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Spatiotemporal Evolution Characteristics of the Coupling and Coordination between Land Ecological Security and Rural Revitalization in the Chishui River Basin

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Abstract: *As a critical ecological functional area in China, the Chishui River Basin plays a vital role in maintaining land ecological security and promoting agricultural and rural development. This study establishes an evaluation index system for land ecological security and rural revitalization, and applies the coupling coordination model to quantitatively analyze the interactive characteristics between ecological security and rural revitalization in the basin from 2012 to 2022. The results indicate a general upward trend in both land ecological security and rural revitalization levels over the study period. The degree of coupling coordination has shown a steady growth trajectory, albeit with spatial heterogeneity across regions, presenting a distinct "high–medium–low" gradient pattern from east to west. These findings offer valuable insights for formulating policies aimed at achieving coordinated and sustainable development in the Chishui River Basin.*

Keywords: *Chishui River Basin; Ecological Security; Rural Revitalization; Coupling and Coordination*

1. Introduction

River basins have historically served as the cradle of civilization, providing abundant and clean freshwater resources that support human production and daily life, and promoting the development of settlements[1]. These basins play a crucial role in the advancement of human civilization. Land, as an integrated entity encompassing natural, social, and economic dimensions, constitutes the foundation for human survival and development[2]. Ensuring land ecological security within river basins has become a key challenge in achieving sustainable development. The implementation of the rural revitalization strategy has further underscored the importance of maintaining a healthy land ecological environment[3]. The principle of green development is deeply embedded throughout the rural revitalization process, aiming to safeguard land ecological security while simultaneously promoting rural economic prosperity and overall societal progress[4]. Land ecological security in river basins not only contributes to the conservation of natural resources but also serves as a critical foundation for the successful implementation of the rural revitalization strategy. In recent years, the Chishui River Basin in China has made notable progress in both ecological conservation and poverty alleviation efforts[5]. However, the region still faces challenges related to an outdated economic development model and pressing ecological issues that require urgent attention.The Chishui River Basin is a typical ecologically sensitive area, where the protection and management of the ecological environment directly influence the realization of land ecological security within the basin[6]. To simultaneously achieve the goals of rural revitalization and ecological conservation, it is essential to adopt systematic approaches that coordinate land use with ecological protection, thereby promoting green and sustainable development. Accordingly, this study investigates the coupling Characteristics between land ecological security and rural revitalization, aiming to guide rural revitalization through the principles of green development, ensure land ecological security, and advance the modernization of harmonious coexistence between human activities and natural ecosystems.

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2. Overview of the Study Area

The Chishui River (104°44′E – 107°1′E, 27°15′N – 28°50′N) (Figure 1) originates in Yuzhong Township, Zhongxiang County, Zhaotong City, Yunnan Province. It flows through Zhaotong City in Yunnan Province, Bijie City and Zunyi City in Guizhou Province, and Luzhou City in Sichuan Province. With a total length of approximately 444.5 km and a drop of 1588 meters, it serves as a first-class tributary of the Yangtze River and is situated within the U-Mong Mountain Ridge. The region experiences a plateau monsoon climate, with rainfall during the flood season accounting for 80% of the annual precipitation, resulting in an average annual rainfall of 897.3 mm. Middle-to-high mountain structural erosion and karst landforms dominate 34.09% of the basin area, with slopes ranging from 15° to 25°. The upper reaches are characterized by numerous hidden caves and waterfalls, while the lower reaches feature a gentler riverbed gradient and valleys shaped like "U" or "V". The basin belongs to the subtropical evergreen broad-leaved forest ecological zone, where the ecological environment is well-preserved and plant resources are abundant. As an important ecological barrier in the upper reaches of the Yangtze River, it plays a crucial role in environmental conservation, water resource protection, and soil retention functions[7]. As of the end of 2022, the Chishui River Basin had a total population of approximately 22,624,400, with an urbanization rate of 51%. The regional GDP reached 1,075.1 billion yuan in that year, and per capita disposable income amounted to 47,519.5 yuan. A characteristic agricultural industry centered around bamboo, kiwi fruit, konjac, pigs, and beef cattle has been initially established within the basin. The industrial structure is primarily composed of coal, agricultural product processing, and wine manufacturing, while the modern service sector mainly encompasses cultural tourism and commercial logistics. Significant disparities exist in the natural geography and levels of economic development across the basin. The upstream region is characterized by a relatively fragile ecological background, weak pillar industries, and an underdeveloped industrial foundation. In contrast, the middle and lower reaches have a more mature wine industry, which heavily relies on water resources and is highly sensitive to water quality. The spatial heterogeneity in ecological conditions and socio-economic development within the basin is evident[8]. As a key national ecological area, the basin serves critical functions in "ecological security," "resource conservation," and "landscape preservation." Under the constraints imposed by resource conservation and environmental protection policies, promoting high-quality development and achieving a balance between ecological security and rural revitalization remains a major practical challenge for the Chishui River Basin.

