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The Synergistic Effect of Urban and Rural Ecological Resilience: Dynamic Trends and Drivers in Yunnan

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Abstract: With the rapid development of the world economy, pollution of urban and rural ecological environments and the decline in anti-risk capabilities are becoming more serious. In order to promote sustainable improvement of urban and rural ecological resilience, based on previous independent research on urban and rural resilience, this paper combines the two to carry out collaborative development research. The dynamic evolution and driving force heterogeneity in the coordinated development level of urban and rural ecological resilience in Yunnan Province in China from 2013 to 2022 were studied using the coordination degree model of composite system and geographical detector. The results show the following: (1) The urban and rural ecological resilience levels in Yunnan Province increased annually, but urban ecological resilience (0.178) lagged behind that of rural areas (0.376). Compared to rural areas, the overall spatial difference in urban ecological resilience level is significant. (2) The overall level of urban–rural ecological resilience synergy in Yunnan Province has been increasing annually, from "no synergy" to "primary synergy". However, there are great differences between prefectures and cities. (3) The combination of urban and rural driving factors is more conducive to improving urban–rural ecological resilience. The interaction between the per capita water supply and fertilizer consumption is the primary and critical driving factor. In the future, we will continue to take the coordinated development of urban and rural ecological resilience as the theme, further expand the research field, and carry out future development trend prediction research. This study provides new ideas for the construction of ecological resilience in similar countries and regions worldwide.

Keywords: urban–rural integration development; urban–rural ecological resilience; dynamic evolution; heterogeneity of driving forces

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1. Introduction

Global urbanization is undergoing a period of rapid acceleration in the context of the accelerated pace of global economic development. The United Nations projects that the global urbanization rate will reach 68% by 2050 [1]. Due to the complex and diversified links between cities, the rapid expansion of cities will lead to a continuous increase in internal and external risks. Among these risks, the problems of environmental pollution and resource abuse caused by rapid urban expansion have become significant challenges for the sustainable development of human societies [2]. In the face of this environmental crisis, systematically promoting the construction of resilient cities and enhancing their ability to resist risks have become urgent tasks for the present and future. China's urbanization is of great significance both domestically and globally as the country is experiencing the largest and most rapid urbanization process [3]. China's social and economic development has entered a new period. However, the problem of regional coordinated development remains significant. This includes ecological environment deterioration, negative impacts of human activities on land, low levels of agricultural modernization, backward industrialization, and inadequate urban resilience [4]. These problems pose challenges to regional development, notably in Yunnan Province, China. Yunnan Province serves as an important economic gateway to south and southeast Asia and acts as a crucial ecological barrier in southwest China. It is the source of numerous international and domestic rivers and is therefore crucial to the ecological security of the region, the country, and the world, especially in South Asia and Southeast Asia. Compared with other regions of China, Yunnan's per capita GDP value ranked 23 among China's 31 provinces in 2018–2022, and its economy is relatively backward [5]. However, in existing research, more authors have taken the economically developed areas as examples and analyzed their urban resilience and rural resilience separately. Few authors have taken economically underdeveloped areas as an example to study the coordinated development of urban and rural ecological resilience. Therefore, it is of great significance to study the dynamic evolution and mechanism driving the coordinated development of urban and rural ecological resilience in Yunnan Province, for the coordinated development of ecology and improvement of urban and rural resilience in Yunnan, China, and even South Asia and Southeast Asia. This will aid policy formulation in relevant departments and help balance economic development with ecological environment protection. Related research can provide suggestions for relevant departments in Yunnan Province in China to formulate policies. It can also provide new ideas for the construction of ecological resilience in similar countries and areas of economic development worldwide.

Urban–rural integration is an essential worldwide development trend [6]. The concept of "urban–rural integration" originated in Thomas More's book "Utopia". In 1847, Engels proposed the concept of "urban–rural integration" and expounded the theory. Since then, related concepts and basic theories of urban–rural relations have been put forward and developed. Research on the relationship between urban and rural areas started relatively early in foreign countries. Most foreign studies emphasize the combination of urban and rural governance and the interconnectivity between urban and rural areas [7]. In the context of new urbanization strategies and rural revitalization, Chen et al. [8] have proposed, from different perspectives, that urban and rural areas should move towards "bilateral interaction" and "urban–rural integration". Influenced by the socio-economic background and related policy orientation, the objective of China to establish a novel urban–rural relationship has transformed "urban and rural coordination" into "urban–rural integration" [9], and its related theory is still expanding [10,11]. From the complex adaptive systems theory perspective, urban–rural integration refers to the coordinated development of social, economic, ecological, and other multi-dimensional systems. Its ultimate goal is to achieve economic coordination, social harmony, cultural sharing, and ecological excellence between urban and rural areas. The two areas complement each other and comprise a community of life [12]. In the face of the challenge of sustainable urban–rural linkages, some studies suggest maximizing synergies to reduce the trade-offs between identified potential solutions and the SDGs [13,14]. By studying the coupling and coordination relationship between urban resilience and new urbanization, Liu et al. [15] found that both concepts promote each other, and their coordinated development is paramount for the realization of sustainable urban development.

The multi-dimensional promotion of resilience construction is a significant strategic measure for sustainable urban development [16]. "Resilience" originated from the Latin "Resilio", which means "returning to the original state" [17]. In 1973, Canadian biologist Holling [18] provided a comprehensive summary of the resilience of ecosystems. This was the inaugural application of the resilience concept to the ecological field, describing the capacity of ecosystems to maintain or restore their original functions after disturbance. Since the origination of the concept of resilience, it has undergone two decisive cognitive shifts from engineering resilience to ecological resilience and then to evolutionary resilience; that is, from a single balance to multiple balances and then to complex adaptive systems [19]. The concept of resilience has received increasing attention in urban planning [20,21]. Influential studies of international cities have defined resilient cities as urban systems capable of maintaining their integrity or rapidly returning to their desired state in the face of shocks or pressures, adapting to changes, and changing functions that constrain current or future adaptive capacities [22,23]. The concept of resilient cities has been widely used in urban emergency management fields such as climate change adaptation, disaster risk reduction, safety, and sustainable development [24,25]. The construction of resilient cities generally includes ensuring economic, social, infrastructure, and ecological resilience [26]. The construction of ecologically resilient cities focuses on improving the diversity, stability, and sustainability of cities and giving full play to the ecosystem functions of natural systems in a natural ecological environment, environmental resource protection, and ecological environment governance. Research related to the resilience of rural areas focuses on factors closely related to developing rural industries, such as agriculture and ecology [27,28]. Resilience construction has a certain commonality between urban and rural areas because of spillover and diffusion effects. Chen [29] stated that there is a conceptual fit and realistic directivity between the perspective of resilience theory and the development of urban and rural construction, which can be regarded as a theoretical carrier and action guide for the smooth flow of urban and rural elements. Therefore, the construction of resilient cities can not only directly benefit the resilience of the surrounding rural areas but also drive the development of rural resilience.

Urban–rural resilience specifically refers to the ability of urban and rural areas to cope with a series of uncertain events, such as natural disasters, extreme weather, and public emergencies. Resilient areas can resist such events and return to their original features and functions. Based on the perspective of urban–rural resilience, Shi et al. [30] discussed and evaluated the impact of land urbanization on regional development in the Beijing–Tianjin–Hebei urban agglomeration and developed a targeted resilience strategy for it. This promotes sustainable development between urban and rural systems. Bo et al. [31] have reviewed the latest research progress in resilient cities and proposed new suggestions for resilient urban–rural construction in China. Building a scientific and reasonable urban–rural resilience evaluation system is paramount. In terms of the urban–rural resilience evaluation system, based on the framework of urban and rural resilience integration, Wu and Wu [32] have created a more universal and operational urban–rural resilience evaluation system with both urban and rural similarities and differences for the Yangtze River Delta region. This system can promote the integration of urban and rural resilience. Many scholars have carried out dynamic evolution analysis of resilient cities [33] or urban–rural integration development [34]. Evolution is an accumulated and transferable change. In collaborative development, co-evolution refers to a dynamic process in which all elements in the system are in a harmonious and benign development environment, from simple to complex and from messy to orderly evolution [35]. Urban evolution is a complex and multi-dimensional process involving changes in population, economy, social structure, ecological environment, and other aspects. The study of urban evolution [36,37] can help reveal the nature of urban evolution, determine the specific driving factors, and improve the influence of these factors and their interactions. Tang et al. [38] studied the spatial and temporal evolution and driving mechanism of the ecological environment related to the ecological security barrier in the national border area. Their work provides a scientific basis and theoretical support for the specific application of the national ecological security barrier and the study of regional ecological environment evolution.

Despite the extensive research conducted by scholars on urban ecological resilience and rural ecological resilience from different perspectives, there are still some shortcomings in the coordinated development of urban and rural ecological resilience. Research conducted by scholars in the past has mainly focused on relatively developed areas, and there are relatively few studies on economically underdeveloped areas; therefore, Yunnan Province in China, which is economically underdeveloped but geographically important, was selected as the research area in this study. As far as the research object is concerned, most studies have analyzed urban and rural resilience separately, and there are few studies on the level of synergy after the integration of resilient cities and resilient villages. Based on the resilience theory and complex adaptive systems, a comprehensive measurement system for the coordinated development level of urban and rural ecological resilience was constructed in this study. Taking 16 prefectures and cities in Yunnan Province as an example, urban ecological resilience and rural ecological resilience from 2013 to 2022 were measured and analyzed. The coordinated development level of urban and rural ecological resilience in the region in the past ten years was measured and analyzed with the help of the composite system synergy model. The geographic detector was used to analyze driving force heterogeneity characteristics of the coordinated development of urban and rural ecological resilience. Finally, considering the actual situation, the coordinated governance strategy of urban and rural ecological resilience is proposed. The purpose of this paper is to provide suggestions for relevant departments in Yunnan Province, China, to formulate policies. It can also provide new ideas for the construction of ecological resilience in similar countries and economic development areas worldwide. The specific research ideas are shown in Figure 1.

