sustainability

MDPI

Essay

Study on Rural Ecological Resilience Measurement and Optimization Strategy Based on PSR-"Taking Weiyuan in Gansu Province as an Example"

Xiaoling Xie *, Gaonan Zhou and Shibao Yu

School of Architecture and Urban Planning, Lanzhou Jiaotong University, Lanzhou 730070, China
* Correspondence: xiexl@mail.lzjtu.cn

Abstract: Under the dual impact of urbanization and ecological crisis, rural ecological resilience research can improve the system's level of resisting external pressure and restoring ecological balance and provide a new perspective for sustainable rural development. This study establishes a rural ecological resilience measurement system in Weiyuan based on the PSR framework, evaluates the level of rural ecological resilience in Weiyuan in 2021 using the entropy method and the GWR model and detects its driving factors. The results show that (1) the spatial characteristics of rural ecological resilience diverge significantly, with the ecological resilience level of the three southern forest farms being higher overall the high values of resilience in Qingyuan, Wuzhu and Xiacheng being distributed in the central villages, while other villages are at low and medium values (2) X5 and X7 have negative driving effects on village ecological resilience, and X1, X5, X9 and X10 have positive driving effects on village ecological resilience (3) the dominant drivers and characteristics, we construct a scheme on stressor repair, state adaptation transformation and response efficiency optimization to provide ideas for improving rural ecological resilience.

Keywords: "pressure-state-response" model; rural area; ecological resilience; sustainability

check for updates

Citation: Xie, X.; Zhou, G.; Yu, S. Study on Rural Ecological Resilience Measurement and Optimization Strategy Based on PSR-"Taking Weiyuan in Gansu Province as an Example". *Sustainability* **2023**, *15*, 5462. https://doi.org/10.3390/su15065462

Academic Editors: Artiom Volkov and Mangirdas Morkunas

Received: 13 February 2023
Revised: 9 March 2023
Accepted: 15 March 2023
Published: 20 March 2023

1. Introduction

Ecosystems (ES) are complex adaptive systems that adapt to external changes to form a new ecological environment, but the uncertainty of ecological damage due to diverse disaster risks makes it difficult for ES to return to a stable state because the disturbances they face far exceed the system's own adaptive capacity. In 1973, the ecologist Holling proposed ecological resilience as a new concept of ecology [1], which has been defined by scholars in different fields, but most studies use the terms 'the ability of an ecosystem to maintain its structure and function in response to external shocks' to explain the nonlinear characteristics of ecosystem change. Ecological resilience studies focus on the ability of the ES to maintain system stability and return to a new equilibrium after a local-scale ES shock, often quantified in terms of biodiversity and ecosystem service capacity. Most ES maintain dynamic equilibrium through species richness, community structure and landscape patterns [2]; of these, connectivity, habitat and habitat quality are considered to be the drivers that influence the maintenance of equilibrium in ecosystems such as rivers and forests [3]; trophic networks and predator prey chains are considered to be the main causal networks affecting the resilience of ecosystems such as lakes and grasslands [4]. A range of international projects provides ideas for ecological resilience management by studying the links between ecological stress, structure and function and ecosystem service provision across scales [5]. However, the mechanisms of interaction between terrestrial ecosystems and social systems are complex, and the role of both on resilience needs to be considered. The Resilience Alliance uses adaptive cycle theory to describe the mechanisms by which social–ecological systems (SES) operate, noting that SES move sequentially through four stages of exploitation (R), conservation (K), release (Ω) and renewal (α) to form cycles [6], thus extending ecological resilience research to the relatively complex social–ecological system (SES) resilience [7]. Related studies focus on the impact of disturbances such as climate change, policy regimes and landscape fragmentation on SES resilience and discuss the mechanisms of SES recovery primarily through adaptive management approaches such as maintaining diversity and redundancy, managing connectivity [8], managing slow variable and feedback [9], and creating opportunities for self-organization [10]. The application extends from ecosystem management, disaster prevention and mitigation and ecological planning to the field of urban planning [11]. However, the complexity, multi-scale nature and multi-steady-state characteristics of SES make the quantification of SES resilience more difficult. Resilience substitution is used as a universal measure, with some studies using ecosystem substitution as an indicator factor for SES achieving steady-state transitions and some studies assessing the sustainability of social–ecological systems using the uncertainty, diversity and self-organizing capacity of SES and ecosystems as a resilience framework [12]. Considering the scale-dependent effects of SES, it has been proposed to quantify functional redundancy [13] and diversity at discontinuous scales using cross-scale resilience models that link measurable proxies to inherent structural scales within ecosystems [14]. The Handbook for Assessing the Resilience of Complex Socio-Ecological Adaptive Systems, which identifies system boundaries, system dynamic evolution, system interactions and adaptive governance as strategic objectives, is also used to assess ecosystem resilience [15]. Relatively speaking, ecosystem resilience assessment methods are developing rapidly, with the emergence of methods and tools such as network analysis, scenario modelling, state space and threshold and breakpoint methods [16]. A threshold is often used to describe the threshold at which one state of a system transitions to another. For example, by simulating scenarios of changes in vegetation cover under stressor impacts, thresholds for the loss of ecological resilience are measured [17], and thresholds for changes in the state of pine community systems in severe drought environments are thresholds and breakpoints for the degree of soil erosion and the corresponding ecosystems [18]. Time series analysis also produces early warning indicators of ecological stability loss by detecting changes in indicators of ecosystem condition (e.g., increasing variance and autocorrelation) [19]. Throughout the existing literature, there is a trend of the diversification of research perspectives and enrichment of research methods in ecological resilience research. Multidisciplinary intersection and integration require ecological resilience to gradually shift from traditional mathematical and physical characteristics analysis to spatial analysis, but ecological resilience is still focused on urban, community and green space levels, with less attention paid to rural ecological resilience issues, and further research on ES resilience is needed to analyze the complex mechanisms of ES at multiple temporal and spatial scales to comprehensively assess its resilience.

The encroachment and overuse of ecological resources by human activities has led to the growing problems of ecological overload, environmental pollution and the reduction of biodiversity in the countryside, seriously undermining the stability of the original ecological structure and increasingly revealing the fragility of rural ecosystems. Rural ecological resilience (RER) has a dynamic time series capacity for the continuous optimization of ecosystems [20]. It can reduce rural ecological vulnerability and enhance system resilience and recovery when rural ecosystems are under constant shocks and threats [21]. It fits in with the goal of ecological livability in rural revitalization. Foreign research on RER has focused on influencing factors, rural construction and development policies. Studies of influencing factors have revealed that the deep-seated causes of rural ecosystem vulnerability include lack of financial support [22], social poverty and climate change [23], etc. Arouri et al. (2015) analyzed that natural disasters are the main factors affecting rural ecological resilience, and policy inputs can effectively strengthen risk resilience [24]. Leocadia (2022) assessed the ecological vulnerability of rural South Africa to climate change impacts in terms of exposure, sensitivity and adaptive capacity in rural construction [25]. In rural con-struction, Wang et al. (2022) constructed a resilience governance framework for physical-energy ecological chains in the context of resource and environmental constraints [26]. Schippers P explored the potential for rural landscapes to increase resilience through ecologically–genetically–economically integrated spatial configurations [27]. In China, studies focus on resilience assessment, disaster response and resilience governance. Liu et al. (2017) compared gentrification and grassroots rural development models and found that the grassroots model is more resilient, and resilience cultivation requires ecological wisdom to guide the transformation [28]. Wang Q.Y. (2022) proposed a resilience planning strategy for the rural villages of the southern Jiangsu water network through the construction of anti-disturbance ecological networks, multi-situational functional zoning and an adaptive circulation system [29]. The study of rural ecological resilience demonstrates the link between the ability of villages to cope with and manage the risks of ecosystem disturbance and rural space, and the achievement of rural ecological sustainability through the process of 'im-pact-disruption-repair-improvement'. The link between the ability of villages to cope with and manage ecosystem disturbance risks and rural spaces is reflected in the study. However, the process of ecological resilience has been neglected, and the spatial representation, characteristics and influencing factors of ecological resilience cannot be accurately presented.

The "Pressure-State-Response" (PSR) mod is more maturely applied in the evaluation systems of ecological security [30], ecosystem health [31] and sustainable land use [32] and is involved in resilience assessment. An example of this is an integrated assessment of ecological vulnerability at three levels of stress, sensitivity and resilience using the PSR model, and it is combined with a weighted decision matrix approach to assess the sensitivity and resilience of rangeland ecosystems in semi-arid regions [33]. These studies reflect the positive and negative feedback relationships between external development impacts on the system through the PSR model and find that there is a logical fit between resilience process characteristics and the PSR model, which complements the lack of process thinking in ecological resilience measurement [34]; however, there are not many studies that combine the PSR model with rural ecological resilience, and it is of practical significance to use the PSR model to establish an ecological resilience assessment framework. Therefore, this paper starts from the connotation of RER, dismantles the complex process of rural ecosystems exerting resilience and introduces the PSR model to sort out the causal factors, change processes and role feedback of ecological problems and then analyzes and defines the composition of RER, which provides support for the construction of a rural ecological resilience evaluation system in this paper.