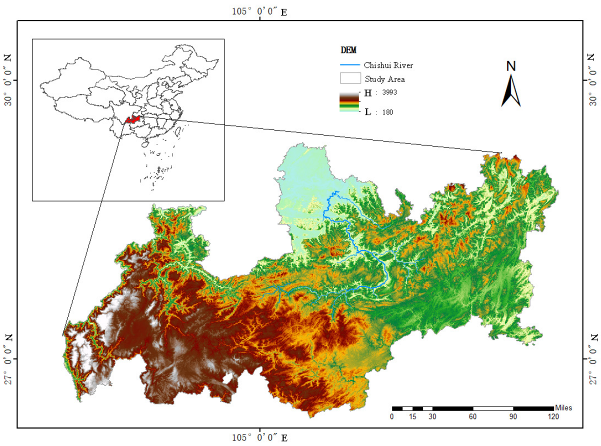

Figure 1 Basic Natural Overview of the Chishui River Basin

3. Research Methods

3.1 Data Sources

This study focuses on the Chishui River Basin as the research area. The data required for the construction of the indicator system are primarily sourced from the statistical yearbooks of Yunnan, Sichuan, and Guizhou provinces for the years 2012, 2017, and 2022, as well as from municipal and county-level statistical yearbooks. Additional data sources include the "China Rural Statistical Yearbook," "Economic and Social Development Bulletin," "Statistics Bulletin on Rural Revitalization," "Government Work Report," the "Macroeconomic Database" and "China Urban and Rural Construction Database" provided by the National Bureau of Statistics, the EPS Data Platform, and the

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Resource and Environment Science and Data Center of the Chinese Academy of Sciences. For certain indicators with missing data, linear interpolation was applied using available data from adjacent years to estimate the missing values.

3.2 Construction of Evaluation Index System

Based on existing research results[9], the land ecological security index system in this study is constructed using the Pressure-State-Response (PSR) model. The three dimensions—pressure, state, and response—are established as criterion layers (Table 1). The rural revitalization index system is developed in accordance with the Chinese government's "Twenty-character" overall requirements for rural revitalization: industry prosperity, ecological livability, rural cultural civilization, effective governance, and prosperous life[10] (Table 2).

Table 1 Comprehensive evaluation index system and weight of land ecological security