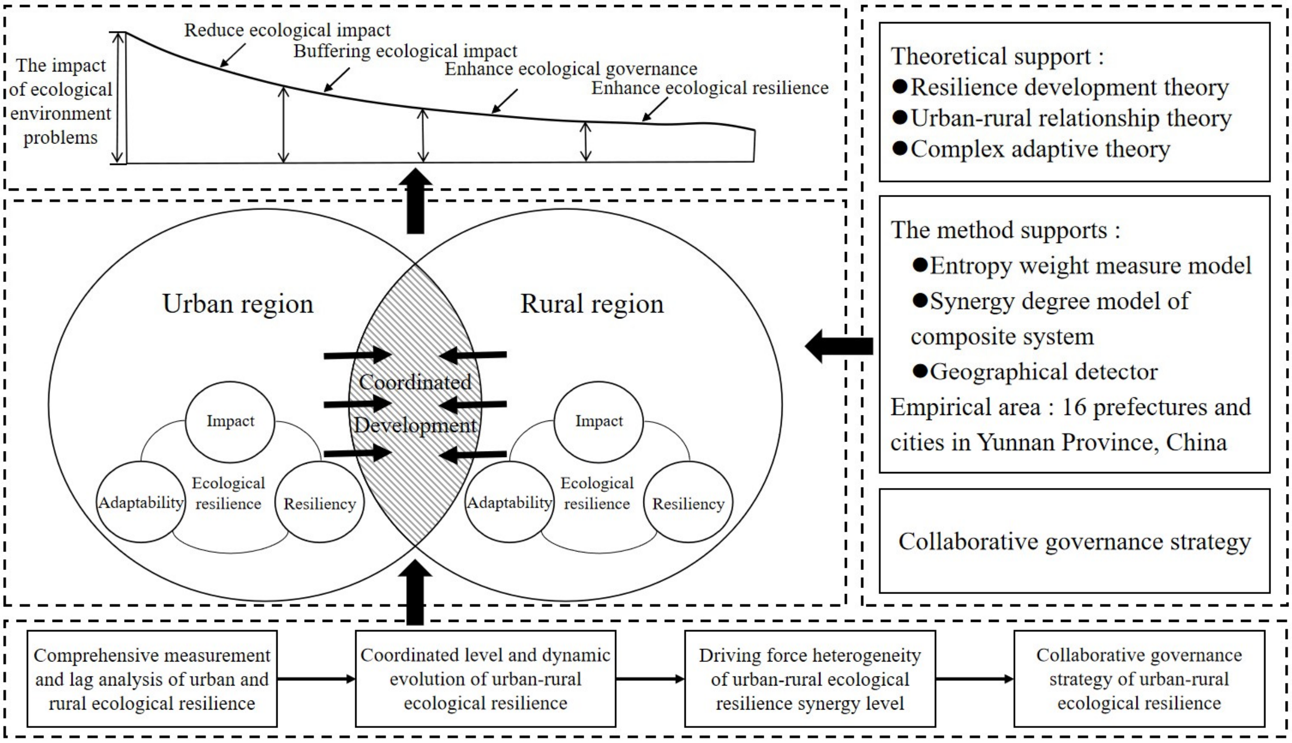

Figure 1. Diagram of research ideas.

2. Methods

This research mainly adopts the research methods of entropy weight-toughness measure model, composite system synergy model, and geographic detector. The entropy weight method is an objective weighting method that is not affected by subjective factors. In order to obtain more accurate measurement results of urban and rural ecological resilience, combined with the resilience measurement model, the urban and rural ecological resilience is measured and analyzed. Compared with other coordination models, the coordination degree model of composite systems can evaluate the coordinated development level between multiple systems more comprehensively, which is suitable for the study of the interaction between multiple subsystems of urban and rural ecological resilience. At the same time, the composite system synergy model can also be used to analyze the lag in the coordinated development of urban and rural ecological resilience. The geographical detector has a module of factor interaction detection, which can effectively study the driving factors affecting the synergistic effect of urban and rural ecological resilience. At the same time, it can also better explain the driving force of multi-factor interaction on the coordinated development of urban and rural ecological resilience.

2.1. Study Area and Data Sources

2.1.1. Study Area

China is a substantial contributor to global ecological protection. It is significant to study the coordinated development of urban and rural ecological resilience in China for global ecological resilience construction and ecological environment protection. On the one hand, Yunnan Province has one of the longest borders of all provinces in China. It borders Myanmar in the west and Laos and Vietnam in the south. The southwest ecological security barrier, with Yunnan Province as the core area, is located upstream or at the source of many international and domestic rivers. Due to its special geographical location and function, the region is rich in biodiversity and is key to maintaining ecological security. On the other hand, Yunnan Province is China's economic radiation center for South Asia and Southeast Asia, and it is also an important part of China's Yangtze River Economic Belt development strategy. Yunnan Province is an economically underdeveloped area in China. The utilization of rich natural resources and the development of tourism are used to enhance the level of economic development. Therefore, there is a problem of excessive consumption of the ecological environment. China has repeatedly stressed the need to promote the high-quality development of the Yangtze River Economic Belt, comprehensively promote socio-economic development and ecological environment protection, and build a strong ecological security barrier in the country's southwest. Yunnan Province has a unique economic geographical location and ecological diversity. Selecting 16 prefectures and cities in Yunnan Province as a complete research area is of great significance for studying the urban and rural ecological resilience construction of underdeveloped areas in China and South and Southeast Asian countries bordering Yunnan Province. Urban and rural ecological data for Yunnan Province in the past 10 years have more reference value for present and future development. However, the government's authoritative data for 2023 have not been released, thus the dynamic evolution laws and driving force heterogeneity characteristics of the coordinated development level of urban and rural ecological resilience in Yunnan Province from 2013 to 2022 were selected. They can promote the coordinated development of urban and rural ecological resilience in the region and enhance the urban and rural ecological anti-risk ability. At the same time, the method of studying the coordinated development of urban and rural ecological resilience by using the composite system synergy model and geographic detector reasonably adopted in this paper can provide new ideas for other people to study the ecological resilience construction of similar countries and economic development areas worldwide.

As of 2022, Yunnan Province has eight prefecture-level cities and eight autonomous prefectures. The eight prefecture-level cities are Kunming City, Qujing City, Yuxi City, Zhaotong City, Baoshan City, Lijiang City, Pu'er City, and Lincang City, and the eight autonomous prefectures are Dehong Dai Jingpo Autonomous Prefecture (hereinafter referred to as Dehong), Nujiang Lisu Autonomous Prefecture (hereinafter referred to as Nujiang), Diqing Tibetan Autonomous Prefecture (hereinafter referred to as Diqing), Dali Bai Autonomous Prefecture (hereinafter referred to as Dali), Chuxiong Yi Autonomous Prefecture (hereinafter referred to as Chuxiong), Honghe Hani Yi Autonomous Prefecture (hereinafter referred to as Honghe), Wenshan Zhuang and Miao Autonomous Prefecture (hereinafter referred to as Wenshan), and Xishuangbanna Dai Autonomous Prefecture (hereinafter referred to as Sipsongpanna). In order to reflect the ecological diversity and geographical location of 16 prefectures and cities in Yunnan Province, this paper adopts the Köppen-Geiger Climate Classification method to draw the study area [39], as shown in Figure 2.

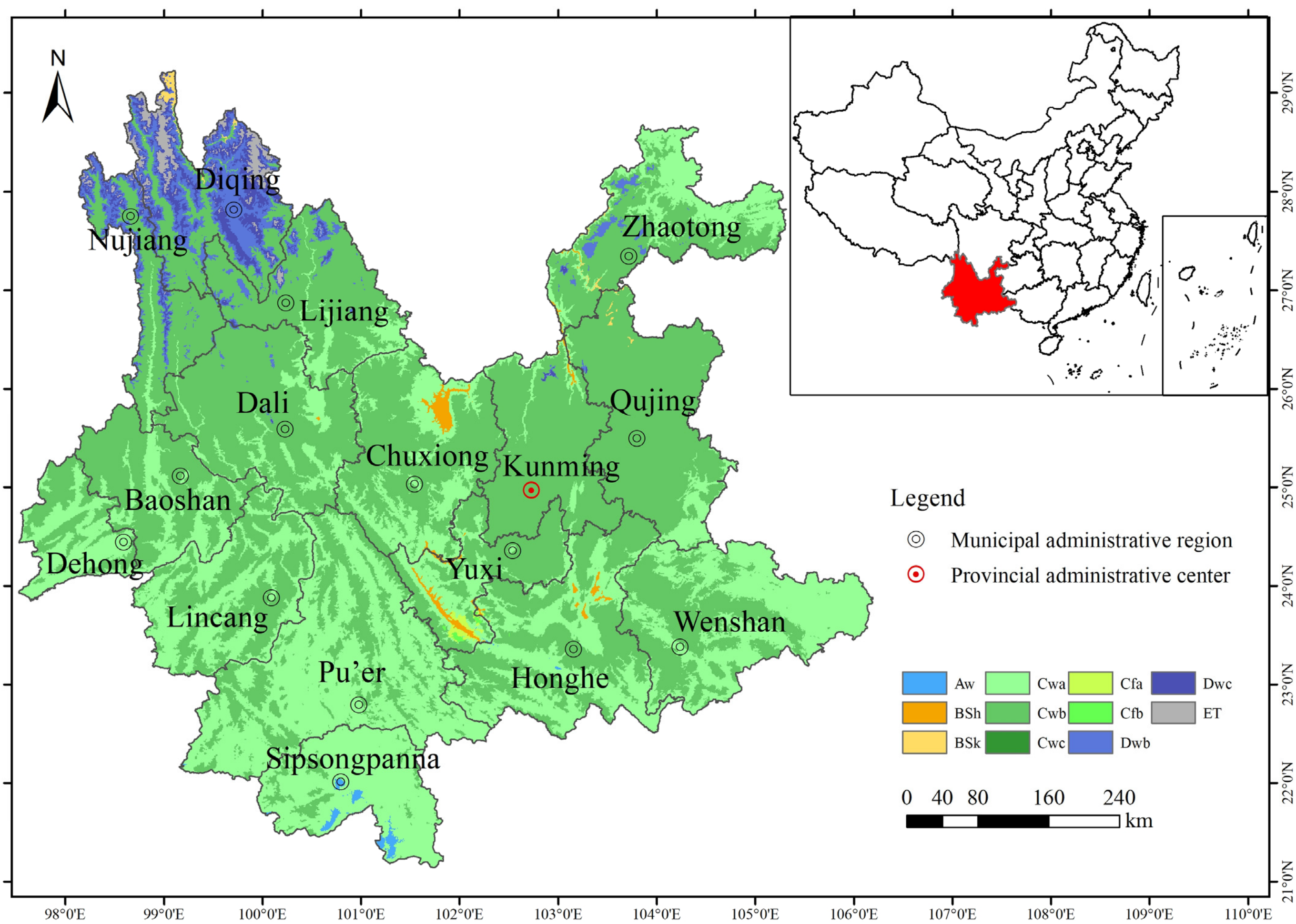

Figure 2. Spatial range and climate classification of Yunnan Province.