This study establishes a rural ecological resilience measurement system based on the PSR framework from the internal and external risks, internal factor changes and subject feedback faced by rural ecosystems [35], evaluates rural ecological resilience in Weiyuan County using the entropy value method and identifies the driving factors affecting ecological resilience in different townships using the GWR model. Through the three stages of rural ecological resilience stressor repair, state adaptation transformation and response measure optimization to improve the resilience, adaptability and recovery of rural ecosystems, the rural ecosystems can mitigate the impact of shocks and can reach a new stable state relatively quickly, providing theoretical support for the improvement of ecological resilience in the northwest arid region and providing certain decision-making references for rural resilience against uncertain risks and ecological restoration and improving zoning governance capacity, enriching and developing the theoretical vision of ecological resilience and ecological civilization to a certain extent.

2. Construction of Rural Ecological Resilience Measurement System

2.1. Application of the PSR Model

The Pressure-State-Response (PSR) model was proposed by Canadian statisticians David and Fried and is used by the Organization for Economic Cooperation and Development (OECD) and the United Nations Environment Programme (UNEP) as a framework for studying environmental issues [34]. According to the OECD framework for the PSR model, this study considers "Pressure" as the external direct or indirect pressure on rural ecosystems, which reflects the causal factors of rural problems; "State" represents the adaptation status of rural ecosystems and "Response" are the response measures taken by human society to alleviate external pressures and improve the resilience and adaptability of rural ecosystems to disturbances.

The PSR model of rural ecological resilience reveals the chain relationship among the system, causal factors and human activities [35], which emphasizes the intrinsic mechanism of interaction and mutual constraints between human activities and rural ecosystems(Figure 1): the human use of natural resources for urban development and economic development activities continuously discharges pollutants into the interior of the system, causing different degrees of ecological balance, resource endowment and land use within the rural system. This has led to environmental changes and frequent natural disasters outside of the system. The superimposed negative effects of the internal and external systems exert enormous pressure on rural ecosystems and affect human life and production activities. Humans prevent, reduce and compensate for the impacts and losses caused by ecological pressure through policy regulation, pollution control and ecological restoration, and so on. The "pressure-state-response" model reflects the cause-and-effect relationship of rural ecological resilience from three different and interlinked perspectives, which well explains the whole process and stages of resilience and provides a unique idea for the next step of constructing a rural ecological resilience evaluation index system, with rich reference value and guidance.

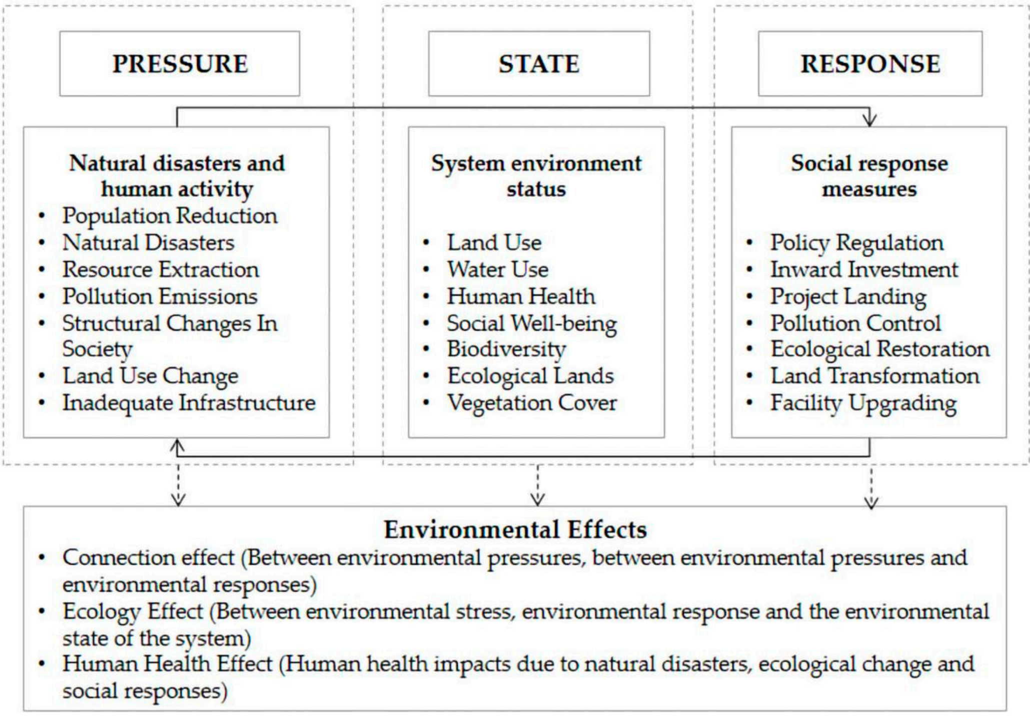

Figure 1. PSR model construction framework of "Pressure-State-Response".

2.2. Rural Ecological Resilience Measurement System Construction

The measurement system of rural ecological resilience was constructed based on the PSR model, focusing on the threat factors that interfere with the operation of rural ecosystems, their own operation status and activities to maintain the balance of the ecosystem. Following the principles of scientificity, appropriateness, quantifiability and data availability, 15 indicators were initially selected from 3 criterion levels of pressure, state and response, and 13 indicators with a strong correlation were screened out using the Pearson correlation coefficient method (Table 1) to establish the rural ecological resilience measurement index system (Table 2).

Table 1. Results of Pearson Correlation Coefficient Analysis for Ecological Resilience Indicators.

	X1	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**
X1	1											
X2	−0.076	1										
X3	−0.081	0.012	1									
X4	0.366 **	−0.244 *	−0.155	1								
X5	0.294 **	−0.349 **	−0.198 *	0.015 **	1							
X6	0.094	0.048	−0.331 **	0.088	0.034	1						
X7	−0.179	−0.489 **	−0.237 *	−0.334 **	0.084	−0.143	1					
X8	−0.091	−0.479 **	−0.155	−0.067	0.344 **	−0.257 **	0.045 **	1				
X9	0.04	0.042 **	0.049	0.041	−0.14	0.029	−0.589 **	−0.745 **	1			
X10	0.014	−0.554 **	0.044	0.054 **	0.032 **	−0.200 *	0.057 **	0.738 **	−0.545 **	1		
X11	0.056	0.034	0.01	0.033	0.009 *	−0.002	−0.112	−0.119	0.068	−0.058	1	
X12	−0.287 **	0.351 **	0.199 *	−0.780 **	−1.000 **	−0.128	−0.09	−0.350 **	0.15	−0.534 **	−0.210 *	1

* $p < 0.05$ ** $p < 0.01$.

Table 2. Rural Ecological Resilience Evaluation Index System.

Integrated Layer	Guideline Layer	Indicator Code	Indicator Layer	Indicator Meaning	Forward and Reverse	Data Source
Rural Ecological Resilience (RER)	Pressure Toughness (PR)	X1	Density of water network in village area	Rural water stress	+	Resource and Environmental Science and Data Center, Chinese Academy of Sciences
		X2	Natural Disaster Situation	Risk perturbation profile	-	Weiyuan County Territorial Spatial Master Plan (2020–2035)
		X3	Proportion of area on slopes ≥ 25°	Production risk index	-	Resource and Environmental Science and Data Center, Chinese Academy of Sciences
		X4	Proportion of abandoned land in the countryside	Status of idle land	-	Weiyuan County Territorial Spatial Master Plan (2020–2035)
	Status Toughness (SR)	X5	Village population density	Degree of hollowing out of the countryside	-	Gansu Province Rural Yearbook (2021)
		X6	Arable land per capita	Living Security Level	+	Weiyuan County Territorial Spatial Master Plan (2020–2035)
		X7	Proportion of ecological land	Household livelihood level	+	Weiyuan County Third National Land Survey
		X8	Forest vegetation cover	Industry economic level	+	Weiyuan County Third National Land Survey
	Response toughness (RR)	X9	Proportion of permanent basic farmland area	Level of farmland protection	+	Weiyuan County Third National Land Survey
		X10	Proportion of ecological protection red line area	Ecological protection level	+	The Third National Land Survey in Dingxi City
		X11	Village road network density	Disaster Response Level	+	Resource and Environmental Science and Data Center, Chinese Academy of Sciences
		X12	Domestic waste disposal rate	Pollution control level	+	Special Plan for Rural Domestic Sewage Treatment in Weiyuan County (2020–2030)

Source: Author's compilation based on calculation results.

