’ attention to the reality of risk in traditional villages. By combining qualitative and quantitative methods, this study integrates the national recognition indicators of village heritage, sustainable development indicators, and general system vulnerability evaluation indicators, and constructs a set of novel and suitable indicator system for vulnerability evaluation of traditional villages. This indicator system injects the new content of “village heritage protection” into the complex development of vulnerability evaluation, which is not only applicable to many traditional villages in Southwestern China, but also easy to replicate and apply to villages in other regions of China. It also possesses enlightenment and reference significance for the evaluation and protection of various communities or rural heritages in the world. Combined with geographic information technology and function models, this study analyzes and demonstrates the typical characterization of the vulnerability of the human settlement environment of traditional villages in Aba Prefecture, the spatial distribution of the vulnerability attributes, as well as the characteristics of the evolution between 2012 and 2019, which realizes the concretization and visualization of the potential vulnerability problems of the villages. In addition, this study also combines the characteristics of the vulnerability attributes of villages and the main influencing factors, and puts forward recommendations for the categorized conservation and development of villages within the municipal scale, which will help municipal and county grass-roots governments to formulate more targeted management policies or programs for traditional villages. The above content is crucial for reducing the vulnerability of traditional villages and promoting their sustainable development.

2. The Essence and Formation Mechanism of Vulnerability in Traditional Villages

Vulnerability holds diverse interpretations across various disciplines and fields [39]. The natural sciences perceive vulnerability as the degree or likelihood of being affected by adverse impacts, while the social sciences emphasize the system's capacity to withstand such impacts and focus on the reasons behind vulnerability generation [40]. According to the IPCC, vulnerability is the extent to which a system is susceptible to climate change or lacks the ability to cope with its adverse effects. It depends on climate change characteristics, magnitude, and rate within a system, along with its sensitivity and adaptive capacity as their function [41]. Vulnerability is regarded as an inherent attribute of a system [42], exhibiting relative and dynamic characteristics [43]. Exposure is used to describe the degree to which a system is exposed to hazards. A high exposure reflects the fact that a system is more exposed to perturbations, which may lead to higher vulnerability [44]. Sensitivity reflects the degree of stabilization of a system in response to perturbations. High sensitivity signals that a system is highly susceptible to developing unstable states that may lead to higher vulnerability [45]. Adaptive capacity reflects the ability of a system to recover from a perturbation. A high adaptive capacity predicts a higher ability of a system to cope with the impacts of a perturbation and a faster recovery from the perturbation, thus reducing the vulnerability of the system [46]. The "exposure-sensitivity-adaptive capacity" framework (vulnerability scoping diagram, VSD) is widely employed [47–51]. Concurrently, values are the core basis for heritage identification, evaluation, conservation, and management [52], and the ultimate goal of heritage disaster risk analysis is to understand "how values are affected" [53]. Consequently, vulnerability of traditional villages refers to the degree of sensitivity a village system has towards disturbances from natural and human activities, resulting in structural and functional changes due to inadequate adaptive capacity, ultimately leading to unfavorable scenarios for the village's values.

Traditional villages continually interact with nature and society, engaging with matter and information to meet the needs of their inhabitants (Figure 1). These interactions lead to exposure (the extent of encountering harm) as they are influenced by external factors. In order to adapt to the external environment, villages not only develop structural states that match the available resources and production methods of their time but also become reliant on the external environment. Their own structure and external dependency determine their response to environmental changes, which defines sensitivity. As villages interact with the external environment, they continuously adjust their own structures to maintain their ability to obtain resources from the outside, leading to adaptive capacity. However, inadequate inherent adaptive capacity to cope with current environmental changes and delayed learning in acquiring postnatal adaptive capacity can create difficulties in balancing exposure, sensitivity, and adaptive capacity, resulting in vulnerability. Although villages may achieve stability again after making adjustments and improvements, the interactive process among exposure, sensitivity, and adaptive capacity has already impacted the village's values. Thus, during the interactive cycle of "exposure-sensitivity-adaptive capacity," the vulnerability of traditional villages persists and dynamically changes.

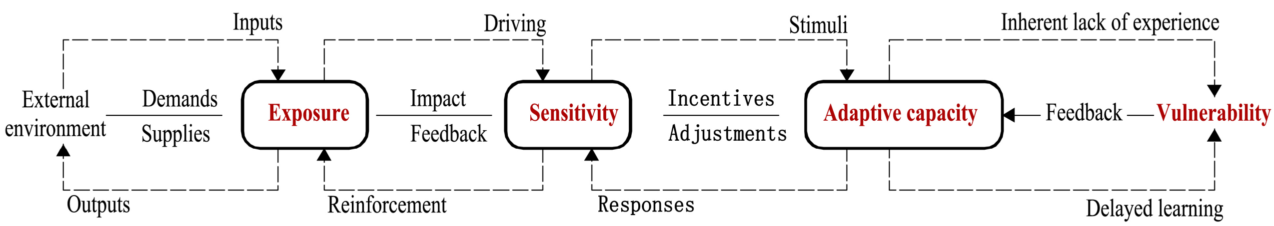

Figure 1. Vulnerability generation process and relationships of traditional villages. (Self-drawn by the author).

3. Materials and Methods

3.1. Study Area

Aba Tibetan and Qiang Autonomous Prefecture (Aba Prefecture) is situated in the northwest of Sichuan Province, China, with geographical coordinates between 100°30′ E–104°27′ E and 30°35′ N–34°19′ N (Figure 2). It lies at the combination of the northern end of the Hengduan Mountains and the high mountain gorges of northwestern Sichuan. The region is renowned for biodiversity conservation and water source preservation. It is one of the areas severely affected by the Wenchuan earthquake and is a concentrated poverty area in China. The average elevation of the terrain ranges from 3500 to 4000 m, with topography changing from high mountains and gorges in the east to hills and plateaus in the west, with a gradual increase in elevation and decrease in valley cutting intensity. Aba Prefecture consists of one city and twelve counties, covering an area of approximately 84,200 km^2. By the end of 2019, 123 villages in Aba were on the conservation list, mainly concentrated in the junction area between Li County and Wenchuan County, the central part of Heishui County, and the southeastern part of Jiuzhaigou County. The elevations of the villages are mainly concentrated between 1000 and 3500 m, accounting for 84.55% (104 villages) of the total. There are 18 villages with elevations above 3500 m, accounting for 14.63%.

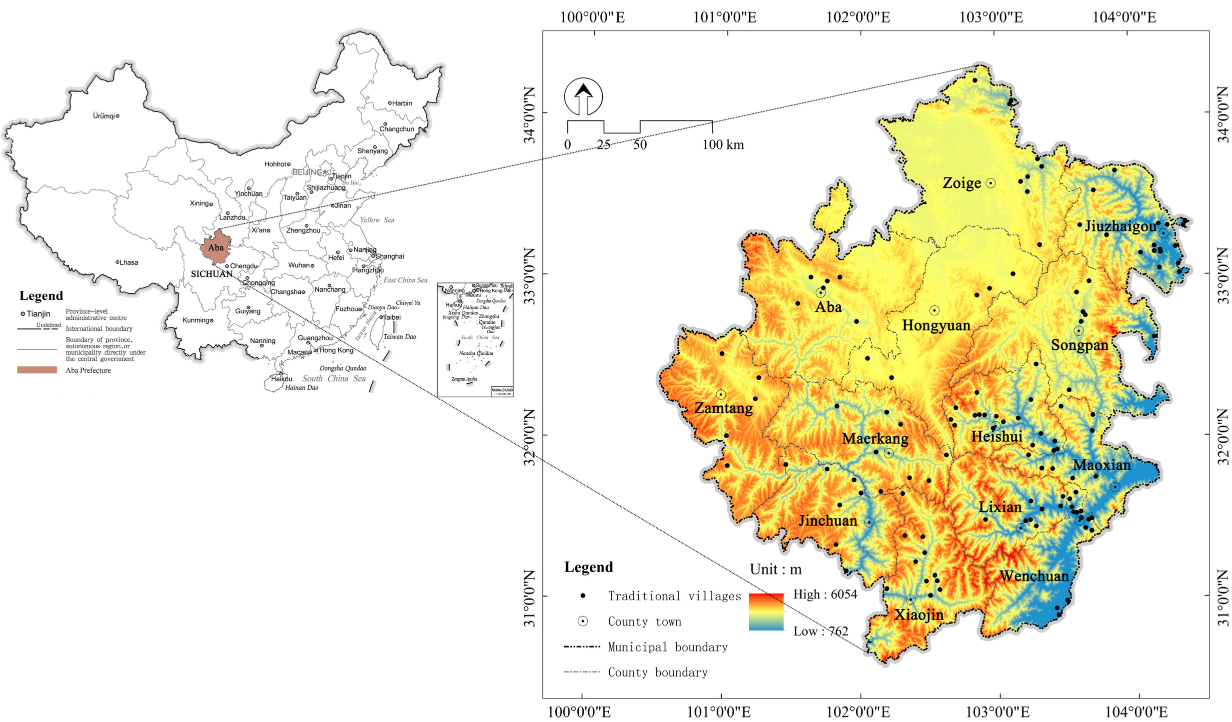

Figure 2. Spatial distribution of traditional villages in Aba Prefecture. (Self-drawn by the author).

3.2. Research Framework

Facing the trend of multidimensional and comprehensive development in vulnerability research, this study summarizes the main vulnerability characteristics of traditional villages in Aba in three aspects (Figure 3), taking into account the existing knowledge base of human settlement environmental systems [54,55] and vulnerability classification [56–59]. Among them, the characterization of the natural environment, social, and cultural aspects mainly reflect the problems of the village in terms of natural, ecological, social, economic, and cultural recognition. The content of "village entity" is mainly used to describe the problem of the value carrier of village heritage, to highlight the particularity of the understanding of the vulnerability of traditional villages. Through the literature review, index use frequency statistics, expert consultation, and other methods, this study formulates vulnerability assessment indicators for traditional villages, and applies a combination of qualitative and quantitative methods to determine the final indicators to be used. Finally, the identification and analysis of vulnerability spatiotemporal differentiation characteristics and influencing factors are realized by function modeling.