2.1.2. Data Sources

The data for this study were mainly derived from the "Yunnan Statistical Yearbook" from 2013 to 2022, the statistical yearbooks of various prefectures and cities, and the websites of the governments of various prefectures and cities. Other small amounts of data were derived from the statistical bulletin of the national economic and social development of Yunnan Province. In addition to the index data directly provided by the yearbook, some missing data were filled in using the interpolation and mean substitution methods, and the data results were all calculated.

2.2. Index System Construction

The principles of scientificity, comprehensiveness, systematization, and data availability of indicators were adhered to in this study based on the existing research foundations [32,40,41] of urban resilience and rural resilience at home and abroad. The actual situation in Yunnan Province was also considered. A comprehensive measurement system for the coordinated development level of urban and rural ecological resilience was constructed. The system evaluates the ecological resilience of urban and rural regions from the perspective of three dimensions: natural ecological environment, environmental resource protection, and ecological environment governance capacity. In terms of the natural ecological environment, C1–C6 and V1–V6 indicators were selected to reflect the ecological impact. In terms of environmental resource protection, C7–C10 and V7–V10 indicators were selected to reflect ecological adaptability. In terms of ecological environment governance capacity, C11–C15 and V11–V15 indicators were selected to reflect ecological resilience, as shown in Table 1.

Table 1. Comprehensive measurement system for urban–rural ecological resilience development levels.

Composite Layer	System Layer	Subsystem Layer	Index Layer		Meaning of Indicators	Direction
Comprehensive measurement system for coordinated development level of urban–rural ecological resilience	Urban ecological resilience system	Natural ecological environment	C1	Population density	Ecological impact level	(−)
			C2	Urban sewage discharge		(−)
			C3	Industrial wastewater emissions		(−)
			C4	General industrial solid waste production		(−)
			C5	Industrial sulfur dioxide emissions		(−)
			C6	Proportion of built-up land area		(−)
		Protection of environmental resources	C7	Per capita public green space area	Ecological adaptability level	(+)
			C8	Green coverage rate of built-up area		(+)
			C9	Green coverage area of built-up area		(+)
			C10	Total water resources per capita		(+)
		Ecological environment governance capacity	C11	Per capita water supply	Ecological resilience level	(+)
			C12	Urban sewage treatment rate		(+)
			C13	General industrial solid waste comprehensive utilization rate		(+)
			C14	Industrial waste gas treatment facilities' processing capacity		(+)
			C15	Per capita GDP		(+)
	Rural ecological resilience system	Natural ecological environment	V1	Fertilizer consumption	Ecological impact level	(−)
			V2	Pesticide usage		(−)
			V3	Agricultural plastic film usage		(−)
			V4	Total agricultural water consumption		(−)
			V5	Total domestic water consumption		(−)
			V6	The proportion of agricultural intermediate consumption in total output value		(−)
		Protection of environmental resources	V7	Per capita cultivated land area	Ecological adaptability level	(+)
			V8	Garden area		(+)
			V9	Reservoir capacity		(+)
			V10	Waters and water conservancy facilities land area		(+)
		Ecological environment governance capacity	V11	Per capita afforestation area	Ecological resilience level	(+)
			V12	Effective irrigation area		(+)
			V13	Per capita net income of farmers		(+)
			V14	Total agricultural output value		(+)
			V15	The proportion of primary industry in GDP		(+)

Note: "+" represents a positive indicator. The larger the value, the better; "−" represents a negative indicator. The smaller the value, the better.

2.3. *Research Methods*

2.3.1. Entropy Weight Resilience Measurement Model

The entropy weight method objectively weights the index by calculating its information entropy. At present, it is widely used in various evaluation systems and decision analysis [42,43]. Entropy is a measure of the degree of information confusion. Among all the indexes, the smaller the entropy value of the information, the greater the dispersion of the attribute value of the index, the greater the influence of the index on the comprehensive evaluation, and the greater the weight coefficient. According to this principle, the larger the value, the better the positive index, and the smaller the value, the better the negative index. The specific steps are as follows:

① The extreme value method is used to non-dimensionalize the original data of each urban–rural ecological resilience system index.

$$\text{Positive indicators}: \ Zij = \frac{xij - \min xij}{\max xij - \min xij} \tag{1}$$

$$\text{Negative indicators}: \ Zij = \frac{\max xij - xij}{\max xij - \min xij} \tag{2}$$

where Z_{ij} represents the standard value after the data are non-dimensionalized, x_{ij} represents the original data value of the i index in the j year, max x_{ij} represents the maximum value of the index data, and min x_{ij} represents the minimum value of the index data.

② The entropy weight method is used to calculate the weight of each index of urban–rural ecological resilience. The calculation steps are as follows:

To avoid the case of small or negative values, the non-dimensionalized data are positively translated. H is the translation amplitude (H = 0.0001) and Y_{ij} is the non-dimensionalized data after translation.

$$Yij = Zij + H \tag{3}$$

The proportion G_{ij} of the i index in the j year is calculated as follows:

$$Gij = \frac{Yij}{\sum_{j=1}^{n} Yij} \tag{4}$$

The entropy value e_i of the i index is calculated as follows:

$$ei = -k * \sum_{j=1}^{n} Gij \ln(Gij), k > 0, k = \frac{1}{\ln n}, 0 \le ei \le 1 \tag{5}$$

where for the i index, the greater the difference in the observed value Y_{ij}, the smaller the entropy value, and n is the number of indicators.

The difference coefficient d_i of the i index is calculated as follows:

$$di = 1 - ei \tag{6}$$

The weight value of each index W_i is calculated as shown below. m is the number of years.

$$Wi = \frac{di}{\sum_{i=1}^{m} di} \tag{7}$$

The evaluation value of the ecological impact, ecological adaptation, and ecological restoration of the urban (rural) subsystem layer S_t is calculated as follows:

$$St = \sum_{i=1}^{n} Wi * Zij(t = 1, 2, 3) \tag{8}$$

The comprehensive measurement level of urban (rural) ecological resilience S is calculated as follows:

$$S = S1 + S2 + S3 \tag{9}$$

where S_1 is the evaluation value of ecological impact, S_2 is the evaluation value of ecological adaptability, and S_3 is the evaluation value of ecological resilience.

2.3.2. Collaborative Degree Model of the Composite System

A composite system is an open, complex, and dynamic system with a unified structure and function that is composed of subsystems with interrelated attributes that interact with each other [44]. The composite system synergy model is a method model that can measure the level of coordinated development of urban and rural ecological resilience. Urban–rural ecological resilience can be improved by constantly coordinating the interaction between urban and rural resilience systems. According to previous studies [45,46], the level of coordinated development of urban and rural ecological resilience is divided into sequence levels, as shown in Table 2.

Table 2. Classification of coordinated development level sequences of an urban and rural composite resilience system.

Level of Synergy	No Collaboration	Reluctant Collaboration	Primary Collaboration	Intermediate Collaboration	Good Collaboration	High-Quality Collaboration
Degree of synergy	[−1, 0)	[0, 0.2)	[0.2, 0.4)	[0.4, 0.6)	[0.6, 0.8)	[0.8, 1]

The specific steps are as follows:

① The Z-score method is used to standardize the original data:

$$X'_{ij} = \frac{Xij - \overline{Xj}}{Sj}(i = 1, 2, \ldots, p) \quad (10)$$

where X'_{ij} is the standardized data, X_{ij} is the original data, $\overline{X_j}$ is the average of X_{ij}, and S_j is the standard deviation of X_{ij}.

② The sub-parameter order degree $u(e_{ji})$ of the order parameter of the subsystem is calculated as

$$u(e_{ji}) = \begin{cases} \frac{e_{ji}-\beta_{ji}}{a_{ji}-\beta_{ji}}, & i \in \left[\ 1, \quad l\ \right] \\ \frac{a_{ji}-e_{ji}}{a_{ji}-\beta_{ji}}, & i \in \left[\ l+1, \quad n\ \right] \end{cases} \quad (11)$$

where $e_j = (e_{j1}, e_{j2}, \ldots, e_{jn})$ is the order parameter $(1 \leq n)$ and α_{ji} and β_{ji} are taken as 1.1 times the maximum value and 0.9 times the minimum value, respectively ($i = 1, 2, \ldots, n$). It was assumed in this work that $e_j = (e_{j1}, e_{j2}, \ldots, e_{jl})$ is a positive indicator and $e_j = (e_{j(l+1)}, \ldots, e_{jn})$ is a negative indicator.

③ The geometric average method is used to integrate the degree of synergy of the urban and rural ecological resilience development systems $u_j(e_j)$:

$$uj(ej) = \sqrt[n]{\left|\prod_{j=1}^{n} uj(eji)\right|} \quad (12)$$

where $u_j(e_j)$ is the system order degree of the order parameter variable e_j, which is usually used to represent the degree of synergy of the urban and rural ecological resilience development systems $u_j(e_j) \in [0, 1]$. The value of $u_j(e_j)$ indicates the degree of influence of e_j on system S_j. The greater the degree of order of the system, the greater the influence of e_j on system S_j and vice versa.