At the level of rural ecosystem pressures, there are direct and indirect pressures. The direct pressure is mainly the environmental pressure faced by villages; the natural disaster situation visually describes the degree of damage to rural ecosystems when hit by disasters, and the rural water network index is an important measure of ecosystem carrying capacity. Indirect pressures are the stagnation or even regression of rural development due to population exodus and the unsustainability of rural production. The proportion of land abandonment and the proportion of land area on slopes ≥ 25° can reflect the potential impact of rural residents on ecosystem pressure.

At the level of environmental status of rural systems, risk disturbance and restoration level are important evaluation criteria to reflect rural ecosystem services, and the selection of forest vegetation cover and ecological land ratio directly reflects the ecosystem status of rural areas [36]. The proportion of forest cover and ecological land directly reflects the ecosystem status of the countryside. Reasonable ecological occupation has positive feedback on natural resource regulation and ecosystem balance, while rural population density and per capita arable land area can quantitatively judge the balance between ecological space and agricultural space.

At the level of social response, ecological resource control is an effective means to carry out the ecological restoration of rural systems, and the inclusion of the ratio of the area of permanent basic agricultural land and ecological protection red line into the ecological resilience evaluation index can objectively reflect the level of protection of ecosystems by policies. Road network density is a limiting condition for the adaptation and early warning ability of rural ecosystems to cope with external pressure, and pollution control is an important means to build a regional ecological security pattern and promote ecological restoration.

3. Materials and Methods

3.1. Overview of the Study Area

Weiyuan (103°44′–104°24′ E, 34°55′–35°25′ N) is located in Dingxi City, Gansu Province, located in the western part of the Loess Plateau of the Longxi Plateau and the western end of the Qinling Trough intersection; it belongs to the southern Longzhong temperate semi-humid zone; the northern part of the county climate, precipitation and vegetation differences are obvious; and the total area is 2053.49 square kilometers with a jurisdiction of 16 towns(Figure 2). In the Lanzhou metropolitan area and Lan Ding integration strategy, Weiyuan County has a high proportion of net population outflow, serious rural land abandonment and a serious ecological and environmental situation. The rich ecological and historical resources are an important growth point for the new tourism pattern in Gansu Province, and the reserve agricultural and forestry resources in Weiyuan County have great potential, and the overall ecological resilience is more optimistic. The selection of Weiyuan County, which has obvious differences in rural ecological levels and rich response measures, as the study area for rural ecological resilience evaluation can provide research ideas for rural ecological resilience research in the northwest arid region and has important practical value.

3.2. Data Sources

The study data mainly include land use, road traffic, socio economic data and other data. Among them, the socio economic data are mainly from the Gansu Rural Yearbook (2021) and the Weiyuan County Territorial Spatial Master Plan (2020–2035), and the land use data are from the Gansu Province Third National Land Survey Main Data Bulletin. Road data and other data were obtained from remote sensing monitoring data from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences.

3.3. Research Methodology

The RER assessment method used in this study consisted of four steps: First, establishing an ecological resilience evaluation index system and applying the entropy method to determine the weights of each index. Second, a comprehensive evaluation of the level of ecological resilience of each village was carried out by combining the weights. Third, the linear regression model was used to gradually screen the drivers with significant effects related to the level of ecological resilience. Fourth, the GWR model was applied to identify the spatial heterogeneity of the RER drivers.

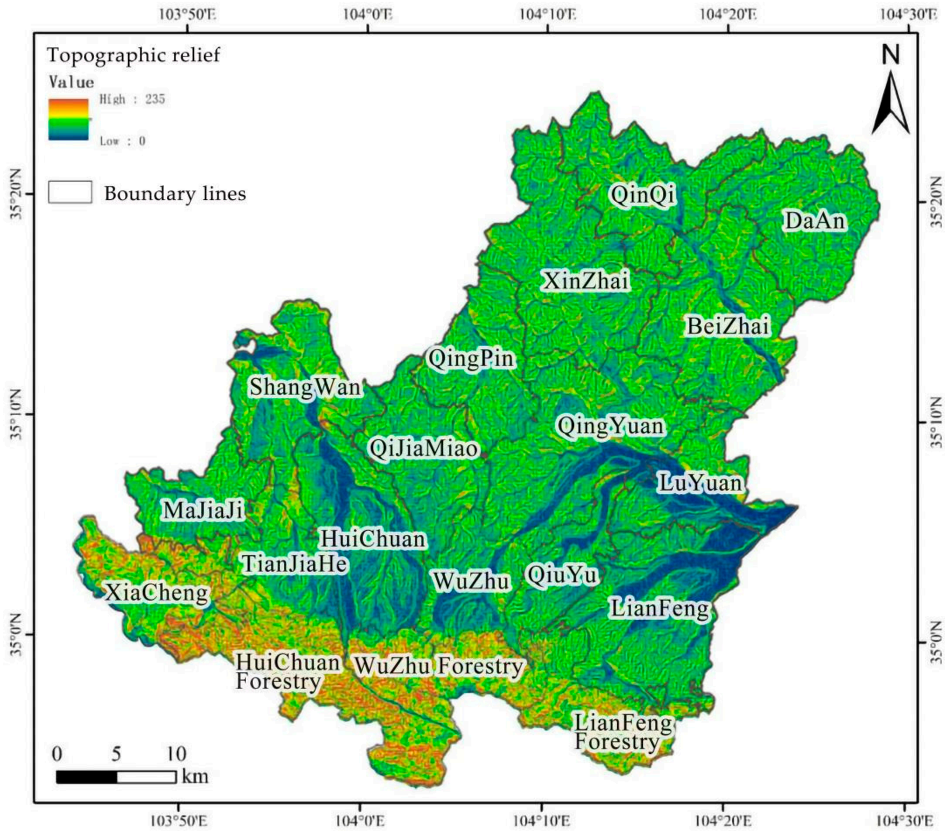

Figure 2. Administrative map of Weiyuan.

3.3.1. Entropy Value Method

(1) Normalize all indicators so that the value of each indicator is between [0, 1], calculated as

$$\text{Positive indicators}: \ X'_{ij} = \frac{X_{ij} - \min\{X_{ij}, \cdots, X_{nj}\}}{\max\{X_{1j}, \cdots, X_{nj}\} - \min\{X_{1j}, \cdots, X_{nj}\}} \tag{1}$$

$$\text{Negative indicators}: \ X'_{ij} = \frac{\max\{X_{ij}, \cdots, X_{nj}\} - X_{ij}}{\max\{X_{1j}, \cdots, X_{nj}\} - \min\{X_{1j}, \cdots, X_{nj}\}} \tag{2}$$

X'_{ij} is the value of the jth indicator for the ith administrative village (i = 1, 2 . . . , n; j = 1, 2, . . . , m) where min denotes the minimum value and max denotes the maximum value.

(2) Calculate the share of the ith administrative village under the jth indicator in the indicator.

$$P_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{n} X'_{ij}} \ (i = 1,\ 2\ \ldots,\ n;\ j = 1, 2, \ldots, m) \tag{3}$$

(3) Calculate the entropy value of the jth index.

$$e_j = -k \sum_{i=1}^{n} P_{ij} \ln(P_{ij}) \tag{4}$$

(4) Calculate the redundancy of information entropy.

$$d_j = 1 - e_j \ \text{Among them}\ k = 1/\ln(n) > 0,\ \text{meet}\ e_j \geq 0 \tag{5}$$

(5) Finally, the weights of each indicator are derived.

$$w_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \tag{6}$$

3.3.2. Comprehensive Evaluation Method

The weights of each index are combined for weighting calculation, and the summation is performed by GIS spatial overlay analysis to evaluate the comprehensive influence degree of pressure resilience, state resilience and response resilience on the resilience of a rural ecosystem system and to obtain the rural ecological resilience index, the level of which is positively correlated with the resilience and adaptive capacity of a rural system. This paper sets as follows:

$$QP = \sum_{j=1}^{4} W_j P_{ij} \tag{7}$$

$$QS = \sum_{j=5}^{8} W_j P_{ij} \tag{8}$$

$$QR = \sum_{j=9}^{12} W_j P_{ij} \tag{9}$$

$$Q = QP + QS + QR \tag{10}$$

where Q is the ecological resilience index of the countryside. QP is the stress resilience index of the countryside. QS is the state resilience index of the countryside. QR is the response resilience index of the countryside.

3.3.3. Stepwise Regression Analysis Method

The 12 indicators in the ecological resilience evaluation index system were used as independent variables, and the ecological resilience measurement results were used as dependent variables for linear regression analysis. After eliminating the indicators with multiple co-linearities, the indicators with significance were screened out using the stepwise regression method as the main driving factors to explain the spatial differences in ecological resilience levels.