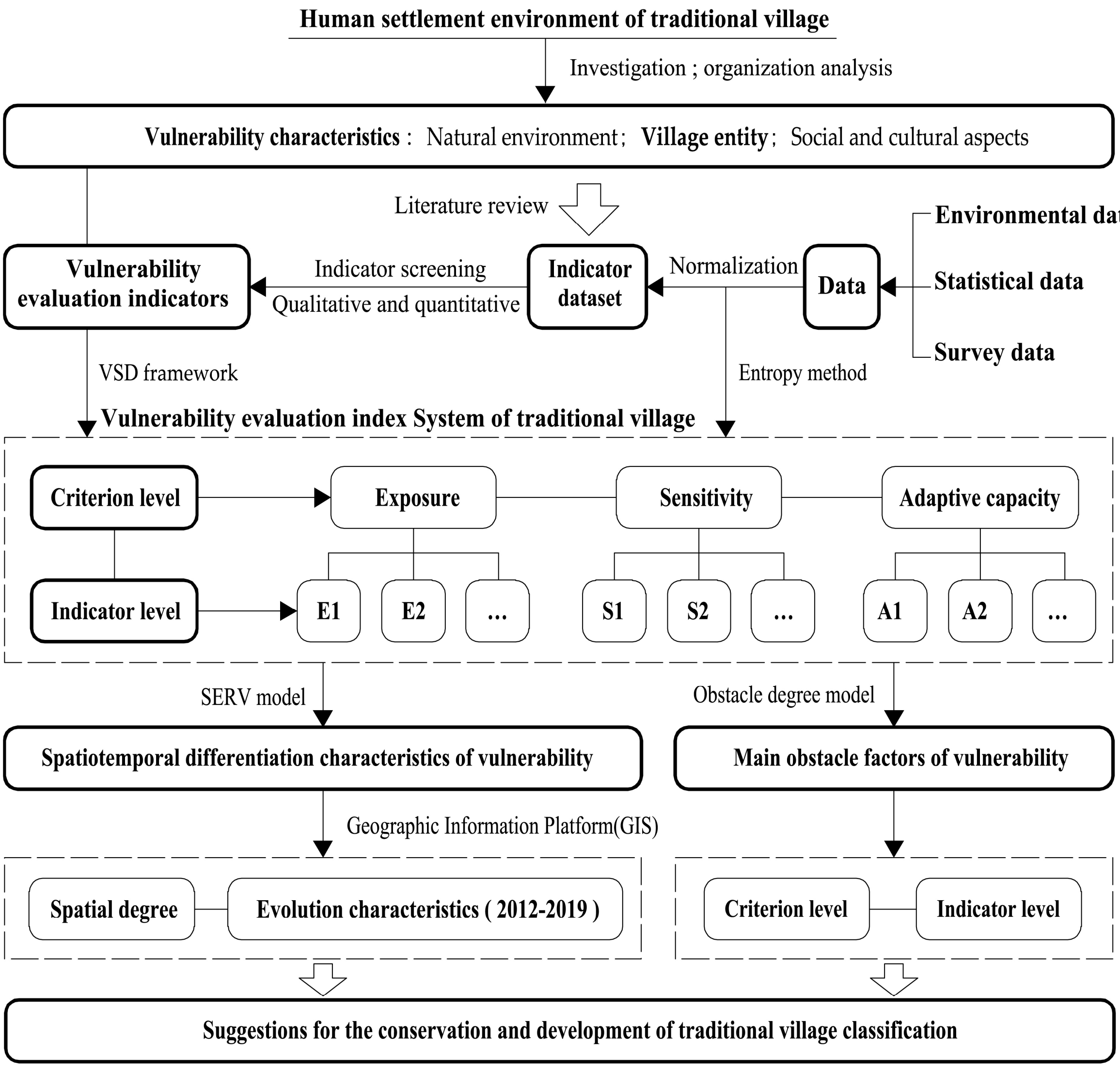

Figure 3. Research framework. (Self-drawn by the author).

3.3. *Vulnerability Investigation and Characterization*

3.3.1. Natural Environment

- Soil Erosion Vulnerability [60]: There are 92 traditional villages with mean soil erodibility values exceeding the average value of all villages in Aba Prefecture. Among them, 47 villages are classified as susceptible to erosion or highly susceptible (Figure 4).
- Reduced Vegetation Coverage [61]: The average Normalized Difference Vegetation Index (NDVI) of traditional villages has decreased from 0.802 (in 2010) to 0.799 (in 2018). There are 26 traditional villages with lower vegetation coverage than the regional average, with 18 villages having low or relatively low vegetation coverage.
- Severe Hazard Threats [62]: The seismic intensity of the areas where traditional villages are located is all above 6.0, with 89 villages having a maximum intensity above 7.5. Additionally, 84 villages have an average density of hidden danger points exceeding 6 points per square kilometer, and 79 villages have a vulnerable population size exceeding 100 people.

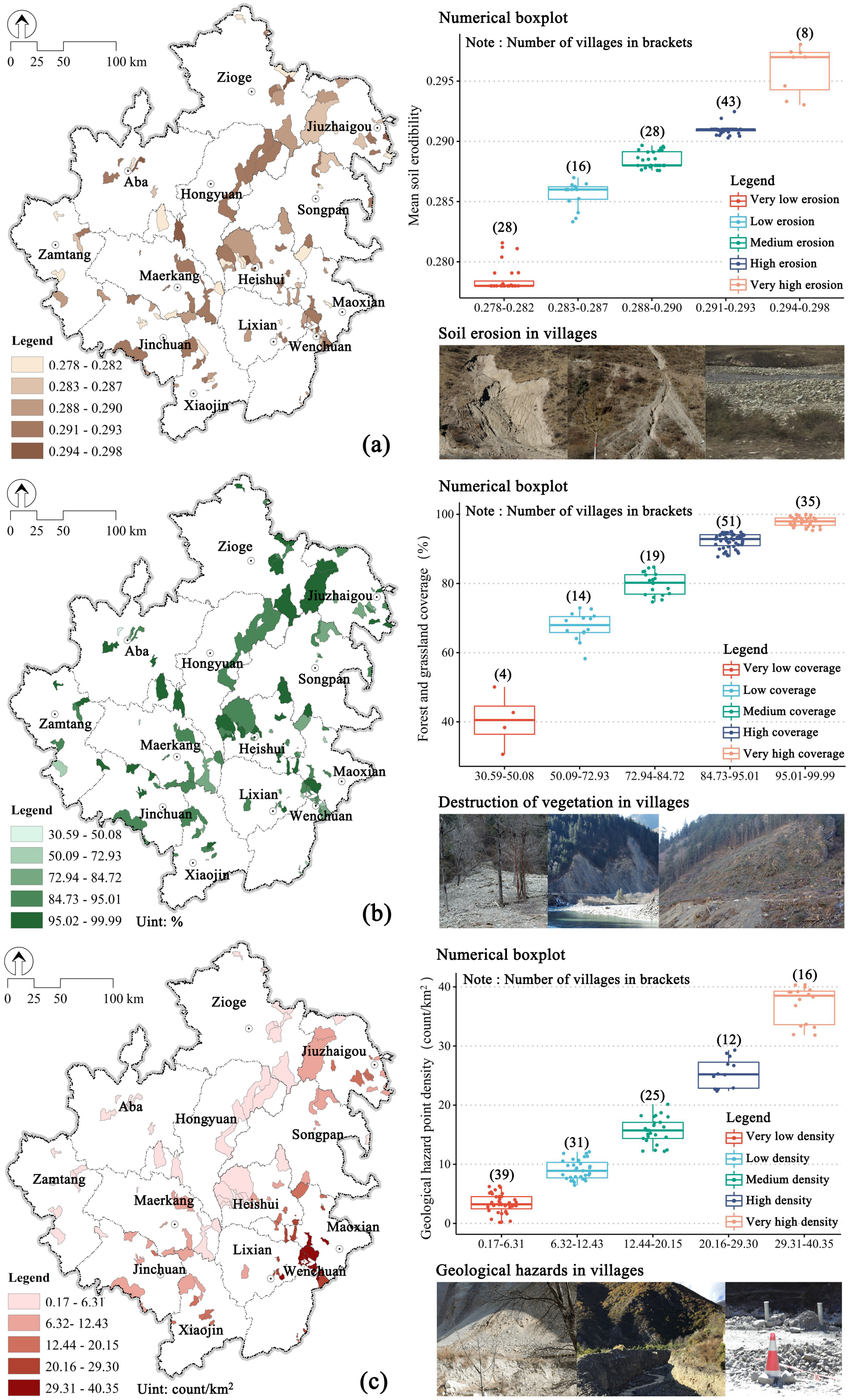

Figure 4. Vulnerability status and spatial distribution of natural environment in traditional villages in Aba Prefecture (2019). (**a**) Mean soil erodibility, (**b**) forest and grassland coverage, (**c**) geological hazard point density. (Self-drawn by the author).

3.3.2. Village Entity

- Decline in Traditional Building Utilization and Landscape Degradation: By the end of 2019, 54 traditional villages had less than 50% of their land occupied by traditional buildings (Figure 5). Among them, 17 villages in Hongyuan, the central part of Li County, and the northern part of Zoige (Ruo'ergai) had less than 20% of land occupied by traditional buildings. In 25 villages in the northern part of Zoige, Hongyuan County, and the western part of Heishui County, the utilization rate of traditional buildings had dropped below 50%. Over 90% of traditional villages faced challenges of modernized decoration, unregulated renovations, and damage to traditional buildings. Additionally, 51 traditional villages had poorly preserved and utilized special spaces, such as blockhouses and religious facilities.
- Inadequate Basic Service Provisions: Village infrastructure suffered from issues such as inadequate facilities, insufficient operational security, significant differences in service quality, weak disaster resistance, and incomplete management systems [63,64].