④ The degree of synergy of the urban–rural composite resilience system λ is calculated as follows:

$$\lambda = \theta \times \sqrt{\left|\prod_{j=1}^{n}\left[u_j^t(ej) - u_j^0(ej)\right]\right|} \quad (13)$$

$$\theta = \frac{\min\left[u_j^t(ej) - u_j^0(ej) \neq 0\right]}{\left|\min\left[u_j^t(ej) - u_j^0(ej) \neq 0\right]\right|}, \lambda \in [-1, 1] \quad (14)$$

where when time is the initial time t_0, the order degree of the system order parameter is $u_j^0(e_j)$, $j = 1, 2, \ldots, n$. With the dynamic evolution of the composite system, when the time is

t, the system order degree of each system order parameter is $u_j^t(e_j)$. The greater the value of the degree of synergy of the urban–rural composite resilience system, the higher the degree of urban–rural resilience integration development, and vice versa.

2.3.3. Geographical Detector

The geographical detector is a statistical method for exploring spatial heterogeneity and identifying driving forces [47], and can effectively study the driving factors related to the system [48]. We can explore the core factors that make the spatial differentiation of the coordinated development of urban and rural ecological resilience in Yunnan Province through the use of factor detection and interactive detection modules in the geographic detector. The detection model is

$$q = 1 - \frac{1}{N\sigma^2}\sum_{k=1}^{L} N_k {\sigma_k}^2 \quad (15)$$

where q is the intensity value of the detection factor on the synergy level of urban and rural ecological resilience, and the value range is [0, 1]. The larger the q value, the stronger the explanatory power of the independent variable to the dependent variable. L is the total number of stratifications of independent variable factors, and k is the number of stratifications (k = 1, 2, . . ., L). N and N_k represent the number of units on the whole region and the k stratifications, and σ_k^2 and σ^2 are the variances of the k stratifications and the whole region, respectively.

3. Empirical Results and Analysis

3.1. Weight Calculation and Analysis of Urban Ecological Resilience and Rural Ecological Resilience

The urban ecological data and rural ecological data were analyzed using Formulas (1)–(7) in the entropy weight resilience measurement model. The index weights of urban ecological data and rural ecological data were obtained. The specific weights are shown in Table 3. The greater the weight, the greater the contribution value of the index to the comprehensive measurement of urban ecological resilience or rural ecological resilience.

Table 3. Index weights of urban ecological data and rural ecological data.

Subsystem Layer		**Urban Ecological Impact Level (0.088)**					**Urban Ecological Adaptability Level (0.257)**					**Urban Ecological Resilience Level (0.654)**			
Index layer		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
weight		0.036	0.006	0.007	0.010	0.008	0.021	0.016	0.013	0.099	0.129	0.028	0.010	0.030	0.535	0.051
Subsystem Layer		**Rural Ecological Impact Level (0.125)**					**Rural Ecological Adaptability Level (0.551)**					**Rural Ecological Resilience Level (0.325)**			
Index layer		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15
weight		0.020	0.017	0.022	0.028	0.009	0.028	0.108	0.176	0.103	0.163	0.130	0.044	0.036	0.070	0.043

Based on the results of weight measurement, from the perspective of the subsystem layer, the weight of urban ecological resilience and rural ecological adaptability is the largest, followed by rural ecological resilience and urban ecological adaptability, and finally, rural and urban ecological impact. The weight of urban ecological resilience and rural ecological adaptability is relatively large, indicating that urban ecological resilience and rural ecological adaptability substantially contribute to the comprehensive measurement of urban ecological resilience and rural ecological resilience, respectively. From the perspective of the index layer, the weight of the processing capacity of industrial waste gas treatment facilities is the largest, followed by the garden area, waters, and water conservancy facilities land area, and the smallest weight is that of industrial wastewater emissions and urban sewage discharge. The processing capacity of industrial waste gas treatment facilities contributes the most to the comprehensive measurement of urban ecological resilience, while the garden area contributes the most to the comprehensive measurement of rural ecological resilience.

3.2. Evolution Analysis of Comprehensive Measurement of Urban Ecological Resilience and Rural Ecological Resilience

Based on the results of weight measurement analysis, Formulas (8) and (9) in the entropy weight resilience measurement model were applied to obtain the comprehensive measurement results and dynamic evolution laws of urban ecological resilience and rural ecological resilience in each state and city in Yunnan Province from 2013 to 2022. Considering that the evolution results are significant, one year every three years was considered representative, and 2013, 2016, 2019, and 2022 were taken as examples to draw the spatial difference distribution map of ecological resilience between urban and rural areas, as shown in Figures 3 and 4.

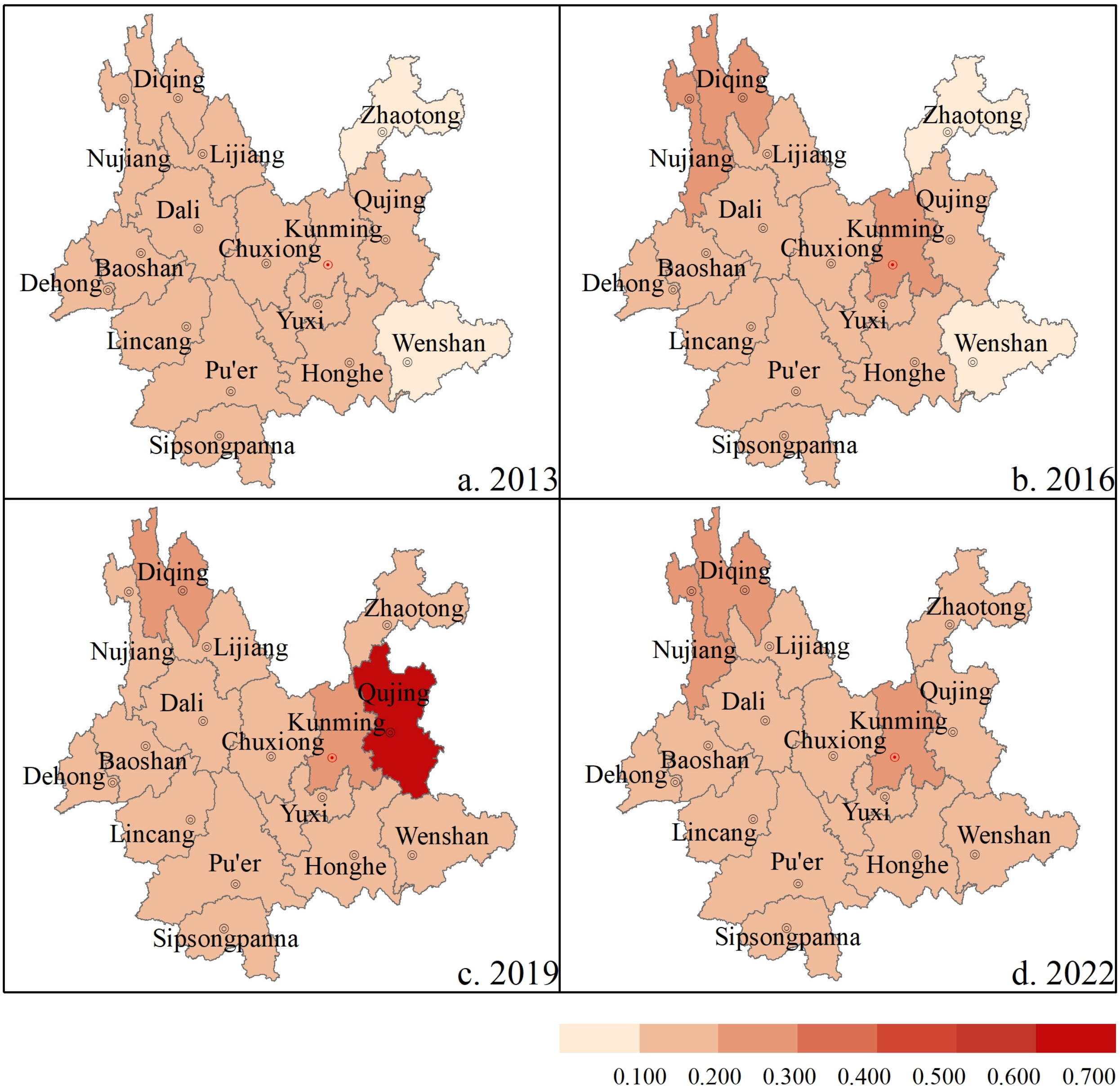

Figure 3. Spatial difference distribution of urban ecological resilience in Yunnan Province.