(1) The regression equation for all $X_1, X_2, \ldots\ldots X_m$ on the dependent variable y was established, and the F-test was conducted for the m independent variables in the equation, taking the minimum value of

$$F_{k1}^{1} = \min\left\{F_1^1, F_2^1, \ldots\ldots, F_m^1\right\} \tag{11}$$

If $F_{k1}^{1} > F_\alpha(1, n-m-1)$, there are no independent variables to eliminate, and at this point the regression equation is optimal; otherwise eliminate; at this point will be recorded; enter step (2).

(2) Establish the regression equation for all $X_1, X_2, \ldots\ldots X_m$ on the dependent variable y, and conduct an F-test on the regression coefficient in the equation, taking the minimum value

$$F_{k2}^{2} = \min\left\{F_1^2, F_2^2, \ldots\ldots, F_{m-1}^2\right\} \tag{12}$$

If $F_{k2}^{2} \leq F_\alpha(1, n-(m-1)-1)$, then no variables need to be eliminated; the equation is optimal at this point, otherwise, it will be eliminated. Let X_{k2} be X_{m-1} and keep iterating until the regression coefficient F value of each variable is greater than the critical value, that is, there is no variable in the equation that can be eliminated until, at this time, the regression equation is the optimal regression equation.

3.3.4. Geographically Weighted Regression Model

The GWR model was constructed with rural ecological resilience as the dependent variable and X1, X4, X5, X7, X9 and X10 as independent variables to explore the main influencing factors. It is assumed that there is a series of explanatory variables with i = 1, 2, . . . , m, j = 1, 2, . . . n observations [x_i] and explanatory variables [y_i]; the geographically weighted regression model is as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{p}(u_i, v_i)x_i + \varepsilon_i(\mathrm{i} = 1,\ 2\ \ldots,\ \mathrm{n}; \mathrm{j} = 1, 2, \ldots, \mathrm{n}) \quad (13)$$

where (u_i, v_i) are the coordinates of the ith sample point in the space, and $\beta k(u_i, v_i)$ is the continuous function $\beta k(u, v)$; the value at point i, and the ε_i is the residual value of the ith sample point.

4. Results

4.1. Rural Ecological Resilience Horizontal Spatial Patterns

In order to express the differences in the ecological resilience levels of different villages, the natural breakpoint method of Arcgis was used to classify the village ecological stress, state, response and comprehensive resilience levels of 217 villages and 3 forest farms in Weiyuan into lower, medium and higher levels according to the criteria in Table 3, and the results were graphically expressed as shown in Figure 3.

Table 3. Grading criteria for the level of ecological resilience of the countryside.

Indices Grading	Pressure Resilience	State Resilience	Response Resilience	Ecological Resilience
Lower level	0.09–0.37	0.13–0.36	0.12–0.35	0.04–0.30
Medium level	0.38–0.66	0.37–0.51	0.36–0.61	0.31–0.49
Higher level	0.67–0.92	0.52–0.78	0.62–0.95	0.50–0.74

4.1.1. Pressure Toughness Spatial Distribution Characteristics

The stress toughness index of rural ecosystems in Weiyuan ranges from 0.09 to 0.92, with the maximum value in Xiaocheng Village and the minimum value in Xinzhai Village, with a mean value of 0.0416. A total of 175 villages has an ecosystem stress toughness at or below the mean value, accounting for 79.54%. From the spatial distribution shown in Figure 3a, the stress resilience in Weiyuan County is characterized by a low overall and high localized stress resilience.

"Stress resilience" refers to the impact effect of rural ecosystems in the face of direct and indirect pressures; the less the disturbance, the greater the ecological stress resilience. The topography of Qingyuan, Shangwan and Huichuan is flat, with sufficient water and arable land resources to support agricultural production and town construction, and the comprehensive carrying capacity of the ecological environment is good, with high levels of stress resilience. Huichuan Forestry, Wuzhu Forestry and the Tianjia River have a large, forested area, and the area flows through the Taohe and Weihe rivers, undertaking ecological regulation and restoration functions, however, riverbank pollution, drought and low rainfall lead to a high level of regional ecological sensitivity and vulnerability to external disturbance. Qinqi, Da'an and Qiuyu are geohazard prone areas, and the system is subject to high external pressures and average levels of pressure resilience.

4.1.2. Spatial Distribution Characteristics of State Toughness

The state toughness of rural ecosystems in Weiyuan ranges from 0.13 to 0.78, with the maximum value in Huichuan Forestry Farm and the minimum value in Laozhuang Village, and the mean value is 0.2899. An amount of 138 villages has state toughness at or below the mean value, accounting for 62.72% of the total. From the spatial distribution shown in

Figure 3b, the overall state toughness of the rural ecosystem in Weiyuan County is high in the south, low in the north, high in the west and low in the east.

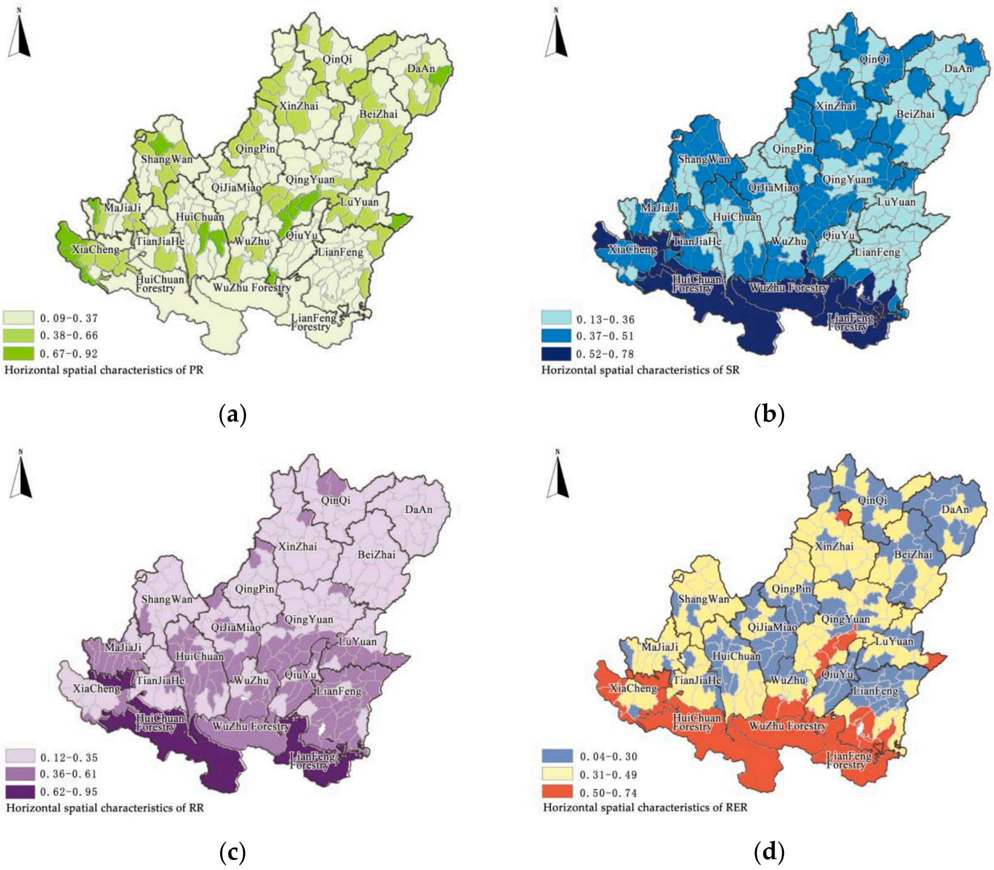

Figure 3. (**a**) Horizontal spatial characteristics of PR; (**b**) Horizontal spatial characteristics of SR; (**c**) Horizontal spatial characteristics of RR; and (**d**) Horizontal spatial characteristics of RER (Note: the Gorge Reservoir, the Disputed Land and the High Shiya Forest Area are not included in the evaluation).

"State resilience" refers to the carrying capacity of rural ecosystems in the process of interaction between system pressure and external response and is in a state of constant change. The accelerated urbanization process has led to an exodus of people from the countryside, the abandonment of arable land in villages in agriculturally disadvantaged areas such as Da'an and Qinqi and the weakening of soil and water conservation capacity, resulting in low levels of ecological resilience due to soil erosion and reduced biodiversity. In contrast, although Xiaocheng, Huichuan Forestry and Wuzhu Forestry are sparsely populated, they have high levels of vegetation cover, complex ecosystem composition and high species richness, and their own resilience is strong, resulting in high levels of ecological state resilience.

4.1.3. Response Toughness Spatial Distribution Characteristics

The response resilience index of rural ecosystems in Weiyuan ranges from 0.12 to 0.95, with the maximum value in Huichuan Forestry Farm and the minimum value in Zhengjiachuan Village, with a mean value of 0.0385. An amount of 200 villages has a response resilience at or below the mean value, accounting for 90.9% of the total. From the spatial distribution shown in Figure 3c, the overall response toughness of the rural ecosystem in Weiyuan County shows a trend of low in the north and high in the south, with high values clustering in Huichuan Forestry and Lianfeng Forestry as a whole, medium values clustering in the southern villages and low values distributed in the northern and central villages in a row.