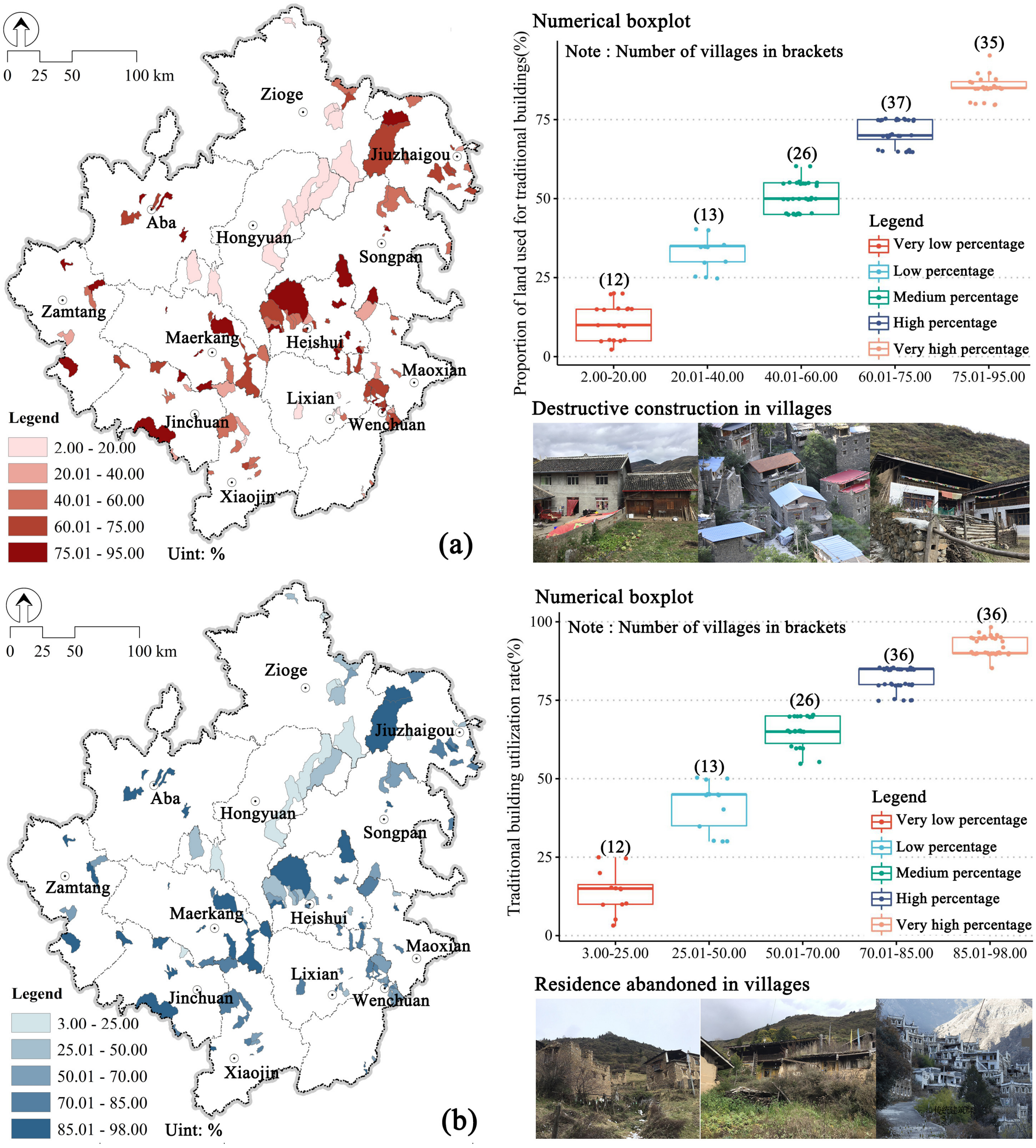

Figure 5. *Cont.*

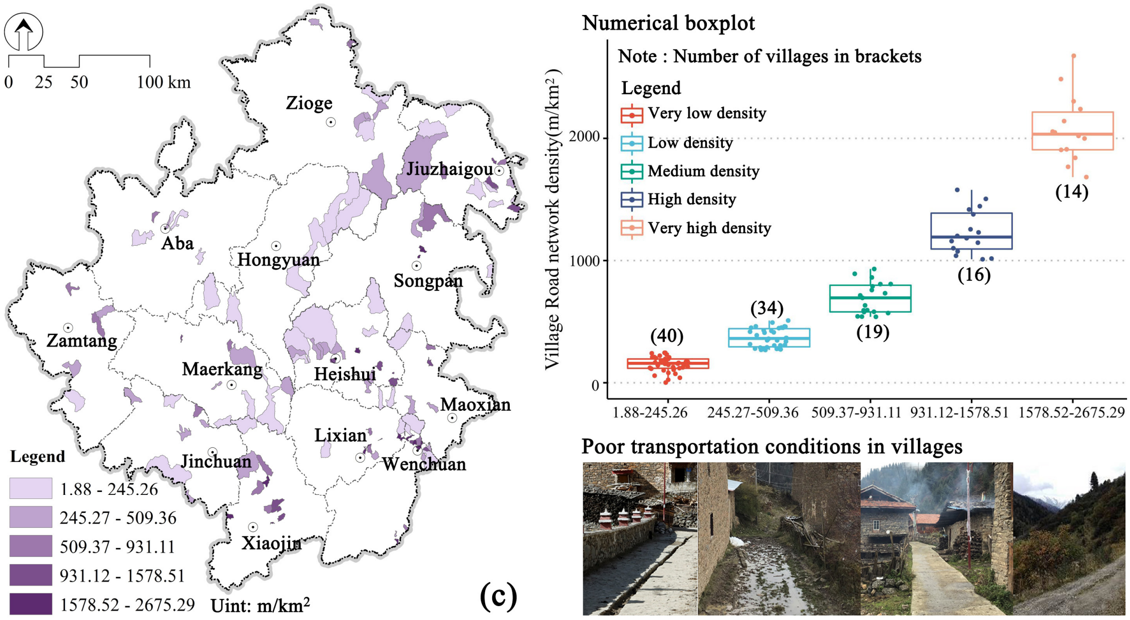

Figure 5. Vulnerability status and spatial distribution of village entity in traditional villages in Aba Prefecture (2019). (**a**) Proportion of traditional building land to total village construction land, (**b**) traditional building utilization rate, (**c**) village Road network density. (Self-drawn by the author).

3.3.3. Social and Cultural Aspects

- Scarcity and Fragmentation of Arable Land, and Low Agricultural and Pastoral Productivity [65]: There are 78 traditional villages with per capita arable land area lower than the regional average (Figure 6). Moreover, the arable land in these villages is scattered, with thin cultivated layers, low phosphorus content, and high gravel content. Among the 61 villages, the proportion of the labor force engaged in the primary industry is below the regional average, and in 50 villages, the rate of unused production land exceeds the regional average. The comprehensive mechanization level of agriculture and animal husbandry in 84 traditional villages is lower than the regional average (50.48%). Furthermore, 40 villages have agricultural and animal husbandry cooperative operation rates below 10%.
- Overreliance on Single Industries and Slow Economic Development [66]: With industrial business concentrated in industrial parks, traditional villages primarily rely on the development of agriculture and animal husbandry, and tourism. The primary industry income accounts for over 50% in 82 traditional villages, with 48 villages having a primary industry income exceeding 75%. The disposable income of farmers and herdsmen in 71 villages is below the regional average. Moreover, 112 villages have production and operation costs higher than the regional average. The tourism development in villages is at an initial stage and easily disrupted by disasters [67].
- Weakening of Cultural Awareness and Challenges in Intangible Cultural Heritage Inheritance [68]: In 2019, the proportion of villages fully participating in cultural inheritance activities was 26.83%, with 28.46% of villages having engaged in only a small or extremely limited number of activities. Traditional folk customs were preserved only to a certain extent or in a limited manner in 67.48% of the villages. Moreover, 39 villages showed only a basic level of recognition or relatively low acceptance of their culture.

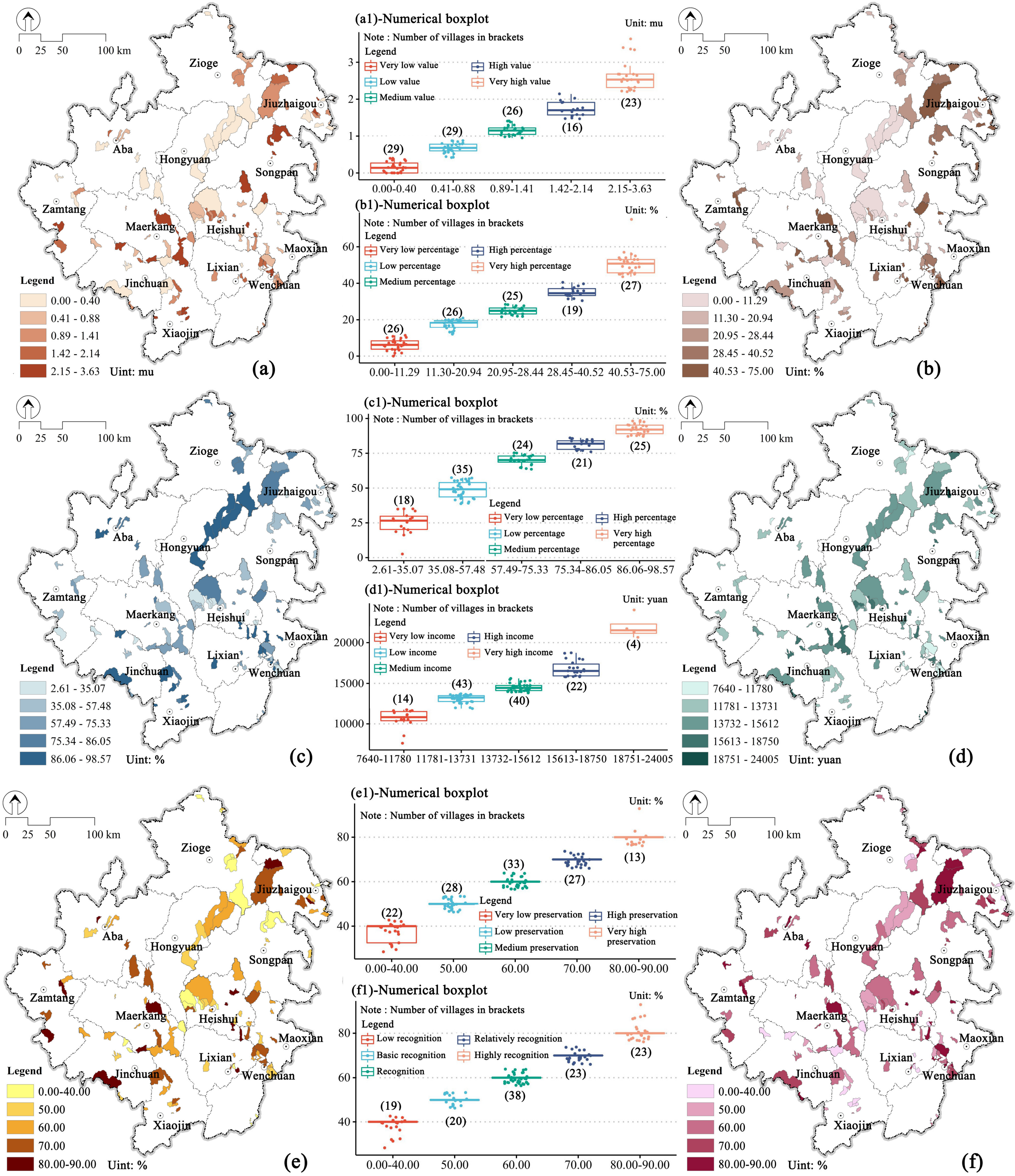

Figure 6. Vulnerability status and spatial distribution of social and cultural aspects in traditional villages in Aba Prefecture (2019). (**a**) Per capita arable land, (**a1**) boxplot of per capita arable land, (**b**) rate of unused production land, (**b1**) boxplot of unused production land ratio, (**c**) proportion of primary industry income in village output, (**c1**) boxplot of the proportion of primary industry income, (**d**) per capita disposable income of farmers and herdsmen, (**d1**) boxplot of per capita disposable income, (**e**) degree of traditional customs preservation, (**e1**) boxplot of the preservation degree of traditional customs, (**f**) village cultural recognition level, (**f1**) boxplot of village cultural recognition level. (Self-drawn by the author).

3.4. Quantitative Model

3.4.1. Vulnerability Assessment Model

This study employs a spatially explicit resilience-vulnerability model (SERV model) based on the function interpretation of vulnerability as defined by the IPCC and the Vulnerability Scoping Diagram (VSD) theoretical framework [69,70]. The calculation formula is as follows:

$$V_i = (E_i + S_i) - A_i \tag{1}$$

In the formula, V_i, E_i, S_i, and A_i represent the values of vulnerability, exposure, sensitivity, and adaptability for the ith village, respectively. Exposure, sensitivity, and adaptability are obtained through weighted summation.

$$E_i = \sum_{j=1}^{k_e} r_{ij} w_j \qquad S_i = \sum_{j=1}^{k_s} r_{ij} w_j \qquad A_i = \sum_{j=1}^{k_a} r_{ij} w_j \tag{2}$$

In the formulas, k_e, k_s, and k_a represent the number of indicators under exposure, sensitivity, and adaptability criteria, respectively. r_{ij} and w_j are the standardized values and weights of village indicators. The values are standardized using the extreme value standard method, and the weights are determined using the entropy weight method.

3.4.2. Obstacle Degree Model

The obstacle degree model is a mathematical and statistical method used to effectively assess the degree of impact of system factors, which has been applied in various fields such as vulnerability, economic development, climate adaptation, and environmental assessment [71–74]. The formula is as follows:

$$I_{ij} = 1 - r_{ij} \tag{3}$$

$$Q_{ij} = \frac{I_{ij} \times w_j}{\sum_{j=1}^{n} (I_{ij} \times w_j)} \times 100\% \tag{4}$$

$$B = \sum_{j=1}^{k} Q_{ij} \tag{5}$$

In the formula, I_{ij} represents the deviation of indicators, r_{ij} represents the standardized value of the jth indicator for the ith village, w_j represents the weight of the jth indicator, Q_{ij} represents the obstacle degree value of the jth indicator for the ith village, n represents the number of indicators, B represents the obstacle degree at the criterion level, and k represents the number of indicators at the criterion level. Higher values of Q_{ij} and B indicate a greater obstacle effect of the indicator or criterion level on the system.