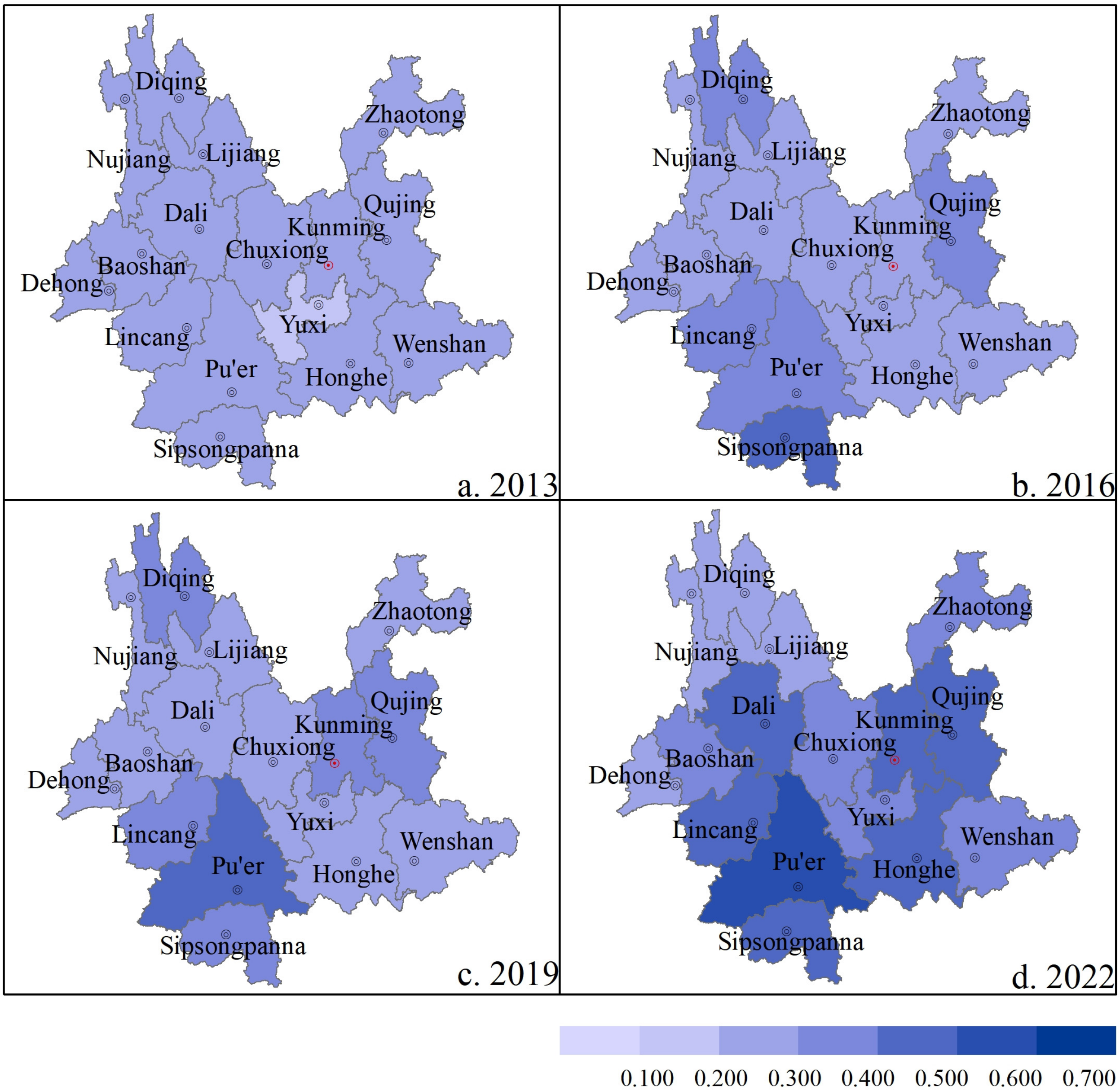

Figure 4. Spatial difference distribution of rural ecological resilience in Yunnan Province.

3.2.1. Evolution Analysis of Comprehensive Measurement of Urban Ecological Resilience

Figure 3 shows the dynamic evolution of urban ecological resilience in Yunnan Province between 2013 and 2022 from the perspective of time series and space. (1) In terms of time series, the overall ecological resilience level of the urban area in Yunnan Province increased annually from 2013 to 2022. The overall ecological resilience of the urban area increased from 0.133 in 2013 to 0.178 in 2022. Qujing had the greatest improvement in urban ecological resilience, increasing from 0.104 in 2013 to 0.182 in 2022, while ecological resilience increased by 0.078. The smallest improvement in urban ecological resilience was exhibited by Sipsongpanna, the value of which fluctuated and did not improve significantly. (2) The spatial difference in urban ecological resilience was small and had no increasing trend, but that of overall urban ecological resilience was large in 2019. The reason is that the processing capacity of industrial waste gas treatment facilities in Qujing in 2019 was much larger than in other regions. The processing capacity of industrial waste gas treatment facilities in Qujing in 2019 reached 560,4891,300 standard cubic meters/hour, while the average capacity of prefectures and cities in Yunnan Province in 2019 was only 402,824,777 standard cubic meters/hour. The urban ecological resilience of Qujing is stronger than that of other regions, hence there was a large spatial difference in 2019.

3.2.2. Evolution Analysis of Comprehensive Measurement of Rural Ecological Resilience

Figure 4 shows the dynamic evolution of rural ecological resilience in Yunnan Province between 2013 and 2022 from the perspective of time series and space. (1) In terms of time series, the overall ecological resilience level of rural areas in Yunnan Province increased annually from 2013 to 2022. The overall ecological resilience measure value of rural areas increased from 0.237 in 2013 to 0.376 in 2022. Among these areas, Pu'er had the largest improvement in rural ecological resilience, increasing from 0.264 in 2013 to 0.522 in 2022. The ecological resilience capacity increased by 0.258, indicating that in Pu'er, greater emphasis is placed on the construction of rural ecological resilience, ecological protection measures are formulated properly, and the improvement effect of ecological resilience capacity is better. The smallest improvement in rural ecological resilience was in Diqing. Due to the trend of first increasing and then decreasing from 2013 to 2022, the overall rural ecological resilience has been poor. (2) The spatial difference in rural ecological resilience in 2013–2022 was small, but its differentiation shows a gradually increasing trend. In 2013, the difference between Qujing (0.289), with better ecological resilience, and Yuxi (0.182), with poor ecological resilience, was only 0.107. However, in 2022, the difference between Pu'er (0.522), with better ecological resilience, and Diqing (0.248), with poor ecological resilience, was 0.274.

A comparative analysis of urban ecological resilience and rural ecological resilience was conducted. In terms of time series, the level of urban ecological resilience and rural ecological resilience in Yunnan Province increased annually. However, the overall urban ecological resilience level still lags behind the rural ecological resilience level. The spatial difference in rural ecological resilience is small, but the difference is gradually increasing. There is no discernible upward trend in the spatial disparity of urban ecological resilience. However, there was a considerable spatial discrepancy in urban ecological resilience in 2019.

3.3. Lag Analysis of Urban Ecological Resilience and Rural Ecological Resilience

The overall level of urban ecological resilience lags behind the level of rural ecological resilience. To address this problem, Formulas (10)–(12) in the composite system synergy model were used to measure and analyze the degree of synergy of the urban ($U1$) and rural ($U2$) ecological resilience development systems from 2013 to 2022. The urban and rural areas were compared to better analyze the synergistic relationship. The results are shown in Table 4, and the comparative evolution trends of the degree of synergy are shown in Figure 5. Among them, $U1 > U2$ is the rural lag type, $U1 < U2$ is the urban lag type, and $U1 = U2$ is the urban–rural synchronous type.

From Table 4, we can determine the following: (1) From the perspective of the average degree of synergy of ecological resilience development in Yunnan Province, urban resilience development is increasing, while rural resilience development showed a trend of first rising, then falling, and then fluctuating horizontally. Compared with 2016, the average degree of synergy of rural overall ecological resilience development in 2019 decreased, and Yuxi and Qujing exhibited large decreases. It was found that the main reason for the decrease in the degree of synergy of rural ecological resilience development in Yuxi is that the per capita afforestation area was reduced. The per capita afforestation area in 2019 decreased by 64.48 square meters per person compared with 2016, hence the overall rural ecological recovery ability was poor and the average degree of synergy of rural ecological resilience development was low. The main reason for the decrease in the degree of synergy of rural ecological resilience development in Qujing was the decline in both the per capita afforestation area and the proportion of primary industry in GDP. The per capita afforestation area in 2019 decreased by 40.48 square meters per person compared with 2016, and the proportion of primary industry in GDP in 2019 decreased by 2.35% compared with 2016. (2) From the perspective of development types, the overall type of coordinated development of urban and rural ecological resilience in Yunnan Province changed from urban lag to rural lag. From 2013 to 2016, the average degree of synergy of rural ecological resilience development was greater than that of urban ecological resilience development. However, since 2017, the Yunnan provincial government has vigorously promoted the construction of resilient cities. Therefore, during 2019–2022, the average degree of synergy of urban ecological resilience development gradually exceeded that of rural ecological resilience development.

Table 4. Degree of synergy of urban and rural ecological resilience development systems in Yunnan Province.

Year	2013			2016			2019			2022		
Region	**Urban**	**Rural**	**Type**	**Urban**	**Rural**	**Type**	**Urban**	**Rural**	**Type**	**Urban**	**Rural**	**Type**
Kunming	0.318	0.331	$U1 < U2$	0.387	0.485	$U1 < U2$	0.454	0.405	$U1 > U2$	0.549	0.491	$U1 > U2$
Qujing	0.333	0.373	$U1 < U2$	0.410	0.495	$U1 < U2$	0.514	0.398	$U1 > U2$	0.529	0.417	$U1 > U2$
Yuxi	0.325	0.319	$U1 > U2$	0.434	0.470	$U1 < U2$	0.457	0.347	$U1 > U2$	0.478	0.472	$U1 > U2$
Baoshan	0.321	0.322	$U1 < U2$	0.418	0.451	$U1 < U2$	0.496	0.461	$U1 > U2$	0.520	0.446	$U1 > U2$
Zhaotong	0.286	0.360	$U1 < U2$	0.424	0.493	$U1 < U2$	0.565	0.443	$U1 > U2$	0.551	0.375	$U1 > U2$
Lijiang	0.328	0.368	$U1 < U2$	0.438	0.494	$U1 < U2$	0.442	0.418	$U1 > U2$	0.558	0.423	$U1 > U2$
Pu'er	0.346	0.297	$U1 > U2$	0.400	0.459	$U1 < U2$	0.487	0.447	$U1 > U2$	0.452	0.403	$U1 > U2$
Lincang	0.362	0.330	$U1 > U2$	0.426	0.451	$U1 < U2$	0.420	0.408	$U1 > U2$	0.504	0.499	$U1 > U2$
Chuxiong	0.302	0.299	$U1 > U2$	0.398	0.471	$U1 < U2$	0.500	0.445	$U1 > U2$	0.552	0.525	$U1 > U2$
Honghe	0.314	0.288	$U1 > U2$	0.428	0.516	$U1 < U2$	0.515	0.434	$U1 > U2$	0.519	0.512	$U1 > U2$
Wenshan	0.345	0.297	$U1 > U2$	0.392	0.496	$U1 < U2$	0.471	0.462	$U1 > U2$	0.575	0.478	$U1 > U2$
Sipsongpanna	0.386	0.312	$U1 > U2$	0.484	0.470	$U1 > U2$	0.382	0.470	$U1 < U2$	0.491	0.474	$U1 > U2$
Dali	0.311	0.310	$U1 > U2$	0.462	0.472	$U1 < U2$	0.532	0.397	$U1 > U2$	0.473	0.511	$U1 < U2$
Dehong	0.379	0.366	$U1 > U2$	0.375	0.454	$U1 < U2$	0.466	0.414	$U1 > U2$	0.476	0.534	$U1 < U2$
Nujiang	0.276	0.351	$U1 < U2$	0.403	0.510	$U1 < U2$	0.492	0.445	$U1 > U2$	0.542	0.378	$U1 > U2$
Diqing	0.364	0.404	$U1 < U2$	0.406	0.456	$U1 < U2$	0.511	0.421	$U1 > U2$	0.558	0.442	$U1 > U2$
Maximum	0.386	0.404	$U1 < U2$	0.484	0.516	$U1 < U2$	0.565	0.470	$U1 > U2$	0.575	0.534	$U1 > U2$
Minimum	0.276	0.288	$U1 < U2$	0.375	0.451	$U1 < U2$	0.382	0.347	$U1 > U2$	0.452	0.375	$U1 > U2$
Average of Yunnan Province	0.331	0.333	$U1 < U2$	0.418	0.478	$U1 < U2$	0.481	0.426	$U1 > U2$	0.521	0.461	$U1 > U2$