The "response resilience" refers to the ability of the government, villagers and other rural subjects to implement response measures when rural ecosystems face disturbances, reflecting the positive external effects of the system. The government and external investment bodies can improve the early warning and restoration capacity of rural ecosystems in a timely manner through policy response, resource control, project implementation and other interventions. Huichuan Forestry, Lianfeng Forestry and Majiaji are richly endowed with ecological and tourism resources and have a strong capacity to provide ecological products and regulate the ecological environment, which plays an important role in attracting external investment and is tilted in response measures such as planning guidance and policy control.

4.1.4. Spatial Distribution Characteristics of Ecological Resilience

The results of the village ecological toughness measure in Weiyuan are shown in Figure 3d with colors ranging from red to blue, indicating that the village ecological toughness ranges from low to high. The rural ecological resilience index ranges from 0.04 to 0.74, with the maximum value in Huichuan Forest, the minimum value in Gushu Village and the mean value of 0.0934. An amount of 189 villages has ecological resilience at or below the mean value, accounting for 85.90% of the total.

Huichuan Forestry, Wuzhu Forestry and Lianfeng Forestry are the natural ecological barriers of Weiyuan and are less subject to human interference. The ecosystems are more stable in the process of adaptation and recovery, with overall high values of ecological resilience gathered. Shangwan, Majiaji and Huichuan, with their obvious location advantages and rich agricultural resources, are highly complex areas for production, living and ecological functions in Weiyuan and have a strong integrated level of pressure, state and response resilience, with a medium-value contiguous distribution of ecological resilience levels. The fragile, natural ecological environment of the northern villages has led to high construction costs for the towns, inconvenient transportation, insufficient resource and locational advantages in the development process, poor links with the outside world due to lagging infrastructure constraints and weak government response mechanisms and control measures, resulting in difficult ecological recovery and low levels of ecological resilience.

4.2. Analysis of Rural Ecological Resilience Drivers

4.2.1. Influencing Factors Selection

Multiple linear regression analysis of the 12 indicators in Table 2 was performed using SPSS with variance inflation factor (VIF) mean > 2, indicating that these indicators have multicollinearity. Since X6 did not pass the significance test, it was removed from the independent variables, and stepwise regression analysis was conducted for the other 11 variables, and it was learned that X1, X4, X5, X7, X9 and X10 had a significant influence relationship on rural ecological resilience, so it was clear that these 6 indicators were independent variables for exploring the spatial heterogeneity affecting the distribution of rural ecological resilience (Table 4).

Table 4. Results of stepwise regression analysis.

	Non-Standardized Coefficients		Standardized Coefficients	t	*p*	VIF
	B	Standard Errors	Beta			
X1	1.886	0.242	0.227	7.788	0.000 **	1.26
X4	4.951	1.067	0.144	4.641	0.000 **	1.422
X5	0	0	0.205	5.667	0.000 **	1.937
X7	0.064	0.019	0.121	3.361	0.001 **	1.917
X9	0.036	0.013	0.113	2.763	0.007 **	2.463
X11	17.337	0.665	1.064	26.086	0.000 **	2.462
R2			0.938			
R2Adjusted			0.934			
F			F (6,92) = 231.123, p = 0.000			
D-W			1.952			

** $p < 0.01$.

4.2.2. Spatial Heterogeneity Analysis of Drivers Based on GWR Model

This paper analyzes the spatial autocorrelation of rural ecological resilience in Weiyuan County in 2021, with the help of Arcgis, and the results show that the *p*-value is 0.003, and the global Moran's I value is 0.14. The results show that rural ecological resilience has spatial aggregation characteristics, and the results provide a basis for the validity of the GWR model analysis.

In order to compare the spatial heterogeneity of the impact of the variables on rural ecological resilience, a geographically weighted regression was conducted with rural ecological resilience as the dependent variable and X1, X4, X5, X7, X9 and X10 as independent variables, and the overall result output of the regression including the fit coefficient, residual sum of squares, bandwidth and AIC values of the regression is given in Table 5, which shows that the overall model performs well, and the model structure is feasible [37]. The detailed statistical parameters of the GWR model are given in Table 6, and Figure 4 uses the natural breakpoint method for coefficient classification to explain the spatial heterogeneity in the distribution of influencing factors. The statistical results show that X4 and X5 have significant negative driving effects on rural ecological resilience; X1, X7 and X10 have positive coefficients accounting for more than 60% of the positive driving effects on rural ecological resilience, while X9 has insignificant positive and negative effects.

1. Water network density in the village. Overall, X1 showed a positive driving effect on village ecological resilience, with strong positive correlations in Huichuan and Lianfeng woodlands, whereas negative correlations were evident in Qinqi, Da'an, Qiuyu and Tianjiahe, but the positive coefficients were significantly larger. This indicates that the changes in ecological resilience caused by changes in water network density in Huichuan and Lianfeng forestry sites are of greater magnitude because of the higher ecological resource endowment of the forestry sites, and the small increase in water network density has a greater change in maintaining soil and water and increasing forest cover, which has a greater increase in the level of ecological resilience.
2. The proportion of abandoned land in villages. The results show that X4 has a negative correlation on the ecological resilience of villages, especially for Huichuan Forestry, Tianjiahe, Luyuan and Wuzhu. Arable land abandonment can restore vegetation and positively contribute to the ecological resilience of Wuzhu Forestry and Lianfeng Forestry. However, the low precipitation in Weiyuan and the abandonment of arable land will cause soil hardening, and some villagers will carry out deforestation and clearing, and the rural ecosystem will be continuously destroyed, and the reduction of the ecological resilience level is the main phenomenon.
3. Village population density. Overall, X5 shows a negative driving effect on village ecological resilience, but a weak positive correlation in some villages of Lianfeng and Luyuan. Comparing the absolute values, it was found that the southern villages such as Xia Cheng and Lianfeng Forestry were more strongly perturbed by the change in population density, as human production and living intensified, and the ecological land area decreased, leading to a decrease in ecological resilience. Relative to the central and northern villages with fragile ecological and other backgrounds, which are more dependent on ecological resources, the decline in ecological resilience is greater.
4. The proportion of ecological land. The results demonstrate that X7 has a significant, positive driving effect on rural ecological resilience, showing a strong positive correlation in Xiacheng and Lianfeng, indicating that ecological resources in the region are effectively protected and utilized, which is beneficial to the restoration of the ecosystem and has a high level of rural ecological resilience. The presence of contiguous patches of weakly positively correlated countryside in Xinzhai, Qinqi, Da'an and Beizhai, as well as areas of low ecological resilience in the countryside, with low vegetation cover and severe soil erosion causing ecological land loss year on year, also contribute to the positive correlation.
5. The percentage of permanent basic farmland area. The overall shows that the negative driving effect of X9 on RER impact is more obvious, but comparing the absolute

values reveals that the positive driving effect has a greater impact;therefore, it cannot indicate that the larger the area of permanent basic farmland is, the higher or lower the level of ecological resilience of the village. In Lianfeng and Xinzhai there was a strong positive correlation; the area of permanent basic farmland increased the ecosystem value per unit of arable land area, producing a positive driving effect. In contrast, a contiguous area of negative driving effect appeared in Qinqi, Qijiaomiao, Beizhai and three forest farms, indicating that human activities have intensified the damage to the environment, leading to a lower ecological resilience level.

6. The area share of ecological protection red line in the village. Regarding X10, the positive effect on ecological resilience drive is obvious, and the strict ecological red line protection system reverses the trend of ecological environment deterioration, effectively protects the natural ecosystems such as forests, grasslands, wetlands and water systems in the county, enhances the service function of the ecological space system and improves the ecological resilience level.

Table 5. Results of GWR model fitting for rural ecological resilience.

Indicators	Bandwidth	Residual Squares	AICc	Sigma	R2	R2Adjusted
results	15,644.943	0.812	−1040.435	0.021	0.827	0.798

Table 6. Statistical results of the GWR model coefficient for rural ecological resilience.