3.5. Indicator Selection

3.5.1. Formulation of Evaluation Indicators

Following the evaluation structure of "target layer-criterion layer-indicator layer", this study established a criterion layer consisting of exposure, sensitivity, and adaptive capacity (Figure 7). Among them, the exposure indicators mainly refer to the objective environmental indicators of human-land system [75,76], social-ecological system [23,77], rural areas [4,69], and other systems in vulnerability assessment. The sensitivity indicators mainly come from the national identification and evaluation system for the protection objects such as historical and cultural towns/villages [78] and traditional villages [79,80]. The adaptability indicators are mainly composed of national beautiful rural construction [81,82], human settlement environment [83], sustainable development [84], and other indicators. The literature on the frequency of use of indicators, as well as the optimization of indicators, also provides a basis for the formulation of indicators.

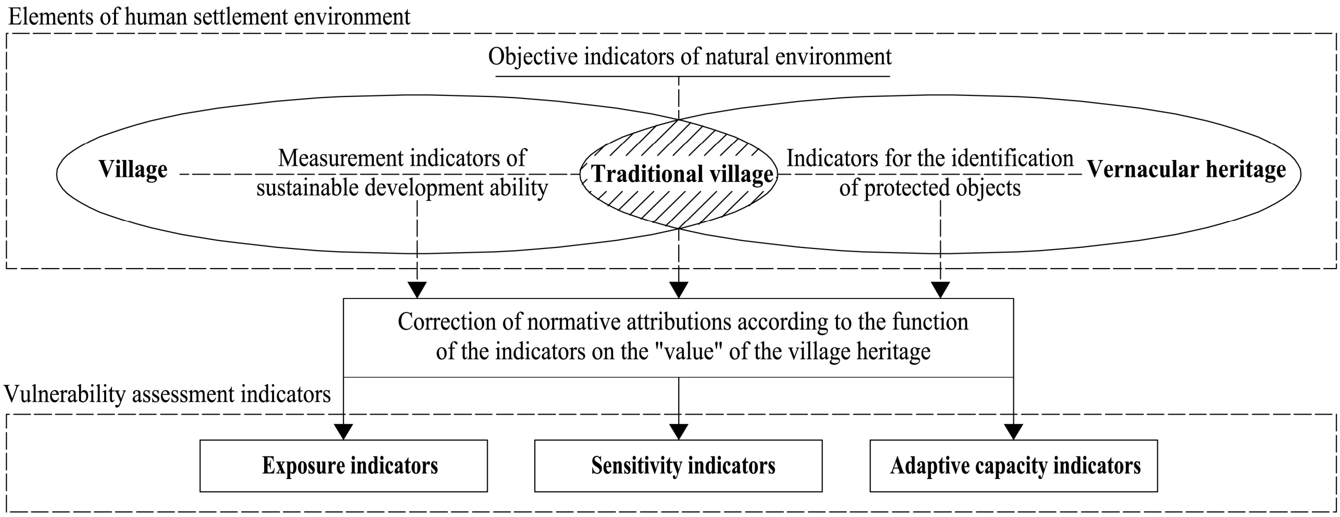

Figure 7. The formulation process of traditional village vulnerability evaluation indicators, (Self-drawn by the author).

The proposed indicators mainly reflect the reality of the village human settlement environment, and there is still a lack of harmonized criteria for identifying the level of vulnerability assessment criteria to which the indicators belong [85]. Taking into account the experience of heritage disaster risk management, this study proposes use of the functional relationship of indicators to investigate the value of village heritage as a guideline. The functional attributes of the indicators were verified qualitatively through expert consultations and discussions at thematic meetings in order to correct the guideline layer to which the indicators belonged. The screening process of indicators strictly followed the general principles of scientific objectivity and operability, as well as the necessary principles of authenticity and integrity of heritage protection. Finally, 96 assessment indicators of traditional village vulnerability were drawn up.

3.5.2. Data Sources

According to the proposed indicators, the study needed to obtain information on the natural environment, architecture, society, economy, culture, and other aspects of the village through various data platforms, the literature, surveys, and other means. The types and sources of natural data and social statistics are shown in Table 1. Indicators such as soil erosion, species richness, etc., needed to be calculated based on the relevant literature data or models, and the references are listed in the description of the indicators (Table 2). From 2019 to 2022, field investigations were conducted for the 123 villages, and interviews or random questionnaires were conducted with the main village managers and residents, covering aspects such as village construction, resident satisfaction, cultural inheritance, and public services. A total of 193 managers were interviewed, with at least one manager from each village. A total of 1560 residents were interviewed, with 10–15 residents from each village participating. The village survey data were mainly used to supplement and amend the established village materials.

3.5.3. Indicator Screening

- Indicators that were deleted due to incomplete data: These mainly included indicators for which data collection was relatively challenging, not observable, or had low data credibility. This comprises 11 indicators such as pesticide application intensity and species endangerment.
- Indicators to be deleted due to overlapping information and low contribution: After applying the linear normalization formula, non-dimensional processing was carried out against the remaining 85 indicator data. Following the principle of retaining indi-

cators with higher information contribution and minimizing the level of information overlap in the indicator set, the entropy weighting method was used to obtain the information contribution value of each indicator. In conjunction with Spearman correlation analysis, indicators with a significant correlation (absolute value of correlation coefficient $R \geq 0.8$ and $p \leq 0.01$) were evaluated, and indicators with low information contribution values were removed. During the process of indicator deletion, the advice of 11 traditional village conservation experts in the southwestern region was acquired. The positive and negative correlations of indicators indicate their impact on vulnerability increase or decrease. Finally, the vulnerability assessment indicator system for traditional villages in Aba Prefecture was obtained (Table 2).

Table 1. Data sources.

Item		Resolution	Time	Source
Natural Basic Data	DEM	30 m	/	Geospatial Data Cloud (http://www.gscloud.cn) (accessed on 10 July 2022)
	Precipitation, temperature	1000 m	1901–2022	National Tibetan Plateau Data Center (https://doi.org/10.5281/zenodo.3185722; https://doi.org/10.5281/zenodo.3114194.)
	Vegetation Index (NDVI)	10–100 m	1980–2019	National Tibetan Plateau Data Center (https://doi.org/10.11888/Ecolo.tpdc.271725)
	Disaster sites, populations at risk	/	2012–2019	Natural Resources Bureau of Aba Tibetan and Qiang Autonomous Prefecture (http://zrzyj.abazhou.gov.cn/) (accessed on 10 July 2022)
	Soil types	/	2010, 2015	Database on Ecosystem Assessment and Ecological Security Patterns in China (https://www.ecosystem.csdb.cn/) (accessed on 10 July 2022)
Social statistical data	Administrative boundaries	/	2013	Resource and Environmental Science and Data Center (https://www.resdc.cn/) (accessed on 10 July 2022)
	Land use dataset		2012–2019	Natural Resources Bureau of Aba Tibetan and Qiang Autonomous Prefecture (http://zrzyj.abazhou.gov.cn/) (accessed on 10 June 2022)
	Population, production conditions, economy	/	2012–2019	Statistics Bureau of Aba Tibetan and Qiang Autonomous Prefecture (http://tjj.abazhou.gov.cn/) (accessed on 12 June 2022)
	Classification and distribution of cultural objects and intangible culture	/	2012–2019	Culture, Sports and Tourism Bureau of Aba Tibetan and Qiang Autonomous Prefecture (http://wtlj.abazhou.gov.cn/) (accessed on 12 June 2022)
	Traditional village declaration and construction data	/	2019	Housing and Urban-Rural Development Bureau of Aba Tibetan and Qiang Autonomous Prefecture (https://zjj.abazhou.gov.cn/) (accessed on 12 June 2022)

Table 2. Vulnerability assessment indicators and weights for traditional villages in Aba Prefecture.

Criterion Level	Indicator Level	Indicator Description and Calculation	Relevance	Weight
Exposure [38,76,83,86–89]	E1 Average elevation(m)	Average elevation within the village domain	+	0.591%
	E2 Average terrain relief (m)	Average variation in terrain relief within the village domain	+	0.654%
	E3 Annual average precipitation (mm)	Yearly average rainfall within the village domain	+	0.344%
	E4 Village River network density (m/km^2)	Length of rivers within the village domain/Village land area	-	0.089%
	E5 Mean soil erodibility	Reflects the degree of soil erosion in the village domain, calculated by the product of erodibility K value for different soil types [90] and the proportion of each soil type area.	+	2.125%
	E6 Forest and grassland coverage (%)	Sum of forest and grassland area within the village domain/Village land area	-	3.895%
	E7 Geological hazard point density (count/km^2)	Average kernel density of geological hazard points within the village domain	+	2.791%
	E8 Population at risk of disasters (people)	Number of people at risk from various geological hazards within the village domain	+	3.280%
	E9 Proportion of built-up area in the village (%)	Artificially built-up area within the village domain/Village land area	+	9.493%

Table 2. *Cont.*

Criterion Level	Indicator Level	Indicator Description and Calculation	Relevance	Weight
Exposure [38,76,83,86–89]	E10 Population density in the village (people/km^2)	Total population in the village/Village land area	+	7.587%
	E11 Gross domestic product density (10,000 yuan/km^2)	Total production value in the village/Village land area	+	8.219%
	E12 Intensity of fertilizer application (kg/hm^2)	Amount of fertilizer applied within the village domain/Total area of productive land in the village	+	1.556%
	E13 Distance to town (km)	Shortest distance from the village boundary to the nearest town, weighted by the distance to both townships and county seats.	-	0.715%
	E14 Distance to tourist scenic area (km)	Shortest distance from the village boundary to the nearest tourist scenic area	-	0.398%
	E15 Distance to natural reserve (km)	Shortest distance from the village boundary to the nearest natural reserve	-	0.611%
Sensibility [36,37,69,80,91–94]	S1 Richness of flora and fauna	Number of aboveground biomass (AGB) within the village domain, calculated based on the normalized vegetation index using the Qinghai-Tibet Plateau cold zone biomass calculation model [95].	-	0.721%
	S2 Village age	The founding period of the village (quantified into five levels)	+	0.983%
	S3 Richness of existing historical environmental elements	Average kernel density of historical environmental elements within the village domain, weighted by the kernel density of natural scenic spots, temples, towers, etc.	-	1.197%
	S4 Completeness of village spatial pattern	Degree of preservation of the traditional village pattern (quantified into five levels)	-	1.204%
	S5 Coordination of new and old architectural styles	Degree of coordination between new and traditional buildings in the village (quantified into five levels)	-	1.401%
	S6 Earliest existing building construction year	The earliest construction year of existing buildings (quantified into five levels)	+	1.368%
	S7 Cultural heritage conservation grade	Grade of cultural heritage within the village domain (quantified into five levels)	+	4.542%
	S8 Proportion of traditional building land to total village construction land (%)	Traditional building land/Village construction land area	-	1.741%
	S9 Traditional building utilization rate (%)	Number of traditional buildings used/Total number of traditional buildings in the village	-	3.092%
	S10 Scarcity of traditional buildings	Scarcity of traditional building groups within the prefecture domain (quantified into five levels)	+	1.008%
	S11 Degree of traditional building restoration	Completeness of traditional building restoration (quantified into five levels)	-	1.127%
	S12 Utilization of special structures	Number and utilization degree of special structures within the village domain (quantified into five levels)	-	1.542%
	S13 Proportion of permanent residents (%)	Number of permanent residents/Total population in the village	-	2.658%
	S14 Proportion of females in permanent residents (%)	Number of females in permanent residents/Total permanent residents in the village	+	1.635%
	S15 Proportion of primary industry workers (%)	Number of primary industry workers/Total labor force in the village	-	1.458%
	S16 Richness of production and operation types	Number of agricultural and livestock production and operation types/Total production and operation types in the village	-	1.339%
	S17 Proportion of primary industry income in village output (%)	Income from primary industries such as agriculture, forestry, animal husbandry, and fishery/Total village output	-	2.069%
	S18 Richness of land resources	Number of land use types in the village domain	-	0.721%
	S19 Land fragmentation	Number of land patches within the village domain/Village land area	+	5.791%