3.4. Analysis of the Synergy Level of an Urban–Rural Ecological Resilience Composite System

The urban–rural ecological resilience composite system is a complex dynamic system formed by the continuous coordination and interaction between the urban and rural ecological resilience development systems. Based on the analysis of the degree of synergy of these two systems, the degree of synergy of the urban–rural ecological resilience composite system in Yunnan Province from 2013 to 2022 was calculated with the help of Formulas (13) and (14) in the composite system's synergy degree model, taking 2012 as the base year. The higher the degree of synergy, the better the level of synergy of urban and rural ecological resilience. The level of synergy of urban and rural ecological resilience in Yunnan Province is shown in Figure 6. According to the preset classification criteria, the evolution histogram of the sequence of the degree of synergy of urban and rural ecological resilience composite systems in Yunnan Province was obtained, as shown in Figure 7.

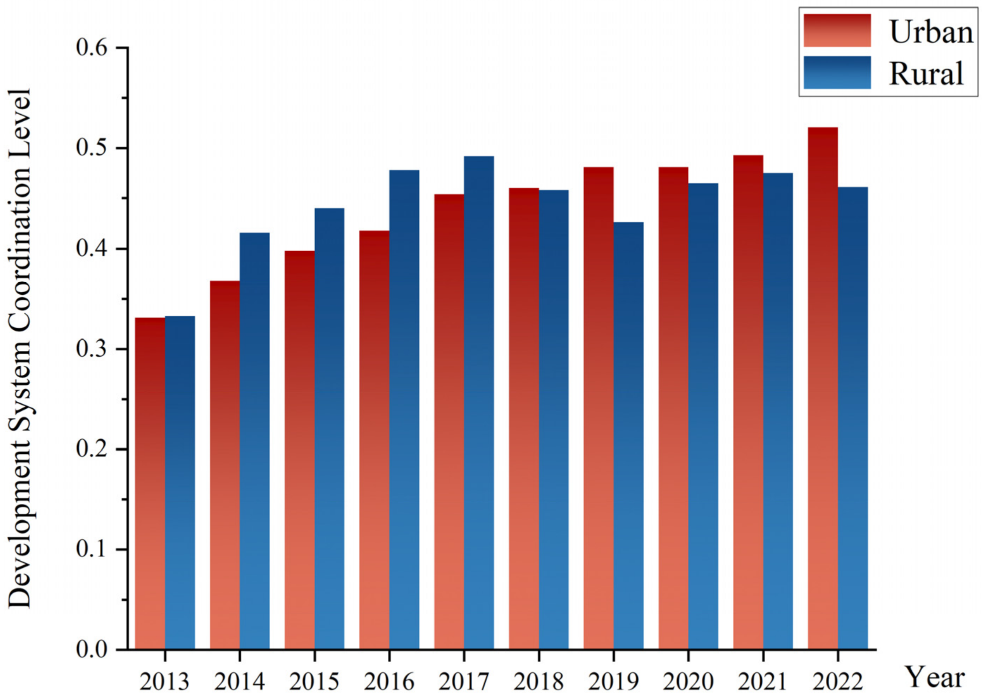

Figure 5. Comparative evolution diagram of urban and rural ecological resilience development system coordination.

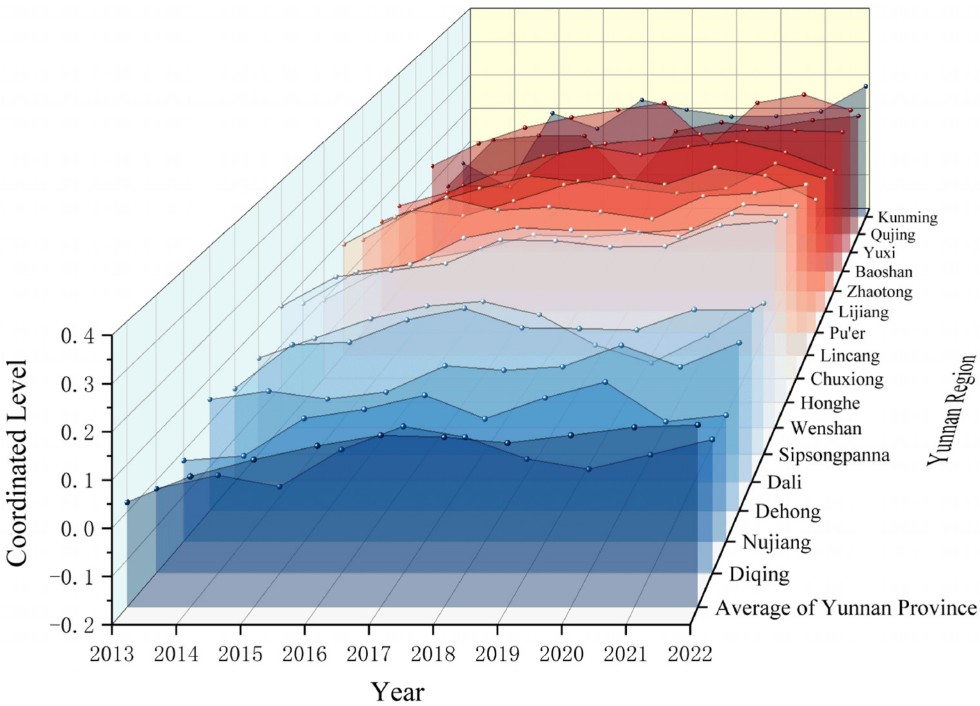

Figure 6. Time series evolution diagram of urban and rural ecological resilience synergy levels.

Overall, from 2013 to 2022, the synergy level of urban and rural ecological resilience in Yunnan Province increased annually from 0.020 to 0.183, indicating that there is a large space for the coordinated development of urban and rural ecological resilience. Although the overall level of urban–rural ecological resilience synergy in Yunnan Province is on the rise, there are considerable differences in the level of ecological resilience synergy among prefectures and cities in the region. This phenomenon is due to a few prefectures and cities in Yunnan Province having better-coordinated development of urban and rural ecological resilience (such as Wenshan, Honghe, and Lincang). Some prefectures and cities also have a large gap in the coordinated development of urban and rural ecological resilience compared to the average in Yunnan Province (such as Diqing, Nujiang, and Qujing).

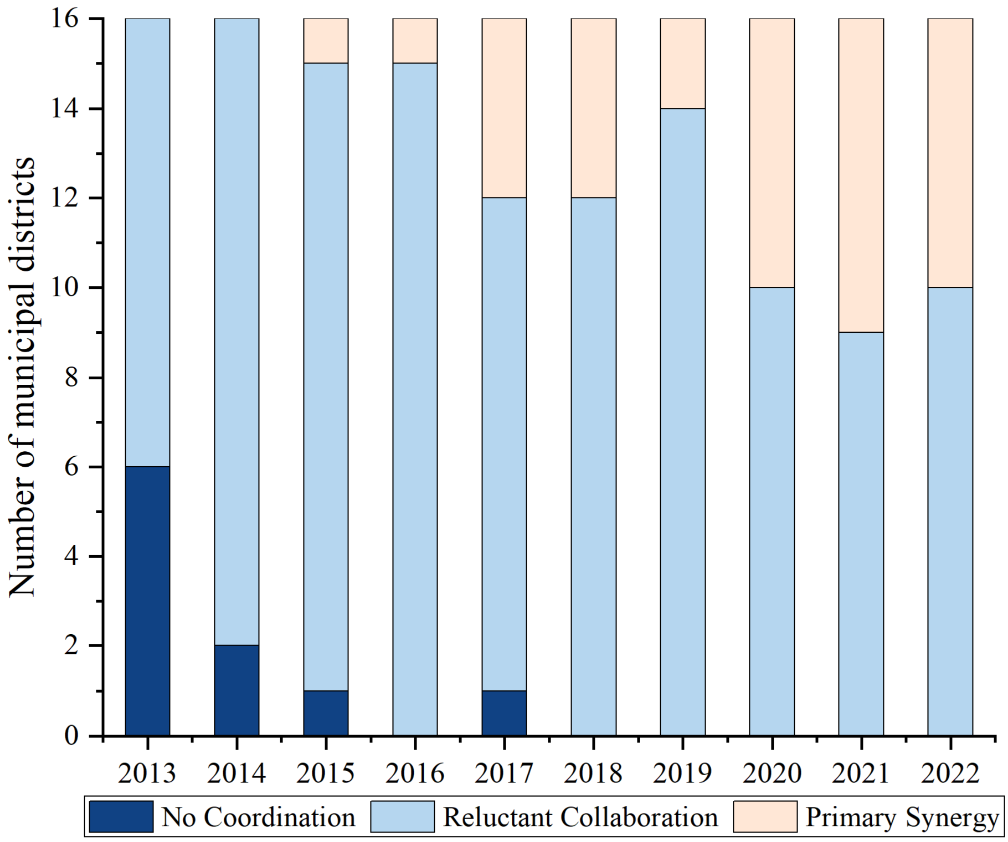

Figure 7. Evolution diagram of the sequence of the degree of synergy of urban–rural ecological resilience.