Influencing Factors	Min	Upper Quartile	Med	Lower Quartile	Max	Positive Percentage	Negative Percentage
X1	−1.692	−0.518	−0.154	0.282	7.118	0.615	0.385
X4	−1.5067	−0.427	−0.180	0.328	7.578	0.349	0.651
X5	−2.008	−0.507	−0.185	0.364	7.792	0.389	0.611
X7	−4.384	−0.439	−0.195	0.242	5.308	0.741	0.259
X9	−2.449	−0.534	−0.156	0.325	7.400	0.602	0.398
X10	−1.280	−0.579	−0.263	0.286	5.256	0.487	0.513

4.2.3. Dominant Driver Partition

To conduct the study of enhancement strategies for different regional characteristics, the mean values of each driver in sixteen townships and three forest farms were compared (Figure 5), and the dominant drivers of rural ecological resilience were analyzed (Figure 6). Then, according to the influence effect of each driver and the characteristics of each dimension of PSR, the study area was divided into three types in Figure 6: stressor restoration area, state adaptation transformation area and response efficiency optimization area. Among them, X1 and X4 as the dominant factors are classified as the stressor repair zone, X5 and X7 as the state adaptation transition zone and X9 and X11 as the response efficiency optimization zone.

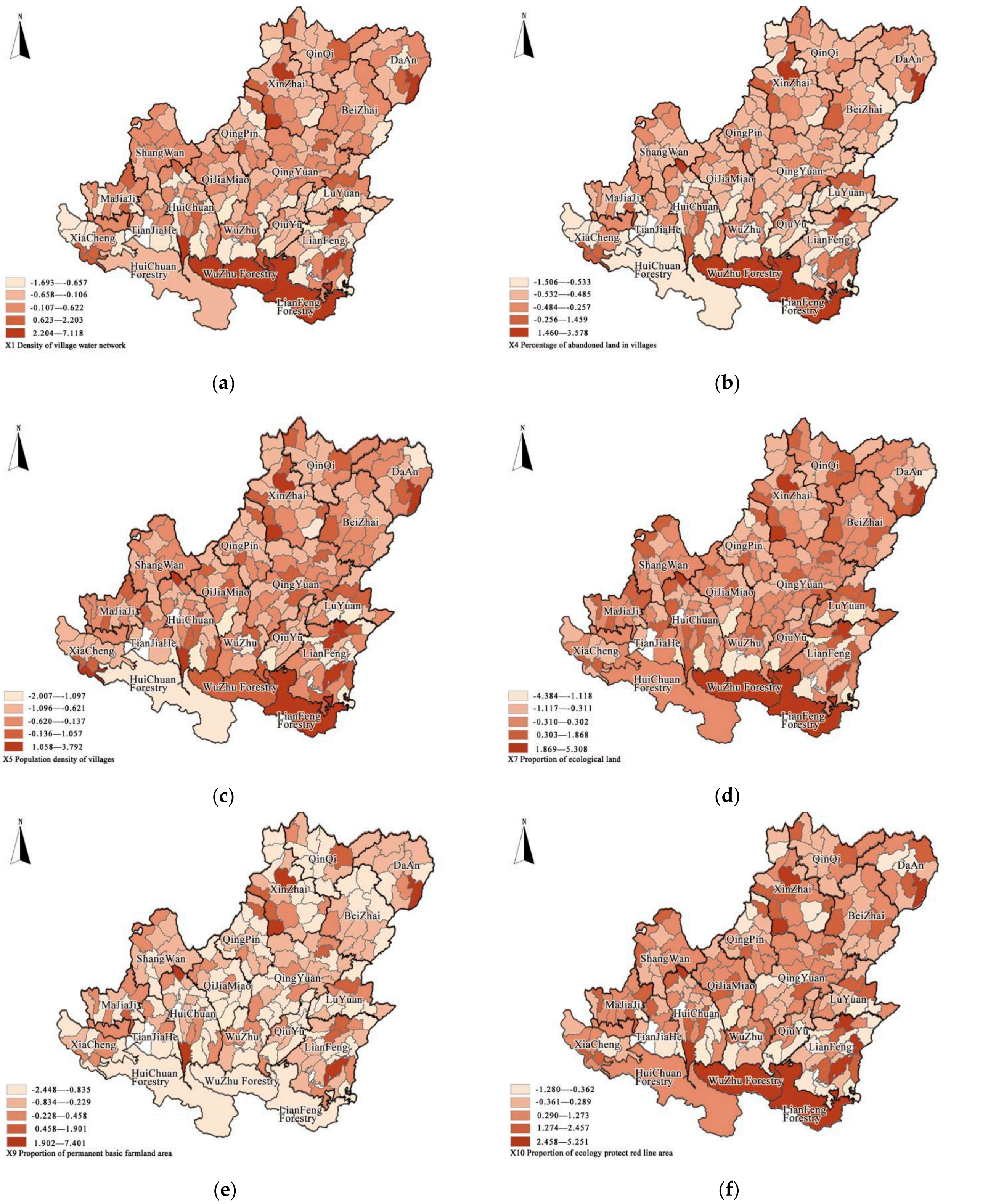

Figure 4. (**a**) X1: Water network density in the village; (**b**) X4: The proportion of abandoned land in villages; (**c**) X5: Village population density; (**d**) X7: The proportion of ecological land; (**e**) X9: The percentage of permanent basic farmland area; and (**f**) X10: The area share of ecological protection red line in the village.

Figure 5. Mean of regression coefficients of drivers for townships.

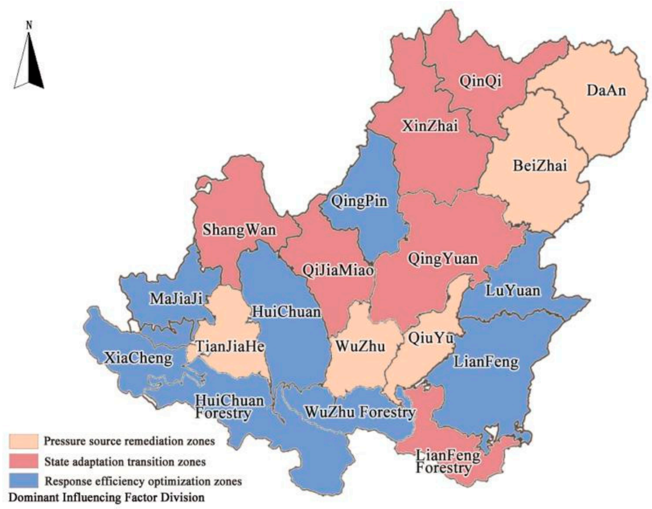

Figure 6. Dominant driver zoning.

5. Discussion

Ecological resilience assessment and zoning play a large role in the conservation and sustainable development of rural areas, from ecosystems to biomes. However, the existing research frameworks and assessment models focus more on the diversity and functional redundancy of different biological communities, with less attention paid to disaster risk response and the time course over which resilience exerts its effects. In Chapter 3, we discuss the spatial distribution of ecological stress resilience, state resilience, response resilience and combined resilience, as well as the identification of dominant drivers. The results of the study found that 79.54% of ecological pressure resilience areas were in the low category; 62.72% of ecological state resilience areas were in the low category, 90.9% of ecological response resilience areas were in the low category and 85.9% of ecological pressure resilience areas were in the low category; thus, Weiyuan presents a poor overall ecological resilience. Our study considers rural ecological resilience as an in-depth analysis of process capabilities. Unlike models based on biological processes that identify critical values [38], the influence of villagers, government and investment institutions on ecological resilience is considered in our indicator system, coinciding with the emphasis on public participation in rural resilience. In the identification of drivers, village population and village abandoned land account for over 60% of the negative impact coefficient on RER, and village water network, ecological land and ecological protection red line account for over 60% of the positive impact coefficient on RER impact, while only accounting for 48.7% of permanent basic agricultural land. The results reaffirm that the designation and management of nature reserves can restore biodiversity and ecosystem function and promote ecological resilience [2], while the ability of water resources to adapt and transform in the face of shocks and stresses can also influence changes in ecological resilience [39].

In previous ecological resilience assessments, the focus has mostly been on a single ecosystem. For example, the attributes of tropical dry forest systems (TDF) are analyzed at the regional landscape and land change levels, and their resilience is mainly assessed in terms of ecological variables such as vegetation structure and biodiversity [40]. An integrated assessment of the ecological resilience of riverine ecosystems uses resilience proxies and ecological thresholds, combining the results of ecological resilience assessments of different biomes with the Resist-Accept-Direct (RAD) framework to predict future ecological trajectories and thus guide ecosystem management [41]. However, rural ecosystems are complex and multifunctional [42]; the assessment and management of rural ecological resilience is necessary to protect complex ecosystem services and functions. However, improving the ecological resilience of villages is a long process, during which the government, capital and grassroots organizations need to work together, injecting management and construction funds into villages according to different regional characteristics and discussing the benefits of a sound management plan for the sustainability of rural ecosystems in the long term.

5.1. Pressure Source Repair Zone Toughness Enhancement Path

The core objective of the ecological resilience concept is to achieve coexistence with uncertain disturbances; therefore, it is necessary to provide early warning and control of "stressors" in rural ecosystems and to make adaptive enhancement in response to different stress triggers. Figure 5 shows that in Wuzhu, Tianjiahe, Qiuyu, Daan and Beizhai, the focus of enhancement is on the protection of village waters and the remediation of abandoned land.