Table 2. *Cont.*

Criterion Level	Indicator Level	Indicator Description and Calculation	Relevance	Weight
Sensibility [36,37,69,80,91–94]	S20 Rate of unused production land (%)	Area of annual sown land/Area of actual arable land within the village domain	+	1.675%
	S21 Intangible cultural heritage grade	Grade of typical intangible cultural heritage within the village domain (quantified into five levels)	+	3.871%
	S22 Richness of intangible cultural heritage	Number of types of intangible cultural heritage within the village domain	-	0.792%
	S23 Scale of inheritance activities	Number of residents participating in intangible cultural heritage activities within the village domain (quantified into five levels)	-	0.848%
	S24 Degree of traditional customs preservation	Degree of preservation of traditional customs, lifestyle, and production tools (quantified into five levels)	-	0.826%
Adaptive capacity [79,81,84,96–99]	A1 Richness of service facility construction	Richness and level of various service facilities within the village domain, obtained by extracting the mean kernel density of various service facilities within the village domain using ArcGIS tools.	-	1.142%
	A2 Village Road network density (m/km^2)	Length of roads at various levels (national, provincial, county, and township) within the village domain/Village land area	-	0.535%
	A3 Main Road hardening rate in the village (%)	Length of major hardened roads for transportation within the village domain/Total length of major roads for transportation in the village	-	1.285%
	A4 Public infrastructure guarantee degree	Level of coverage and guarantee capacity of public infrastructure (quantified into five levels)	-	0.720%
	A5 Proportion of labor force in permanent residents (%)	Number of labor force in permanent residents/Total permanent residents in the village	-	1.105%
	A6 Average education level of permanent residents	Average education level and proportion of permanent residents within the village domain (quantified into five levels)	-	0.536%
	A7 Per capita disposable income of farmers and herdsmen (yuan)	Per capita disposable income of farmers and herdsmen within the village domain, reflecting the overall living standard of farmers and herdsmen	-	0.301%
	A8 Proportion of primary industry production costs (%)	Production expenditure of the primary industry in the village/Total village output	+	1.499%
	A9 Comprehensive level of agricultural and livestock mechanization (kW/mu)	Agricultural and livestock machinery power/Total area of productive land within the village domain	-	1.376%
	A10 Commodity rate of agricultural, forestry, livestock, and fishery products (%)	Income from the sale of agricultural, forestry, livestock, and fishery products/Total village output	-	0.691%
	A11 Percentage of households engaged in cooperative operations (%)	Number of labor force participating in rural cooperatives/Total labor force in the village	-	0.529%
	A12 Per capita output value of agriculture, forestry, livestock, and fishery (yuan)	Total agricultural, forestry, livestock, and fishery production value/Number of people engaged in the primary industry within the village domain	-	0.356%
	A13 Richness of Propaganda and Education Activities	Frequency and level of propaganda and education activities within the village domain (quantified into five levels)	-	0.980%
	A14 Village satisfaction level	Overall satisfaction of residents with the village (quantified into five levels)	-	1.766%
	A15 Village cultural recognition level	Residents' confidence in and expectations for cultural inheritance in the village (quantified into five levels)	-	1.222%

4. Results

By calculating the vulnerability index (V), exposure index (E), sensitivity index (S), and adaptability index (A) of traditional villages, as well as the obstacle degree values (Q) of village indicators and B of criterion levels, and by applying the "Natural Breaks Method" in ArcGIS 10.2, we classified values into five levels: very high, high, medium, low, and very low. We used the "Hotspot Analysis Method" to identify the distribution of value aggregation. The "coefficient of variation" was used to analyze the degree of variation between values. To ensure consistent comparison of value changes between 2012 and 2019, the value of level classification was based on the average of the natural break points for each year.

4.1. Spatiotemporal Differentiation Characteristics of Vulnerability

4.1.1. Vulnerability

From 2012 to 2019, the vulnerability of traditional villages showed a fluctuating upward trend, and the coefficient of variation continued to decrease, indicating a gradual transformation from low vulnerability and high disparity to high vulnerability and low disparity. The number of villages classified as extremely vulnerable remained stable, while the proportions of low vulnerability and slightly vulnerable villages fluctuated and decreased. The vulnerability changed from an echelon sorting combination of low vulnerability, medium vulnerability, slightly vulnerable, and high vulnerability to a combination of medium vulnerability, low vulnerability, high vulnerability, and slightly vulnerable (Table 3). The number of villages classified as medium and high vulnerability increased, with their spatial distribution extending to the southern and northern counties of the prefecture (Figure 8). High-value aggregation areas of vulnerability were distributed at the junction of Li, Mao, and Wenchuan counties, while low-value aggregation areas were found in the central and western parts of Heishui County and the southeastern region of Maerkang City.

Table 3. Proportions of different vulnerability types of traditional villages in Aba Prefecture in different years (2012–2019).

Degree Level	2012	2013	2014	2015	2016	2017	2018	2019
Very Low Vulnerability (<0.124)	21.95%	19.51%	20.33%	19.51%	19.51%	17.89%	17.07%	16.26%
Low Vulnerability (0.124–0.163)	29.27%	30.08%	27.64%	26.83%	26.83%	26.83%	27.64%	27.64%
Medium Vulnerability (0.163–0.204)	26.02%	27.64%	27.64%	29.27%	29.27%	30.08%	29.27%	30.08%
High Vulnerability (0.204–0.287)	17.89%	17.89%	19.51%	19.51%	19.51%	21.14%	21.95%	21.95%
Very High Vulnerability (≥0.287)	4.88%	4.88%	4.88%	4.88%	4.88%	4.07%	4.07%	4.07%

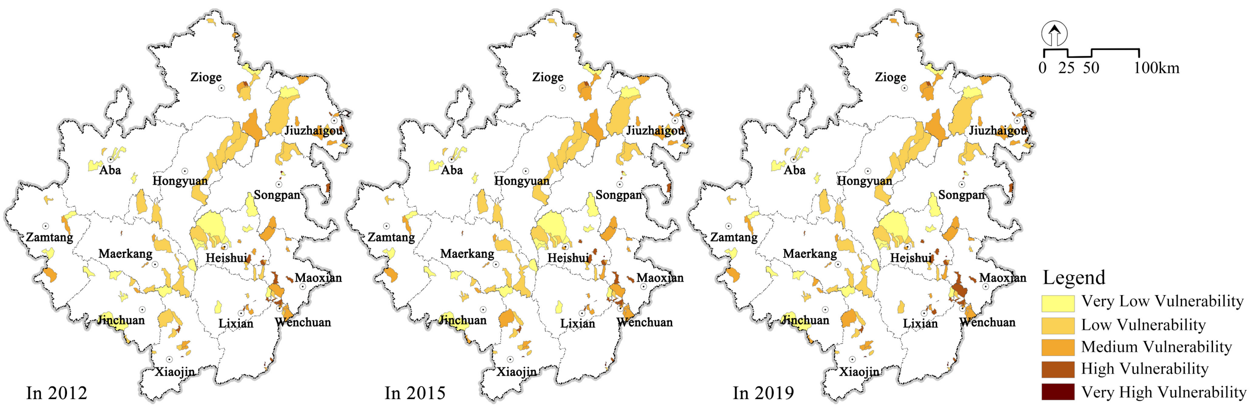

Figure 8. Spatial distribution of vulnerability of traditional villages in Aba Prefecture in different years. (Self-drawn by the author).

4.1.2. Exposure

Between 2012 and 2019, the exposure of traditional villages displayed a fluctuating increasing trend while the coefficient of variation decreased, indicating an overall enhancement in the exposure level among villages, with reduced differences among them. The number and proportion of villages with very high and low exposure remained relatively stable, whereas the number of villages with very low exposure fluctuated and decreased, and the number of villages with high and medium exposure gradually increased (Table 4). The transition from very low exposure to medium and high exposure primarily occurred in the southern region of Maerkang City, Jinchuan County, Xiaojin County, the eastern region of Jiuzhaigou County, and Mao County (Figure 9). Villages with relatively high exposure were concentrated in the junction area of Mao, Li, and Wenchuan counties, while villages in the eastern part of Zoige, western Jiuzhaigou County, northern Hongyuan County, western Heishui County, and eastern Maerkang City had relatively low exposure.

Table 4. Proportions of different exposure types of traditional villages in Aba Prefecture in different years (2012–2019).

Degree Level	2012	2013	2014	2015	2016	2017	2018	2019
Very Low Exposure (<0.057)	32.52%	34.96%	31.71%	30.08%	30.08%	30.89%	30.89%	30.89%
Low Exposure (0.057–0.082)	38.21%	34.96%	38.21%	39.84%	39.84%	38.21%	38.21%	38.21%
Medium Exposure (0.082–0.118)	17.07%	17.07%	17.07%	17.07%	17.89%	18.70%	18.70%	17.89%
High Exposure (0.118–0.168)	7.32%	8.13%	8.13%	8.13%	7.32%	8.13%	8.13%	8.94%
Very High Exposure (≥0.168)	4.88%	4.88%	4.88%	4.88%	4.88%	4.07%	4.07%	4.07%

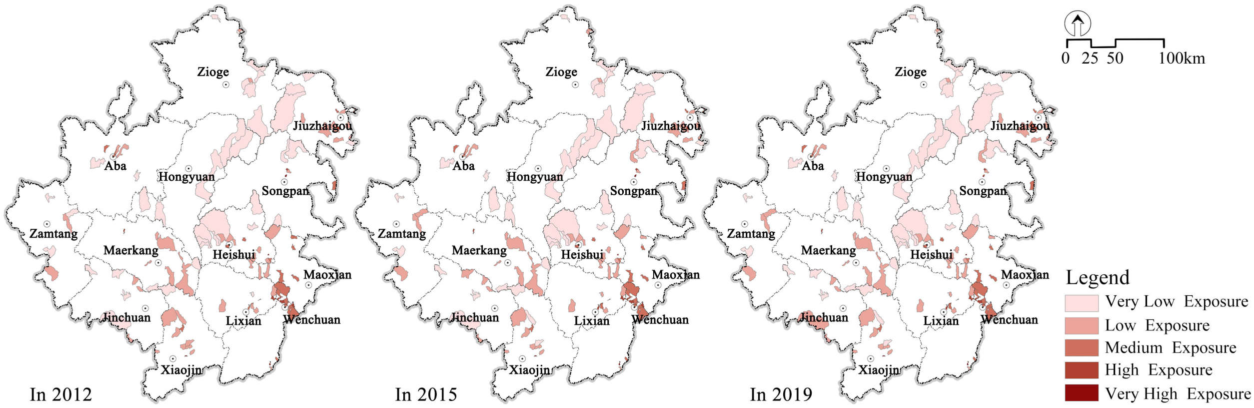

Figure 9. Spatial distribution of exposure of traditional villages in Aba Prefecture in different years. (Self-drawn by the author).