It can be seen from Figure 7 that in 2013, there were six prefectures and cities with "no coordination" of urban–rural ecological resilience in Yunnan Province and ten prefectures and cities with "reluctant coordination". In 2022, there were ten prefectures and cities that had "reluctant coordination", and six prefectures and cities that had "primary coordination" in Yunnan Province. On the whole, the level of coordinated development of urban and rural ecological resilience in Yunnan Province has crossed from "no coordination" to "primary coordination". From the perspective of time nodes, since 2015, the coordinated development level of urban and rural ecological resilience in Yunnan Province has entered the primary coordination stage. The number of areas with primary coordination has gradually exceeded the number with no coordination, indicating that the urban–rural coordination relationship based on the level of ecological resilience in various prefectures and cities continues to develop in a good direction. In 2017, due to the weak urban ecological adaptability of Qujing, the dyssynergy of urban and rural ecological resilience occurred again. The urban ecological adaptability of Qujing is weak, which is due to the low per capita park green space area and the low green coverage rate in the built-up area by the concurrent drought and flood. From 2018 to 2022, the overall ecological resilience construction in Yunnan Province was generally good. Therefore, the level of coordinated development of urban and rural ecological resilience is on the rise, and there is still room for development in the future.

4. Study of the Heterogeneity of Forces Driving the Coordinated Development of Urban and Rural Ecological Resilience

The driving factors behind urban and rural ecological resilience were systematically analyzed to further scientifically clarify the internal causes of its coordinated development based on previous research in Yunnan Province. The geographic detector was utilized for this purpose. Before using the geographic detector, the natural fracture method of Arcgis 10.8.1 software was used to transform the comprehensive measurement index of the coordinated development level of urban and rural ecological resilience listed above into type variables. This transformation facilitated the analysis of the changes in the core factors as well as the explanatory power of the interaction of various factors in the coordinated development of urban and rural ecological resilience. During the ten years, due to the great changes in economic development and the rapid development of science and technology, the ecological resilience factors affected by social, economic, technological, and environmental impacts changed greatly. Compared with the ten-year data, data from the past four years are more convincing for studying the heterogeneity of forces driving the coordinated development of urban and rural ecological resilience. Therefore, the driving factors in the past four years, from 2019 to 2022, were selected for geographical detection.

4.1. Factor Detection Analysis

The factor detection model can examine the influence of a certain factor on the dependent variable. The factor detection model of the geographic detector was used to analyze the driving factors from 2019 to 2022 to explore the core factors driving heterogeneous changes in the coordinated development of urban and rural ecological resilience in Yunnan Province. The significance of the evaluation index was considered along with factor detection analysis. To ensure the driving factors had sufficient explanatory power, 23 significant driving factors (p values all greater than 0.05) were selected for analysis. The detection results of the factors are shown in Table 5, and the q values of the action strength in the table were calculated using Formula (15). The larger the q value, the stronger the driving factor's influence on the coordinated development level of urban and rural ecological resilience.

As far as Yunnan is concerned, the different drivers that have a synergistic effect on urban and rural ecological resilience show significant heterogeneity. From the time perspective, the highest driving factor value is for the total domestic water consumption (0.705), and the lowest factor is for the urban sewage treatment rate (0.126). Comparing the top 10 factors in terms of q values of the action intensity over the years, it can be observed that the q values of the action intensity of fertilizer consumption, agricultural plastic film usage, total agricultural water consumption, effective irrigation area, and total agricultural output value are ranked in the top 10 in at least four years. This shows that these five variables are the core factors driving the spatial differentiation of the urban and rural ecological resilience synergy level in Yunnan Province. Considering the driving effect of urban ecological resilience, urban ecological adaptability is strong, and urban ecological impact and urban ecological resilience are weak. Therefore, in the future, urban development in Yunnan Province should pay attention to the driving development of urban ecological adaptability. Considering the driving effect of rural ecological resilience, there is a small gap between the driving effect of the overall rural ecological resilience ability. Among them, rural ecological resilience is strong, and rural ecological impact and rural ecological adaptability are relatively weak. Comparing the driving effects of urban and rural ecological resilience, the driving effect of rural ecological resilience is higher than that of urban ecological resilience.

4.2. Interaction Detection Analysis

Interaction detection can be used to identify the driving effect on the dependent variable and the degree of the interaction of two factors. Interaction detection analysis of 23 driving factors with strong significance from 2019 to 2022 was carried out to explore the explanatory power of the interaction of various factors in the coordinated development level of urban and rural ecological resilience in Yunnan Province. As shown in Figure 8, X1–X11 are the factors driving urban ecological resilience, and X12–X23 are the factors driving rural ecological resilience. The interaction type between any two factors was two-factor enhancement or non-linear enhancement. The driving strength of the two-factor effect was greater than that of single factors, indicating that the spatial differentiation of the synergistic level of urban and rural ecological resilience in Yunnan Province resulted from the combined action of multiple driving factors.

Table 5. The factor detection results of the coordinated development of urban and rural ecological resilience.

System Layer	Subsystem Layer	Indicator Layer	Factor Detection Force q Value				
			2019	2020	2021	2022	Average
Urban ecological resilience driving force	Urban ecological impact	Population density (X1)	0.606 **	0.425 **	0.263 **	0.277 **	0.393
		Industrial wastewater emissions (X2)	0.351 **	0.213 *	0.392 **	0.402 **	0.340
		Industrial sulfur dioxide emissions (X3)	0.292 **	0.327 **	0.524 **	0.364 **	0.377
		Proportion of built-up land area (X4)	0.461 **	0.371 **	0.191 **	0.201 **	0.306
	Urban ecological adaptability	Per capita public green space area (X5)	0.309 **	0.248 **	0.215 **	0.532 **	0.326
		Green coverage rate of built-up area (X6)	0.389 **	0.461 **	0.219 **	0.277 **	0.336
		Green coverage area of built-up area (X7)	0.585 **	0.540 **	0.611 **	0.501 **	0.559
		Total water resources per capita (X8)	0.382 **	0.341 **	0.588 **	0.508 **	0.455
	Urban ecological resilience	Per capita water supply (X9)	0.322 **	0.212 **	0.183 **	0.207 **	0.231
		Urban sewage treatment rate (X10)	0.126 *	0.174 **	0.553 **	0.411 **	0.316
		General industrial solid waste comprehensive utilization rate (X11)	0.139 **	0.196 **	0.185 **	0.221 **	0.185
Driving force of rural ecological resilience	Rural ecological impact	Fertilizer consumption (X12)	0.523 **	0.510 **	0.601 **	0.662 **	0.574
		Pesticide usage (X13)	0.383 **	0.314 **	0.522 **	0.601 **	0.455
		Agricultural plastic film usage (X14)	0.530 **	0.551 **	0.601 **	0.599 **	0.570
		Total agricultural water consumption (X15)	0.502 **	0.387 **	0.539 **	0.598 **	0.506
		Total domestic water consumption (X16)	0.574 **	0.467 **	0.667 **	0.705 **	0.603
		The proportion of agricultural intermediate consumption in total output value (X17)	0.268 **	0.172 *	0.311 **	0.399 **	0.288
	Rural ecological adaptability	Per capita cultivated land area (X18)	0.472 **	0.461 **	0.380 **	0.335 **	0.412
		Garden area (X19)	0.352 **	0.461 **	0.536 **	0.564 **	0.478
		Reservoir capacity (X20)	0.552 **	0.489 **	0.666 **	0.487 **	0.549
	Rural ecological resilience	Effective irrigation area (X21)	0.658 **	0.540 **	0.564 **	0.593 **	0.589
		Per capita net income of farmers (X22)	0.499 **	0.447 **	0.508 **	0.529 **	0.496
		Total agricultural output value (X23)	0.507 **	0.531 **	0.651 **	0.561 **	0.563

Note: "**" and "*" represent the 0.01 and 0.05 significance levels.

From the time perspective, from 2019 to 2022, the factors with the strongest interaction in the coordinated development of urban and rural ecological resilience in Yunnan Province were proportion of built-up land area (X4) ∩ population density (X1) (2019, q = 0.936); per capita water supply (X9) ∩ green coverage rate of built-up area (X6) (2020, q = 0.891); agricultural plastic film usage (X14) ∩ urban sewage treatment rate (X10) (2021, q = 0.926); and fertilizer consumption (X12) ∩ proportion of built-up land area (X4) (2022, q = 0.927). Among these factors, the average q value of the driving force of the per capita water supply (X9) is not more than 0.231, but its interaction with other factors is significantly enhanced, indicating that per capita water supply is the basic driving factor for the coordinated development of urban and rural ecological resilience. Among them, the q value of the interaction between per capita water supply and fertilizer consumption has been increasing, and was greater than 0.9 in the past two years, indicating that the interaction between per capita water supply and fertilizer consumption is the key factor driving the coordinated development of urban and rural ecological resilience. Overall, the driving force of the multi-factor synergistic effect on the synergistic level of urban and rural ecological resilience in Yunnan Province is greater than that of single factors, and the interaction type between any two factors is a two-factor enhancement or non-linear enhancement. Further research shows that the better interaction effect is mainly due to the coordinated development of urban and rural ecological driving forces. The combination of urban and rural driving factors is more conducive to improving urban and rural ecological resilience. Therefore, we should promote the coordinated development of urban and rural ecological impact and maximize the ability of urban and rural ecological resilience.