Defensive ecological space management: there is a mismatch between the supply and demand of water resources in Weiyuan County. It is necessary to strengthen the artificial storage of surface water resources in southern villages such as Wuzhu and Tianjiahe, improve engineering facilities, promote water-saving irrigation in northern villages such as Daan and Beizhai and improve the utilization rate of ecological water, which can improve the ecological function of the countryside, lead the damaged ecosystem to gradually recover or make it develop in the direction of a virtuous cycle, lead to the gradual restoration of damaged ecosystems or make them develop in the direction of good circulation, restore the self-regulating ability of ecosystems and reduce the risk of potential natural disasters.

Governance of disturbed production space: first of all, we should strictly implement the policy of arable land protection, carry out comprehensive improvement of abandoned land, improve the arable land balance index, adopt scientific methods to improve the level of facilities supporting arable land resources, increase the effective irrigation area, improve the irrigation index and replanting index of arable land and then improve the production capacity of arable land, fully exploit the potential of intensive use of arable land and realize intensive land use.

Targeted treatment of characteristic areas: Wuzhu, Tianjiahe and Qiuyu are located in the semi-humid soil and rocky mountainous area, and the focus should be on improving the water connotation function of the land through artificial afforestation, differentiated forestry construction and agricultural water conservation projects. While Da'an and Beizhai are located in the Loess Plateau, soil erosion is serious; actively implementing the slope to ladder land comprehensive improvement project can effectively intercept surface runoff and increase soil rainfall infiltration and is an effective means to establish a benign ecological environment and reduce and prevent soil erosion.

5.2. State Adaptation Transition Zone Toughness Enhancement Path

Areas with fragile ecological status often have a limited ability to resist and recover on their own, so it is important to turn "danger" into "opportunity" and promote a robust adaptive transformation of the ecological environment. Figure 5 shows that Qinqi, Xinzhai, Qingyuan, Shangwan, Qijiamiao and Lianfeng Forestry Field have focused on guiding human activities in villages and protecting ecological lands.

Improving the state of environmental overload: Qingyuan, Shangwan and Qijiamiao are densely populated areas, and the increase of rural ecosystem load makes its operation under duress and the ecological environment more fragile. Therefore, it is necessary to give full play to the basic priority role of ecological space resource protection in the spatial planning of land and natural resources protection and utilization of spatial coordination, so as to coordinate land use with ecological environment resilience, improve ecological quality, facilitate the adaptive transformation of the rural ecological overload state and build up strength for the construction of modernization in which people and nature live in harmony.

Adaptive protection of ecological resources: on the one hand, through the construction of green corridors and a green network system in the county, strengthening the connectivity between ecological substrates and patches can effectively toughen ecological substrates, optimize the stability and redundancy of rural ecological space states such as mountains, water, forests, fields, lakes and grasses and make every effort to enhance the service capacity of an ecological space. On the other hand, Lianfeng Forestry, as a concentrated distribution area of natural forests, needs to build a reforestation demonstration base, improve forest coverage and forest resource quality, strictly control the intensity and scale of grassland utilization, restore and improve the ecological functions of forests and grasslands and achieve significant improvements in the quality of the county's ecological environment.

5.3. Response Efficiency Optimization Zone Toughness Enhancement Path

Response efficiency is a reflection of the rural governance capacity of the main body of grassroots organizations, and, usually, areas with outstanding resource advantages and location advantages also have weaker government response mechanisms and control measures, resulting in the ecosystem being disturbed and difficult to recover. Figure 5 shows that Qingping, Luyuan, Lianfeng, Xiacheng, Majiji, Huichuan, Huichuan Forestry and Wuzhu Forestry are focused on the improvement of arable land protection and ecological protection.

Developing a strict protection system: to strictly adhere to the ecological protection red line, the implementation of the strict protection of nature reserves, water systems, wetlands, forests and other important ecological resources, to adhere to the direction of high-standard basic farmland, the establishment of basic farmland protection incentives, to increase the proportion of high-yield and stable production of basic farmland and to increase the basic farmland protection zone arable land finishing efforts. Huichuan Forestry and Wuzhu Forestry should implement the natural forest management and protection system, actively carry out the closure of hills to grazing and forestry, steadily increase the forest area, strengthen the construction of management and protection infrastructure and achieve full coverage of the management and protection area.

Dedicated funds are being invested to increase. Not only should the county ecological early warning and supervision system be built to strengthen the dynamic monitoring of pollution sources, natural disasters and environmental quality but also to provide technical support for ecological and environmental toughness enhancement and management. It should increase investment in land management, vigorously carry out small watershed source management projects and low- and middle-yielding land renovation, implement the integrated management of mountains, water, fields, forests and roads and restore and rebuild degraded land ecosystems.

6. Conclusions

This study aims to establish a PSR-based rural ecological resilience measurement system to assess the resilience and recovery of rural ecosystems throughout their operation and to detect the dominant drivers. From the above study, we conclude that (1) the spatial characteristics of rural ecological resilience are clearly differentiated, and the level of ecological resilience in the southern villages is higher overall; (2) the high proportion of abandoned land and the inadequate protection of ecological land are the main reasons for the low ecological resilience of the northern and central villages; and (3) in the different ecological resilience level zones, it is necessary to discuss the resilience enhancement strategies of the zones in conjunction with the analysis of the dominant drivers and the regional characteristics, so as to promote more target-oriented rural ecological resilience studies and to concretize the evaluation results.

Using villages as the research object, this study combines spatial analysis and factor-differentiated diagnosis on the basis of empirical analysis and appropriate geostatistical mapping and zoning of rural ecological resilience development profiles and constraints in Weiyuan. It has the value of guiding practical applications and helping decision-makers to develop resilience strategies and resilience action plans in a more scientific manner. It also provides reference for local governments to identify restoration and treatment measures and priority areas for funding for different ecological zones. However, due to the lack of data, such as the lack of ecological diversity, landscape index and ecological-related data in the past years, it is not possible to further understand the changing patterns of ecological resilience levels in villages, and its results have certain limitations.

Rural ecosystems are in a constant state of development and evolution. Future rural planning should analyze the driving mechanisms of changes in ecological resilience levels over long time scales, and new adaptations to research methods are being made to keep up with research on rural ecological resilience, so as to formulate dynamic measures to enhance the defense and adaptive capacity of rural ecosystems and promote the construction of a spatially intensive and compact village with excellent ecological environment and a harmonious relationship between people and land to achieve the sustainable development of the rural ecological environment.

Author Contributions: Conceptualization, G.Z. and X.X.; methodology, G.Z.; software, S.Y.; validation, X.X., G.Z. and S.Y.; formal analysis, X.X.; investigation, G.Z.; resources, S.Y.; data curation, G.Z.; writing—original draft preparation, G.Z.; writing—review and editing, X.X.; visualization, G.Z.; supervision, S.Y.; project administration, X.X. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Social Science Foundation of China, grant number 51968037, Gansu Provincial Science and Technology Plan Project, grant number 21CX6ZA072, and Department of Science and Technology of Gansu Province, Basic Research Program-Natural Science Foundation Project, grant number 22JR11RA158.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: These data were collected by the research team and will not be disclosed. If anyone requires data, they can contact the corresponding author.