4.1.3. Sensitivity

From 2012 to 2019, the sensitivity and coefficient of variation in traditional villages exhibited significant fluctuations, with increased fluctuation and reduced differences among villages within the prefecture. Different categories of traditional villages showed obvious fluctuations in quantity, with a decrease in low sensitivity and medium sensitivity villages, and an increase in high sensitivity and very high sensitivity villages (Table 5). The main feature of the distribution of villages in different sensitivity categories was spatial dispersion (Figure 10). Traditional villages with higher sensitivity were concentrated in the southeastern part of Jiuzhaigou County, as well as in the junction area of Li County, Mao County, and Wenchuan County. Villages with relatively low sensitivity were mainly distributed in Aba County, the western part of Heishui County, the eastern part of Maerkang City, and the northern part of Jinchuan County.

Table 5. Proportions of different sensitivity types of traditional villages in Aba Prefecture in different years (2012–2019).

Degree Level	2012	2013	2014	2015	2016	2017	2018	2019
Very Low Sensitivity (<0.123)	13.82%	13.82%	13.82%	12.20%	12.20%	14.63%	14.63%	13.82%
Low Sensitivity (0.123–0.152)	22.76%	20.33%	18.70%	20.33%	20.33%	19.51%	21.95%	20.33%
Medium Sensitivity (0.152–0.175)	31.71%	33.33%	34.15%	33.33%	31.71%	33.33%	32.52%	29.27%
High Sensitivity (0.175–0.196)	19.51%	18.70%	18.70%	19.51%	21.14%	19.51%	18.70%	23.58%
Very High Sensitivity (≥0.196)	12.20%	13.82%	14.63%	14.63%	14.63%	13.01%	12.20%	13.01%

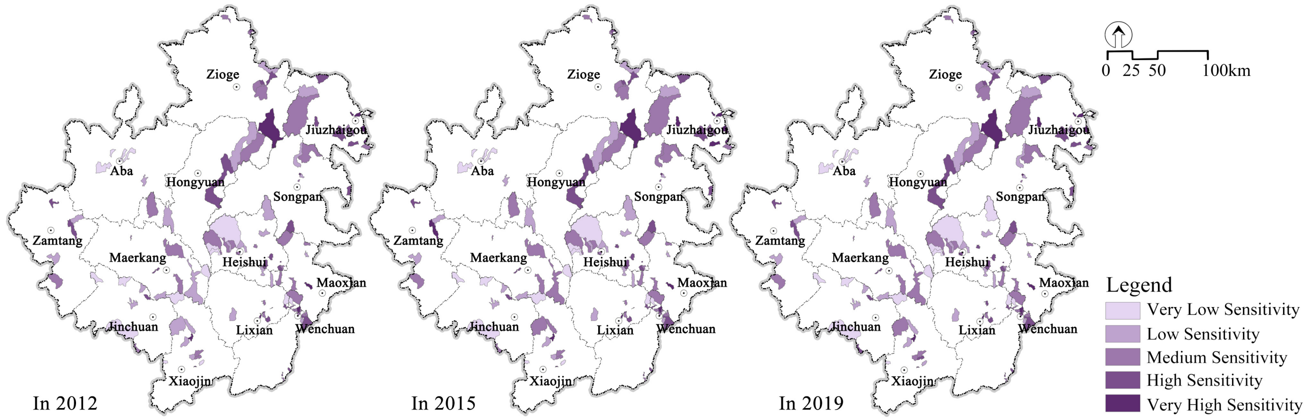

Figure 10. Spatial distribution of sensitivity of traditional villages in Aba Prefecture in different years. (Self-drawn by the author).

4.1.4. Adaptive Capacity

From 2012 to 2019, the adaptability of traditional villages showed reduced fluctuation and increased individual differences. The number of villages classified as extremely adaptable remained stable, while the proportion of slightly adaptable villages increased (Table 6). The types of village adaptability shifted from being dominated by medium adaptability, high adaptability, and low adaptability to a balanced pattern of medium adaptability, low adaptability, slightly adaptability, and high adaptability. Different types of villages were spatially distributed in a dispersed manner (Figure 11). High-value aggregation areas of adaptability were mainly distributed in the junction area of Wenchuan County, Li County, and Mao County, as well as the central and eastern part of Jiuzhaigou County and the northern part of Songpan County. The villages with low-value concentration were mainly located in Xiaojin County and the eastern part of Zoige County.

Table 6. Proportions of different adaptability types of traditional villages in Aba Prefecture in different years (2012–2019).

Degree Level	2012	2013	2014	2015	2016	2017	2018	2019
Very Low Adaptability (<0.054)	13.82%	17.07%	20.33%	21.14%	21.14%	21.14%	21.95%	21.95%
Low Adaptability (0.054–0.064)	23.58%	21.95%	22.76%	21.14%	21.14%	21.95%	24.39%	23.58%
Medium Adaptability (0.064–0.073)	28.46%	26.02%	24.39%	22.76%	21.14%	21.95%	22.76%	23.58%
High Adaptability (0.073–0.086)	24.39%	26.02%	22.76%	24.39%	26.02%	24.39%	20.33%	20.33%
Very High Adaptability (≥0.086)	9.76%	8.94%	9.76%	10.57%	10.57%	10.57%	10.57%	10.57%

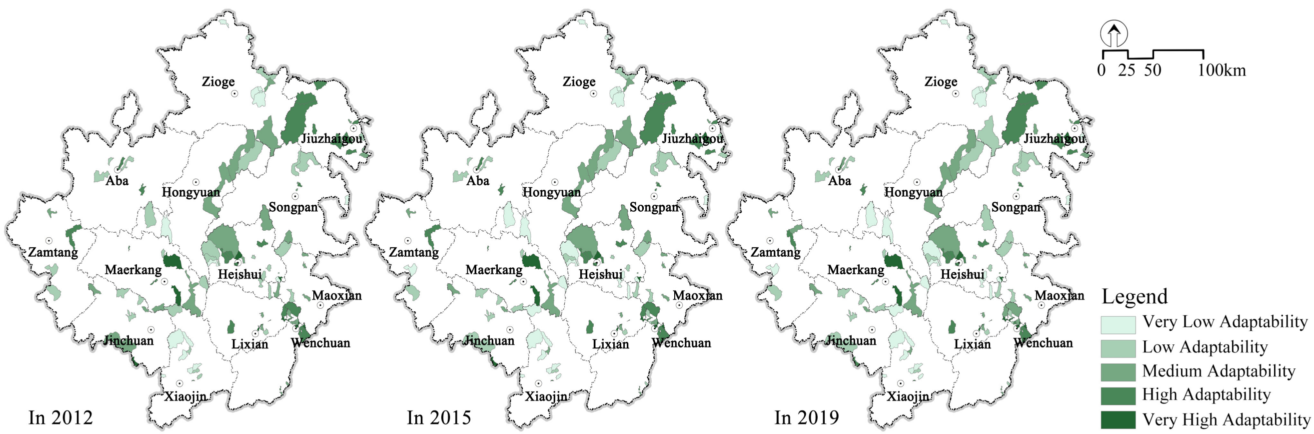

Figure 11. Spatial distribution of adaptability of traditional villages in Aba Prefecture in different years. (Self-drawn by the author).

4.2. Main Obstacle Factors of Vulnerability

4.2.1. Obstacle Degree at Criterion Level

Based on Formulas (3)–(5), the obstacle degree values of the criterion level and each indicator factor were computed.

(1) Prefecture-level Scale

Between 2012 and 2019, the impact of exposure, sensitivity, and adaptability of village vulnerability fluctuated but remained stable at the state level, with average obstacle degree values of 49.87%, 40.14%, and 9.99%, respectively. The obstacle degree of adaptability exhibited relatively high variation coefficients, reflecting significant differences in the impact of adaptability on vulnerability among different villages and an increasing trend in the degree of differential effects.

(2) Village Scale

As the impact of the criterion level remained stable during 2012–2019, the study analyzed spatial differentiation based on the average obstacle degree value as the obstacle degree value of each village (Figure 12).

Among the total of 115 villages, the main obstacle to vulnerability came from exposure, with obstacle degree values ranging from 42.88% to 56.94%. High-value "hotspot" areas were distributed in the eastern part of Zoige County, the northern part of Hongyuan County, and the western part of Jiuzhaigou County. Low-value aggregation areas were mainly distributed in the central part of Heishui County and the junction area of Wenchuan County, Li County, and Mao County. Villages in the southeastern part of Jiuzhaigou County and the junction area of Wenchuan County, Li County, and Mao County showed significant annual variations in the impact of exposure.

The obstacle degree values of sensitivity on vulnerability of villages ranged from 33.82% to 53.67%, and eight villages, including Jiaochang Village (Li County), Laoren Village, Kugua Village, Guanzhai Village, Exiu Village, Donggou Village, Xiepo Village, and Datun Village, had sensitivity as their main obstacle. High-value aggregation areas of sensitivity were distributed in the central part of Aba County and the western part of Mao County, while low-value aggregation areas were in Jiuzhaigou County and the eastern part of Zoige County. Villages in Jiuzhaigou County exhibited significant annual variations in the effect of sensitivity, while villages in the central part of Heishui County showed small annual variations in the effect of sensitivity.

The obstacle degree values of adaptability on vulnerability of villages ranged from 6.03% to 24.71%. High-value aggregation "hotspot" areas were distributed in the junction area of Wenchuan County, Li County, and Mao County, as well as the eastern part of Jiuzhaigou County. Among them, Jiaochang Village in Li County had the highest value of adaptability obstacle degree. Villages with low-value concentration were mainly distributed in the central part of Xiaojin County and the northern part of Zoige County. Villages with high and very high variation coefficients of adaptability were scattered in the eastern and southern regions, while villages in the western part of Heishui County showed small annual variations in the effect of adaptability.

4.2.2. Obstacle Degree of Indicator Factors

(1) Prefecture-level Scale

The average obstacle degree values of each indicator factor for each year were counted as the state-level factor obstacle degree values. Referring to the method of obstacle degree value and sorting screening [100,101], 23 factors with obstacle degree values >1.0% were identified as major obstacle factors, while the remaining 31 factors were classified as minor obstacle factors. From 2012 to 2019, the ranking of the top 13 factors, such as construction-land-use ratio (E9) and GDP density (E11), remained unchanged (Table 7), and the sum of obstacle degrees ranged from 70.10% to 70.63%, representing the core and stable factors affecting village vulnerability. The sum of obstacle degrees of four factors, including construction-land-use ratio, GDP density, population density, and land fragmentation, increased from 41.03% in 2012 to 41.67% in 2019, indicating an increasing impact of these factors on village vulnerability, gradually becoming the dominant factors. The obstacle degree of five factors, including the grade of cultural relic protection units, the scale of the population threatened by disasters, the utilization rate of traditional buildings, the density of geological hazard points, and the proportion of primary industry income, showed a continuous or fluctuating downward trend, indicating a gradual weakening of their impact on village vulnerability.