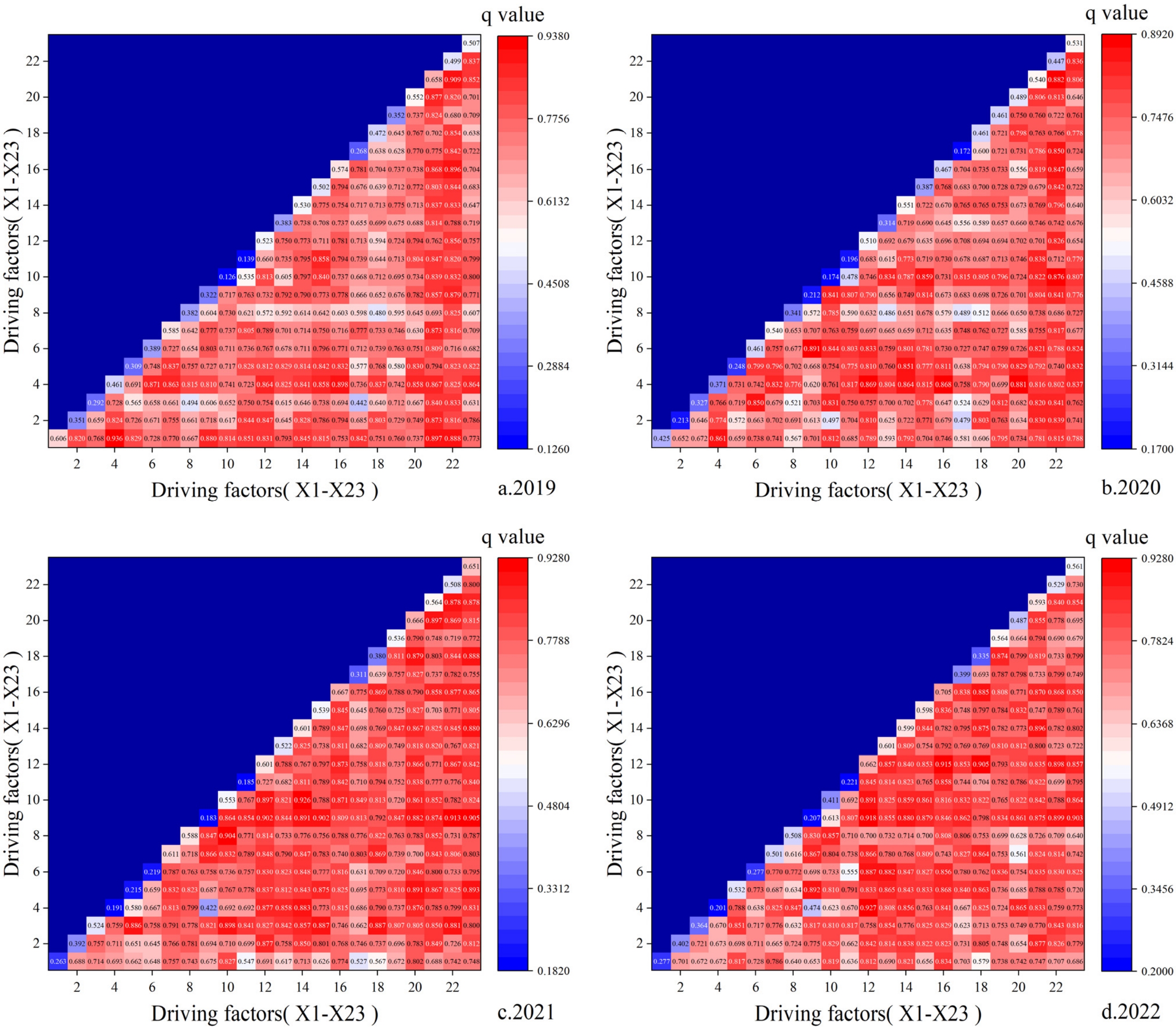

Figure 8. Interactive detection results of factors driving urban–rural ecological resilience synergy levels.

5. Discussion

In the dynamic evolution of the coordinated development of urban and rural ecological resilience, it is found that the urban and rural ecological resilience levels in Yunnan Province increased annually, but urban ecological resilience lagged behind that of rural areas. In order to alleviate the unbalanced development of urban and rural ecological resilience, the study found that urban–rural ecological resilience and anti-risk capabilities can be improved by promoting the coordinated development of urban and rural ecological resilience. When studying the coordinated development of urban and rural ecological resilience, it is found that there are significant differences between different prefectures and cities in Yunnan Province. Among them, the five variables of fertilizer consumption, agricultural plastic film usage, total agricultural water consumption, effective irrigation area, and total agricultural output value are the core factors driving the spatial differentiation of urban and rural ecological resilience synergy levels in Yunnan Province. The study of interaction factor detection shows that the combination of urban and rural driving factors is more conducive to improving urban–rural ecological resilience. Among them, the interaction between per capita water supply and fertilizer consumption is the key factor driving the coordinated development of urban and rural ecological resilience. The improvement of urban–rural ecological resilience can strengthen the ability of urban and rural areas to resist risks and cope with climate change, enhance the protection ability of the ecological environment, and ensure the sustainable development of human society. The following strategies are proposed based on the laws and characteristics found in the study of dynamic evolution and driving force heterogeneity of the coordinated development of urban and rural ecological resilience combined with the actual situation in Yunnan Province:

(1) Promote the coordinated development of urban and rural ecological resilience and enhance the ability of urban and rural ecological governance. From the lag analysis of urban ecological resilience and rural ecological resilience, it can be seen that the overall type of coordinated development of urban and rural ecological resilience in Yunnan Province has changed from urban lag to rural lag. Whether it is urban lag or rural lag, it is hindered by the development of ecological resilience. The study of interaction factor detection shows that most of the better interaction results are due to the coordinated development of urban and rural ecological driving forces. The combination of urban and rural driving factors is more conducive to improving urban and rural ecological resilience. Therefore, we should promote the coordinated development of urban and rural ecological resilience, balance the relationship between urban and rural ecological environment governance with the help of urban and rural mutual penetration, and improve the ability of urban and rural ecological two-way governance.

(2) Strengthen scientific and technological support for the coordinated development of urban and rural ecological resilience and steadily improve urban and rural ecological resilience. Through interactive detection analysis, it can be observed that the interaction between per capita water supply and fertilizer consumption is the primary driving factor for the coordinated development level of urban and rural ecological resilience. Enhancing the interaction between per capita water supply and fertilizer consumption not only enhances its own driving effect on the coordinated development of urban and rural ecological resilience but also those of other factors. To improve the coordinated development level of urban and rural ecological resilience, we should make rational use of various advantageous resources in urban and rural areas. On the one hand, urban areas should increase investment in green industries, encourage enterprises to develop innovations, and use green and efficient process equipment to increase per capita water supply. Concurrently, the level of urban and rural water supply security can be improved by rationally planning water resources and strengthening water resource management. On the other hand, agriculture is the main industry in rural areas. Combined with the five core driving factors obtained from the single factor detection analysis, it was found that in order to promote the coordinated development of urban and rural ecological resilience and enhance urban and rural ecological resilience, it is necessary to increase investment in green agriculture, vigorously promote green technology agricultural production mode, and thoroughly implement zero growth action of chemical fertilizer and pesticide use and reduce the consumption of agricultural plastic film. At the same time, increasing investment in farmland water conservancy facilities can improve irrigation conditions, improve the utilization rate and irrigation efficiency of farmland water conservancy facilities, and reduce the wastage of agricultural water resources. On this basis, strengthening scientific and technological support will achieve the goal of improving the output efficiency of agricultural production.

(3) Pay attention to the spatial imbalance in the coordinated development of urban and rural ecological resilience in Yunnan Province and explore the path of differentiated regional development. Combined with the overall level of coordinated development

of urban and rural ecological resilience, the core factors in various regions are taken as the starting point for formulating a differentiated coordinated development strategy. For example, the development strategy of increasing the per capita afforestation area and per capita cultivated land area should be formulated for the ecological environment problems in Diqing. To increase per capita afforestation area, on the one hand, the government and the forestry sector should increase the existing forest area and improve the existing forest coverage and forest quality by implementing scientific protection and ecological restoration measures for forest and grassland resources. On the other hand, per capita afforestation area can be directly improved by adding new green areas for afforestation. To increase the per capita cultivated land area, it is necessary for the Diqing government to strictly control the scale of land development, carry out in-depth protection and improvement of cultivated land quality, and prevent land desertification and degradation.

In summary, the collaborative development trend found in the study is consistent with the trend of urban–rural integration development-related research and the collaborative governance strategy proposed in the article is in line with the "comprehensive promotion of coordinated urban–rural and regional development" and sustainable development goals proposed by the Chinese government. Therefore, relevant research on the coordinated development of urban and rural ecological resilience in Yunnan Province has theoretical reference value for Yunnan, China, and even South and Southeast Asia.

6. Conclusions

Based on the theory of resilience and complex adaptive systems, a comprehensive measurement system was constructed in this study from the perspective of the coordinated development of urban and rural ecological resilience. The urban and rural ecological resilience of 16 cities in Yunnan Province in China from 2013 to 2022 was measured by using the resilience measurement model. The synergy degree model of the composite system was used to measure the synergy level. The heterogeneity of the driving force of the coordinated development of urban and rural ecological resilience was explored using the geographical detector. The main conclusions are as follows:

(1) From the perspective of time series, the overall urban and rural ecological resilience level of Yunnan Province increased annually from 2013 to 2022, and the urban ecological resilience level lagged behind the rural ecological resilience level. From the perspective of spatial distribution, the overall spatial difference in rural ecological resilience level is small, while the overall spatial difference in urban ecological resilience level is large.

(2) The synergy level of urban and rural ecological resilience in Yunnan Province increased annually from 2013 to 2022, from "no collaboration" to "primary collaboration". The urban–rural relationship based on the level of ecological resilience in various states and cities has continued to develop in a good direction; however, there are significant differences in the level of synergy of urban–rural ecological resilience between various prefectures and cities in Yunnan Province.

(3) The trend of evolution of the level of synergy of urban and rural ecological resilience in Yunnan Province is affected by multiple driving factors. The interaction between various factors has a two-factor enhancement or non-linear enhancement relationship with the development of urban and rural ecological resilience. From the perspective of the evolution of the driving effect of interactive factors, the better interaction results are mostly those of the coordinated development of urban and rural ecological driving forces. The interaction between per capita water supply and fertilizer consumption is the primary and key driving factor for the coordinated development level of urban and rural ecological resilience. Based on the above analysis, the actual situation in Yunnan Province was considered in this study to formulate relevant collaborative governance strategies.

In summary, in the context of both urban–rural integration development and resilient city construction, this paper explores the dynamic evolution and driving force heterogeneity in the coordinated development level of urban–rural ecological resilience in Yunnan Province, China, and presents the formulated urban–rural ecological collaborative governance strategies. This provides suggestions for relevant departments in Yunnan Province in China to formulate policies. At the same time, it provides new ideas for the study of urban–rural integration and ecological resilience in similar countries and economic development regions worldwide. The article has the limitations of the research area and lacks the level of prediction of coordinated development of urban and rural ecological resilience in Yunnan Province. In the future, we will continue to take the coordinated development of urban and rural ecological resilience as the theme, further expand the research area, and carry out predictive research on future development trends.

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