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

References

1. Holling, C.S. Resilience and Stability of Ecological Systems. *Annu. Rev. Ecol. Syst.* **1973**, *4*, 1–23. [CrossRef]
2. Olds, A.D.; Pitt, K.A.; Maxwell, P.S.; Connolly, R.M. Synergistic effects of reserves and connectivity on ecological resilience. *J. Appl. Ecol.* **2012**, *49*, 1195–1203. [CrossRef]
3. Timpane-Padgham, B.L.; Beechie, T.; Klinger, T. A systematic review of ecological attributes that confer resilience to climate change in environmental restoration. *PLoS ONE* **2017**, *12*, e0173812. [CrossRef] [PubMed]
4. Roberts, C.P.; Twidwell, D.; Angeler, D.G.; Allen, C.R. How do ecological resilience metrics relate to community stability and collapse? *Ecol. Indic.* **2019**, *107*, 105552. [CrossRef]
5. Hering, D.; Carvalho, L.; Argillier, C.; Beklioglu, M.; Borja, A.; Cardoso, A.C.; Duel, H.; Ferreira, T.; Globevnuk, L.; Hanganu, J.; et al. Managing aquatic ecosystems and water resources under multiple stress—An introduction to the MARS project. *Sci. Total Environ.* **2015**, *503*, 10–21. [CrossRef] [PubMed]
6. Holling, C.S.; Gunderson, L.H. *Panarchy: Understanding Transformations in Human and Natural Systems*; Island Press: Washington, DC, USA, 2002.
7. Walker, B.; Holling, C.S.; Carpenter, S.R.; Kinzig, A. Resilience, Adaptability and Transformability in Social-ecological Systems. *Ecol. Soc.* **2004**, *9*, 2. [CrossRef]
8. Biggs, R.; Schlüter, M.; Schoon, M.L. Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems. Cambridge University Press: Cambridge, UK, 2015.
9. González-Quintero, C.; Avila-Foucat, V.S. Operationalization and measurement of social-ecological resilience: A systematic review. *Sustainability* **2019**, *11*, 6073. [CrossRef]
10. Berkes, F. Understanding uncertainty and reducing vulnerability: Lessons from resilience thinking. *Nat. Hazards* **2007**, *41*, 283–295. [CrossRef]
11. Richard, R.R.; Benjamin, L.R. The vulnerability and resilience of a city's water footprint: The case of Flagstaff, Arizona, USA. *Water Resour. Res.* **2016**, *52*, 2698–2714.
12. Fikret, B.; Cristiana, S.S. Building Resilience in Lagoon Social-Ecological Systems: A Local-Level Perspective. *Ecosystems* **2005**, *8*, 967–974.
13. Nash, K.L.; Allen, C.R.; Angeler, D.G.; Barichievy, C.; Eason, T.; Garmestani, A.S.; Graham, N.A.; Granholm, D.; Knutson, M.; Nelson, R.J.; et al. Discontinuities, cross-scale patterns, and the organization of ecosystems. *Ecology* **2014**, *95*, 654–667. [CrossRef] [PubMed]
14. Bouska, K.L. Discontinuities and functional resilience of large river fish assemblages. *EcoSphere* **2018**, *9*, e02351. [CrossRef]
15. Gunderson, L.; Kinzig, A.; Quinlan, A. Resilience Alliance: Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners. Version 2.0. 2010. Available online: https://www.semanticscholar.org/paper/Assessing-Resilience-in-Social-Ecological-Systems-%3A-Gunderson-Kinzig/2aa9d57839231015bbcffff27a213a292120ef6b (accessed on 12 February 2023).
16. Zhou, X. A review of methods for measuring social-ecological system resilience. *J. Ecol.* **2017**, *37*, 4278–4288.
17. Rasch, S.; Heckelei, T.; Storm, H.; Oomen, R.; Naumann, C. Multi-scale resilience of communal rangeland system in South Africa. *Ecol. Econ.* **2017**, *131*, 129–138. [CrossRef]
18. Lin, B.B.; Petersen, B. Resilience, regime shifts, and guided transition under climate change: Examining the practical difficulties of managing continually changing systems. *Ecol. Soc.* **2013**, *18*, 28. [CrossRef]
19. Dakos, V.; Bascompte, J. Critical slowing down as early warning for the onset of collapse in mutualistic communities. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 17546–17551. [CrossRef]
20. Fang, C.; Yang, J.; Fang, J.; Huang, X.; Zhou, Y. Optimization Transmission Theory and Technical Pathways that Describe Multiscale Urban Agglomeration Spaces. *Chin. Geogr. Sci.* **2018**, *28*, 543–554. [CrossRef]
21. Mark, S. Resilience: A Conceptual Lens for Rural Studies? *Geogr. Compass* **2013**, *7*, 597–610.
22. Heath, L.C.; Tiwari, P.; Sadhukhan, B.; Tiwari, S.; Chapagain, P.; Xu, T.; Li, G.; Ailikun; Joshi, B.; Yan, J. Building climate change resilience by using a versatile toolkit for local governments and communities in rural Himalaya. *Environ. Res.* **2020**, *188*, 109636. [CrossRef]
23. Anthopoulou, T.; Kaberis, N.; Petrou, M. aspects and experiences of crisis in rural Greece. narratives of rural resilience. *J. Rural. Stud.* **2017**, *52*, 1–11. [CrossRef]

24. Arouri, M.; Nguyen, C.; Ben Youssef, A. Natural Disasters, Household Welfare, and Resilience: Evidence from Rural Vietnam. *World Dev.* **2015**, *70*, 59–77. [CrossRef]
25. Zhou, L.; Kori, D.S.; Sibanda, M.; Nhundu, K. An Analysis of the Differences in Vulnerability to Climate Change: A Review of Rural and Urban Areas in South Africa. *Climate* **2022**, *10*, 118. [CrossRef]
26. Wang, P.; Luo, F.; Fang, Y. Research on resilience governance models of rural biomass energy eco-industrial chain. *Energy Rep.* **2022**, *8*, 1508–1517. [CrossRef]
27. Zuidema, P.A.; Baker, P.; Groenendijk, P.; Schippers, P.; van der Sleen, P.; Vlam, M.; Sterck, F. Tropical forests and global change: Filling knowledge gaps. *Trends Plant Sci.* **2013**, *18*, 413–419. [CrossRef] [PubMed]
28. Yan, W.; Lu, J. Two models of rural community revitalization:Insights and reflections from the perspective of resilience. *Int. Urban Plan.* **2017**, *32*, 22–28. [CrossRef]
29. Wang, Q.; Ding, J. Resilience planning of water network villages based on landscape ecological risk evaluation–a case study of Changbaidang area. *South. Archit.* **2022**, *5*, 10–17.
30. Lai, S.; Sha, J.; Eladawy, A.; Li, X.; Wang, J.; Kurbanov, E.; Lina, Z.; Wu, L.; Han, R.; Su, Y.-C. Evaluation of ecological security and ecological maintenance based on pressure-state-response (PSR) model, case study: Fuzhou Human and Ecological Risk Assessment: An Analysis of the Impacts of the Human and Ecological Risk Assessment on the Environment. *Hum. Ecol. Risk Assess. Int. J.* **2022**, *28*, 734–761. [CrossRef]
31. Das, S.; Pradhan, B.; Shit, P.; Alamri, A. Assessment of Wetland Ecosystem Health Using the Pressure- State-Response (PSR) Model: A Case Study of Mursidabad District of West Bengal (India). *Sustainability* **2020**, *12*, 5932. [CrossRef]
32. Ruan, J.; Chen, Y.; Yang, Z. Assessment of temporal and spatial progress of urban resilience in Guangzhou under rainstorm scenarios. *Int. J. Disaster Risk Reduct.* **2021**, *66*, 102578. [CrossRef]
33. Zheng, H.; Wang, Y.; Ma, W. Evaluation of ecological vulnerability of the Pearl River Delta based on PSR model. *Soil Water Conserv. Bull.* **2022**, *42*, 210–217+381.
34. Raj, A.; Sharma, L.K. Spatial E-PSR modelling for ecological sensitivity assessment for arid rangeland resilience and management. *Ecol. Model.* **2023**, *478*, 110283. [CrossRef]
35. Chen, M.; Jiang, Y.; Wang, E.; Wang, Y.; Zhang, J. Measuring Urban Infrastructure Resilience via Pressure- State-Response Framework in Four Chinese Municipalities. *Appl. Sci.* **2022**, *12*, 2819. [CrossRef]
36. Su, S.; Xiao, R.; Zhang, Y. Multi-scale analysis of spatially varying relationships between agricultural landscape patterns and urbanization using geographically weighted regression. *Appl. Geogr.* **2011**, *32*, 360–375. [CrossRef]
37. Huang, X.; Huang, X.; Liu, M.; Wang, B.; Zhao, Y. Spatial-temporal Dynamics and Driving orces of Land Development Intensity in the Western China from 2000 to 2015. *Chin. Geogr. Sci.* **2020**, *30*, 16–29. [CrossRef]
38. Tonkin, J.D.; Poff, N.L.; Bond, N.R.; Horne, A.; Merritt, D.M.; Reynolds, L.V.; Olden, J.; Ruhi, A.; Lytle, D.A. Prepare river ecosystems for an uncertain future. *Nature* **2019**, *570*, 301–303. [CrossRef]
39. Saikia, P.; Beane, G.; Garriga, R.G.; Avello, P.; Ellis, L.; Fisher, S.; Leten, J.; Ruiz-Apilánez, I.; Shouler, M.; Ward, R.; et al. City Water Resilience Framework: A governance based planning tool to enhance urban water resilience. *Sustain. Cities Soc.* **2022**, *77*, 103497. [CrossRef]
40. Guerra-Martinez, F.; García-Romero, A.; Martínez-Morales, M.A. Assessment of the ecological resilience of tropical dry forests: A multi-scalar approach. *Madera Bosques* **2020**, *26*, e2631983.
41. Bouska, K.L.; De Jager, N.R.; Houser, J.N. Resisting-Accepting-Directing: Ecosystem Management Guided by an Ecological Resilience Assessment. *Environ. Manag.* **2022**, *70*, 381–400. [CrossRef]
42. Fernández Martínez, P.; de Castro-Pardo, M.; Barroso, V.M.; Azevedo, J.C. Assessing sustainable rural development based on ecosystem services vulnerability. *Land* **2020**, *9*, 222. [CrossRef]