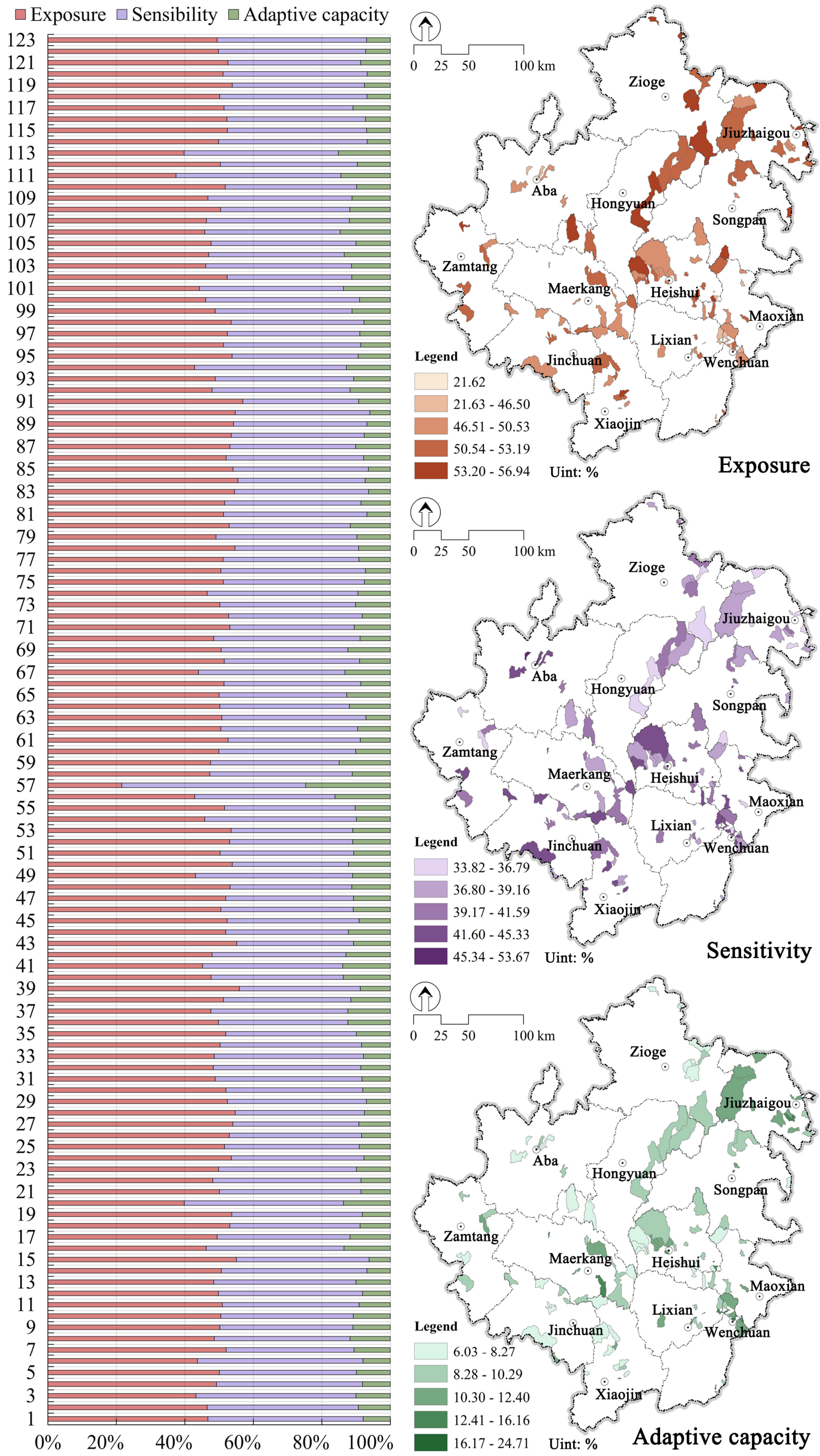

Figure 12. Obstacle degree at the criterion level for vulnerability of traditional villages in Aba Prefecture. (Self-drawn by the author).

Table 7. Obstacle degree of major factors at the prefecture-level scale (2012–2019).

Rank	Factors (Obstacle Degree Value, %)							
	2012	2013	2014	2015	2016	2017	2018	2019
1	E9 (13.12)	E9 (13.17)	E9 (13.22)	E9 (13.23)	E9 (13.23)	E9 (13.23)	E9 (13.25)	E9 (13.29)
2	E11 (10.51)	E11 (10.62)	E11 (10.67)	E11 (10.69)	E11 (10.67)	E11 (10.73)	E11 (10.79)	E11 (10.78)
3	E10 (9.82)	E10 (9.86)	E10 (9.89)	E10 (9.9)	E10 (9.9)	E10 (9.9)	E10 (9.92)	E10 (9.94)
4	S19 (7.58)	S19 (7.61)	S19 (7.63)	S19 (7.64)	S19 (7.64)	S19 (7.63)	S19 (7.64)	S19 (7.66)
5	E6 (4.61)	E6 (4.63)	E6 (4.64)	E6 (4.66)	E6 (4.67)	E6 (4.6)	E6 (4.61)	E6 (4.64)
6	S7 (4.39)	S7 (4.34)	S7 (4.36)	S7 (4.36)	S7 (4.36)	S7 (4.29)	S7 (4.29)	S7 (4.22)
7	E8 (4)	E8 (3.98)	E8 (3.92)	E8 (3.86)	E8 (3.8)	E8 (3.69)	E8 (3.65)	E8 (3.64)
8	S9 (3.57)	S9 (3.49)	S9 (3.43)	S9 (3.4)	S9 (3.36)	S9 (3.32)	S9 (3.28)	S9 (3.25)
9	S21 (3.23)	S21 (3.24)	S21 (3.22)	S21 (3.22)	S21 (3.22)	S21 (3.22)	S21 (3.23)	S21 (3.23)
10	S13 (3.12)	S13 (3.13)	S13 (3.13)	S13 (3.12)	S13 (3.11)	S13 (3.11)	S13 (3.12)	S13 (3.13)
11	E7 (2.94)	E7 (2.82)	E7 (2.79)	E7 (2.77)	E7 (2.8)	E7 (2.7)	E7 (2.68)	E7 (2.68)
12	S17 (2.11)	S17 (2.03)	S17 (2.03)	S17 (1.98)	S17 (1.99)	S17 (1.99)	S17 (1.96)	S17 (1.94)
13	E5 (1.68)	E5 (1.69)	E5 (1.7)	E5 (1.7)	E5 (1.7)	E5 (1.69)	E5 (1.7)	E5 (1.7)
14	A14 (1.58)	A14 (1.58)	A14 (1.59)	A14 (1.59)	A14 (1.58)	A14 (1.57)	S14 (1.63)	S14 (1.6)
15	S14 (1.52)	S14 (1.52)	S14 (1.52)	S14 (1.52)	S14 (1.52)	S14 (1.54)	S20 (1.58)	S20 (1.59)
16	S8 (1.44)	S8 (1.45)	S8 (1.46)	S8 (1.46)	S8 (1.46)	S20 (1.54)	A14 (1.57)	A14 (1.56)
17	E12 (1.43)	E12 (1.43)	E12 (1.44)	E12 (1.44)	E12 (1.44)	S8 (1.45)	S8 (1.45)	E12 (1.44)
18	S15 (1.29)	A8 (1.3)	A8 (1.32)	A8 (1.33)	A8 (1.34)	E12 (1.44)	E12 (1.44)	S8 (1.44)
19	A8 (1.28)	S15 (1.3)	S15 (1.3)	S15 (1.3)	S15 (1.31)	A8 (1.33)	A8 (1.32)	A8 (1.33)
20	A3 (1.19)	A3 (1.17)	S16 (1.16)	S16 (1.16)	A3 (1.16)	S15 (1.3)	S15 (1.31)	S15 (1.3)
21	S16 (1.15)	S16 (1.15)	S12 (1.13)	S12 (1.13)	S16 (1.16)	A3 (1.19)	S16 (1.16)	S16 (1.16)
22	S12 (1.12)	S12 (1.13)	A3 (1.12)	A3 (1.13)	S20 (1.16)	S16 (1.16)	A3 (1.15)	A3 (1.15)
23	S20 (1.07)	S20 (1.08)	S20 (1.09)	S20 (1.13)	S12 (1.13)	S12 (1.13)	S12 (1.14)	S12 (1.14)
24–54	(<1.0)	(<1.0)	(<1.0)	(<1.0)	(<1.0)	(<1.0)	(<1.0)	(<1.0)

(2) Village Scale

From 2012 to 2019, the obstacle degree values and rankings of each indicator for villages remained relatively stable. The study determined the average obstacle degree value of each year as the village scale obstacle degree value. According to the prefecture-level indicator obstacle degree rankings, the sum of obstacle degrees for the top 23 factors for each village was above 75%. The top four factors, including construction-land-use ratio, GDP density, population density, and land fragmentation, appeared 121, 116, 113, and 114 times out of a total of 123 villages, respectively. The fifth-ranked factor with the highest frequency was "grade of cultural relic protection units", which appeared 46 times. As the ranking decreased, the frequency of common factors decreased, reflecting the diversity in main obstacle factors and the variability in type and ranking combinations at the village scale.

5. Discussion

5.1. Vulnerability of Traditional Villages: Dynamic and Persistent

As a kind of "living heritage" [102], traditional villages are subject to continuous dynamic changes in spatial, cultural, and social aspects due to the combined effects of internal and external factors [103]. Along with the accumulation or change in the heritage value of the village, adverse problems in the village begin to emerge, stabilize, intensify, or weaken. Responding to problems and perpetuating values have become key initiatives to promote the sustainable development of traditional villages. Values have received more attention in traditional village studies [104–106] because of their "favorability to human needs" [107], and village issues are often neglected. The vulnerability analysis based on the classification of human settlement environment provides a new perspective for the systematic understanding of the adverse problems of traditional villages and can obtain regular explanations in combination with the recognized vulnerability framework. This would be conducive to facilitating the transformation of village heritage conservation from a retrospective to a prospective activity [108]. On the basis of the classification of human settlement system (natural, social, human, residential, and support), this study sorted out the typical vulnerability characterization and spatial distribution status of traditional villages in Aba Prefecture in the three aspects of the natural environment, village entity, and social humanity. This is the first systematic summary of the main problems of the current situation of traditional villages in Southwest China. These problems have mainly been briefly described or separately analyzed in previous studies of traditional villages, such as hollowing out of villages [109], irrational infrastructures [110], disaster threats [62], and landscape changes [16]. At the same time, the three aspects of vulnerability characterization have an echoing relationship with the village environmental exposure, its own composition, and social adaptive capacity, which helps to explain the vulnerability of traditional villages in terms of exposure, sensitivity, and adaptive capacity, and also helps to extract the corresponding indicators from the analysis of the current situation.

This study has screened and formulated a total of 54 indicators by integrating the indicators for the identification of traditional villages, sustainable development, and various types of systematic evaluation. Compared with the evaluations of cultural landscape vulnerability (23 indicators) [37], landscape vulnerability (22 indicators) [111], and historical environment vulnerability (13 indicators) [38] of traditional villages, it realized the examination of the influencing factors of the vulnerability of traditional villages from a more fine-grained, multidimensional, and comprehensive perspective. Due to the limitations in ecological protection policies and the level of social development in western China, indicators such as tourism income, the proportion of industrial income, and the urbanization rate, which are used in the central and eastern parts of the country, are difficult to obtain or use in remote villages in the mountainous regions of southwestern China. The spatial distribution of vulnerability of traditional villages in the study area, characterized by high in the southeast and low in the northwest, is basically consistent with the results of the vulnerability distribution of ecological and social-ecological systems in Aba Prefecture [112,113]. Due to the difficulty of obtaining village data and the large number of villages, the vulnerability assessment studies of traditional villages in Hunan, Zhejiang, and Henan mainly utilized cross-sectional data to obtain static assessment results. This study analyzes the evolution characteristics of the vulnerability of traditional villages in Aba Prefecture from 2012 to 2019 for the first time and demonstrates the trend of changes in the vulnerability and attribute dimensions of villages. This is more conducive to the local government's understanding of the dynamic process of village development, so that it can formulate a more reasonable conservation management process based on the urgency of the development and change in village vulnerability.

5.2. Influencing Factors of Traditional Village Vulnerability: Regional and Scale

There are differences in the effects of internal and external factors on traditional villages in different regions [114]. At the macro scale of national and provincial units, the influence of some factors has both positive and negative effects [115,116]. This is not conducive to the formulation of targeted traditional village management policies by management units at different levels. The overall influencing factors determined at the macro scale may not be suitable for specific village units; the management plan for individual villages needs further integration and coordination in order to achieve the formulation of regional macro-strategy. The analysis of factors affecting the vulnerability of traditional villages performed is still limited to the single level of the village unit [37,111] or the region as a whole [38]. In order to clearly describe the vulnerability obstacle factors of traditional villages, this study analyzes the function degree and evolution characteristics of criterion layer and indicators from the two scales: region and village. This is very beneficial for different managers at the regional and village level to formulate policies. In view of the degree of obstacles in the criterion layer, a relatively comprehensive policy can be proposed from the indicators included in the criterion layer. For example, strategies to reduce the exposure of villages may include land remediation, vegetation restoration, and disaster management [117]. Combined with the degree of obstacles of specific indicators, more specific response programs can be proposed. For example, in response to the high level of obstacles in the indicator on the proportion of construction land, it is possible to control the expansion of construction land and to demolish irrational construction [15].

The spatial structure of traditional villages in central and eastern China has been basically stabilized due to factors such as convenient transportation conditions, gradual improvement of the tourism industry, and earlier intervention of protection policies [10]. The influencing factors of vulnerability mainly come from the intensity of tourism development, investment in protection funds, and cultural construction [37,111], which belong to the two aspects of exposure and adaptive capacity. Most of the traditional villages in the study area are located in the closed area of alpine canyons, and the residents are mainly engaged in traditional farming and breeding industries. The complex mountainous environment causes great differences in the production conditions of villages. The indicators related to the survival of residents, such as land (proportion of built-up area in the village, the degree of land fragmentation, etc.) and disasters (geological hazard point density, population at risk of disasters), play an important role in the vulnerability of villages. Influenced by the post-earthquake reconstruction (Wenchuan Earthquake in 2008 and Jiuzhaigou Earthquake in 2017) and the new village construction policy, the proportion of land for village construction has continued to increase [118]. Rapid rural construction has a great impact on the natural environment of traditional villages, the use and preservation of traditional buildings, cultural landscapes, and residents' lives [119]. These traditional villages are in the dynamic stage of rapid flow and change in material, information, and resources [120]. The factors from both exposure and sensitivity play a major role in the vulnerability of the village. Driven by regional tourism policies, a few traditional villages have been able to develop their industries and economies by taking advantage of the construction of transportation routes and the upgrading of scenic spots [121], which has led to an increase in the differences in adaptive capacity among villages. Due to the differences in the basic conditions of villages and the degree of acquired development, the types and rankings of obstacle factors vary greatly within the village unit.

5.3. Proposals for Categorized Village Development

Using the vulnerability and exposure, sensitivity, and adaptability evaluation values of 2019 as variables, the "k-means" clustering algorithm was applied to obtain the optimal number of clusters, which was 5, with the highest value being the average F-statistic for measuring intra-group similarity and inter-group difference. According to the degree of elevation of average values within each group, they were named as very high, high, medium, low, and very low vulnerability types (Table 8).

Table 8. Village classification characteristics and strategic directions.

Village Type	Number	Characteristics			Strategic Directions
		Exposure	Sensitivity	Adaptability	
Very High Vulnerability	5	Very High	Very High	Medium	Reduce exposure and sensitivity, implement targeted measures
High Vulnerability	27	High	High	Very High	Reduce exposure and sensitivity, improve quality
Medium Vulnerability	40	Low	Medium	Very Low	Improve living standards, optimize the environment
Low Vulnerability	25	Medium	Low	High	Integrate into advantageous groups, gather for development
Very Low Vulnerability	26	Very Low	Very Low	Low	Enhance economic level, implement adaptive management

(1) Very High Vulnerability Villages. This category comprises five villages, namely Kugua Village, Xiepo Village, Jiaochang Village (Li County), Laoren Village, and Guanzhai Village. In the analysis, these villages exhibit very high exposure and sensitivity, with moderate adaptability. Each village demonstrates certain indicators with the highest or lowest values. For instance, Jiaochang Village (Li County) has the highest construction-land-use ratio and GDP density, while Guanzhai Village faces the most

severe land fragmentation. Consequently, there are significant variations in obstacle factors among these villages (decreasing with ranking), and the interactions between these factors fluctuate considerably. For this category of villages, protective and developmental strategies should be devised based on the sorting of their obstacle factors, with a primary focus on reducing exposure and sensitivity.

(2) High Vulnerability Villages. This category includes 27 villages, such as Se'ergu Village and Shabangou Village. These villages exhibit high exposure, high sensitivity, and very high adaptability, which contribute to their vulnerable characteristics. These villages possess advantageous locations or heritage resources, leading to their enhanced adaptability. Generally, these villages face obstacles from seven factors, including construction-land-use ratio, GDP density, population density, land fragmentation, forest and grass coverage, proportion of permanent residents, and utilization rate of traditional buildings. While reducing exposure and sensitivity in these villages, emphasis should be placed on shaping their distinctive characteristics and improving their quality, while also highlighting sustainable protection and utilization of resources.

(3) Medium Vulnerability Villages. This category includes 40 villages, such as Zhuba Village and Wabo Village. These villages have low exposure, medium sensitivity, and very low adaptability, which contribute to their vulnerable characteristics. These villages are generally influenced by indicators such as construction-land-use ratio, population density, GDP density, land fragmentation, forest and grass coverage, proportion of permanent residents, and the scale of the population threatened by disasters. Faced with relatively ordinary resource conditions, changing the current living environment and improving economic development are the primary tasks for enhancing village adaptability and development. While adhering to the requirements for conserving a good ecological environment, adjusting and optimizing the village landscape environment and stabilizing the relationship between people and land are also areas of concern for the villages' sustained development.

(4) Low Vulnerability Villages. This category includes 25 villages, such as Shenzuo Village and Yangrong Village. These villages have moderate exposure, low sensitivity, and high adaptability, contributing to their vulnerable characteristics. Common obstacle factors for these villages include construction-land-use ratio, population density, GDP density, land fragmentation, forest and grass coverage, the scale of the population threatened by disasters, the utilization rate of traditional buildings, and the density of geological hazard points. Building upon the development foundation already established in these villages, with the support of policies or the radiative effect of surrounding scenic areas and towns, actively integrating into advantageous groups and seeking collective development are the main directions for the protection and utilization of these villages.

(5) Very Low Vulnerability Villages. This category includes 26 villages, such as Qilaluo Village and Gaxiu Village. These villages have very low exposure, sensitivity, and low adaptability, contributing to their vulnerable characteristics. The common obstacle factors for these villages include construction-land fragmentation, land-use ratio, population density, GDP density, proportion of permanent residents, the scale of the population threatened by disasters, the utilization rate of traditional buildings, and forest and grass coverage. Confronting a state of low, slow, and closed development, enhancing village adaptability and improving economic levels become the primary tasks for these villages. In the process of adaptive management, gradually establishing the villages' development direction becomes crucial.

5.4. Research Limitations and Future Prospects

This study strives to comprehensively analyze the vulnerability of traditional (Chinese) villages by integrating core indicators for determining traditional villages focus on the villages themselves and adopting a multidimensional approach to assess the living environment. However, certain limitations remain due to the challenges of collecting long-term panel data for mountainous villages and the subjectivity and complexity of heritage value identification and evaluation [122]. The following limitations should be acknowledged. (1) Changes in the value of village heritage due to the accumulation of environmental vulnerability and the mechanisms by which vulnerability affects value should be further explored in future research. (2) As the 54 indicators require a high degree of village data completeness, they can be streamlined to obtain application in geographical units such as the whole country, provinces, watersheds, and unique cultural areas. Through the differentiated analysis of village vulnerability in different geographical areas and within geographical areas, it provides information for broader village development. (3) While the study has proposed strategies for village classification and development based on main obstacle factors, the formulation of specific village plans should provide targeted recommendations considering the common constraints of factor rankings, as well as conservation and sustainable development criteria. (4) Based on the main impact indicators identified in the study, such as proportion of built-up area, population density, gross domestic product density, land fragmentation, and so on, future research can analyze the impact of single dimensions (non-agricultural construction, economic development, population loss, etc.) on village vulnerability and heritage value through in-depth investigation of material and non-material elements of typical villages.

6. Conclusions

In light of the connotation and generation rules of vulnerability in Chinese traditional villages, this study has successfully outlined the vulnerable characteristics of traditional villages in Aba Prefecture. By combining qualitative and quantitative methods, an indicator system for evaluating village vulnerability is developed. The vulnerability index and obstacle degree model are then utilized to analyze the spatiotemporal differentiation characteristics and main obstacle factors of vulnerability from 2012 to 2019. Subsequently, practical suggestions for the protection and development of classified villages are proposed. The key findings can be summarized as follows.

(1) Interaction Among Exposure, Sensitivity, and Adaptability: The intricate interaction of "exposure-sensitivity-adaptability" in traditional villages often leads to challenges in maintaining a balance. As a result, village living environments and values experience adverse changes, leading to vulnerability. The vulnerable characteristics observed in traditional villages of Aba Prefecture include issues such as soil erosion, reduced vegetation coverage, severe disaster threats, decreased utilization of traditional buildings, transformation of traditional landscapes, inadequate basic services, scarcity and fragmentation of arable land, low agricultural and pastoral productivity, reliance on single industries, slow economic development, and weakened cultural awareness with difficulties in inheriting intangible cultural heritage.

(2) Spatial Pattern of Vulnerability: Traditional villages in Aba Prefecture exhibit an "east high, west low" spatial pattern with an agglomerated distribution. From 2012 to 2019, the overall vulnerability level of villages fluctuated with reduced individual differences. The number of villages classified as medium and high vulnerability increased, extending to the southern and northern regions of the prefecture. Exposure, sensitivity, and adaptability in villages demonstrated distinct evolutionary and spatial differentiation characteristics.

(3) Main Obstacles to Vulnerability: The primary obstacles to vulnerability in traditional villages of Aba Prefecture are jointly influenced by exposure and sensitivity factors. Factors such as construction-land-use ratio, GDP, population, and land fragmentation have consistently exerted significant and stable effects. Based on the identified characteristics of village vulnerability and main obstacle factors, strategic suggestions for village classification, protection, and development have been proposed.

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