Target Layer	Guideline Layer	Index Layer	Weight
Land ecological security	Pressure	X1: Natural population growth rate (-)	0.031
		X2: Urbanization rate (+)	0.063
		X3: Per unit area of plastic film usage (-)	0.035
		X4: Proportion of primary industry economy (-)	0.076
		X5: Per unit area of chemical fertilizer usage (-)	0.048
	Status	X6: Per capita cultivated land area (+)	0.028
		X7: Conversion rate (+)	0.036
		X8: Forest coverage rate (+)	0.044
		X9: Slope (-)	0.101
		X10: Per capita grain output (+)	0.084
		X11: Per capita water resources possession (+)	0.039
		X12: Per unit area of GDP (+)	0.084
	Response	X13: Concentrated treatment rate of sewage treatment plants (+)	0.032
		X14: Proportion of expenditure on energy conservation and environmental protection (+)	0.070
		X15: Per unit area of fixed asset investment (+)	0.088
		X16: Per capita level of agricultural machinery (+)	0.045
		X17: Rate of harmless treatment of household waste (+)	0.036
		X18: Proportion of expenditure on agriculture, forestry and water conservancy (+)	0.061

Table 2 Comprehensive evaluation index system and weights of rural revitalization

Target Layer	Guideline Layer	Index Layer	Weight
Rural revitalization	Prosperity of the industry	Y1: Proportion of the tertiary industry economy (+)	0.042
		Y2: Per capita output value of agriculture, forestry, animal husbandry and fishery (+)	0.073
		Y3: Main business income of large-scale agricultural product processing enterprises (+)	0.066
	Ecologically friendly and livable	Y4: Rural greening rate (+)	0.058
		Y5: Average pesticide and fertilizer application per hectare (-)	0.046
		Y6: Road hardening rate in villages (+)	0.059
	Village Morality and Civilization	Y7: Number of rural cultural centers (+)	0.064
		Y8: Number of full-time teachers per 10,000 primary school students (+)	0.055
		Y9: Number of medical staff per 1,000 people in rural areas (+)	0.064
	Effective governance	Y10: Proportion of administrative villages that have launched Internet broadband services (+)	0.071
		Y11: Per capita income of farmers (+)	0.085
		Y12: Implementation rate of village improvement projects (+)	0.065
	Living in affluence	Y13: Rural Engel's Coefficient	0.071
		Y14: Rural Residents' Expenditure on Education, Culture and Entertainment (+)	0.064
		Y15: Ratio of Urban and Rural Residents' Income (-)	0.118

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3.3 Data Standardization Processing

In the indicator system for land ecological security and rural revitalization, the units and scales of individual indicators vary, making direct comparisons impossible. As a result, these indicators cannot be effectively used to assess the relative performance of systems or determine the degree of their superiority. To address this issue, the range normalization method is employed to standardize the data, projecting all values onto the interval [0, 1]. This process eliminates discrepancies caused by different measurement units, unifies the data range, and aligns the evaluation direction. The specific calculation is shown in formulas (1) and (2).

$$\text{Positive indicators: } x_{\mathrm{ij}}^{'} = 0.1 + 0.9 \times \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{1}$$

$$\text{Negative indicators: } x_{ij}^{'} = 0.1 + 0.9 \times \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{2}$$

In the formula, $x_{ij}^{'}$ represents the standard value after processing by the range formula; x_{ij} represents the original data value before processing; $\max x_{ij}$ represents the maximum value in the original data; $\min x_{ij}$ represents the minimum value in the original data. To avoid the influence of subjective preferences, after data standardization, the entropy weight method is used to calculate the weight coefficients W of each indicator.

3.4 Comprehensive Evaluation Value

$$\text{Comprehensive evaluation value of land ecological security: } U_1 = \sum_{i=1}^{m} (w_i x_{ij}^{'}) \tag{3}$$

$$\text{Comprehensive Evaluation Value of Rural Revitalization: } U_2 = \sum_{i=1}^{n} (w_i x_{ij}^{'}) \tag{4}$$

In the formula, U_1 represents the comprehensive evaluation value of land ecological security, U_2 represents the comprehensive evaluation value of rural revitalization, w_i is the weight coefficient of the i-th indicator, and $x_{ij}^{'}$ is the standardized value of the j-th indicator in the i-th year.

3.5 Construction of Coupling and Coordination Model

To calculate the coupling coordination level of land ecological security and rural revitalization, we draw on the existing coupling coordination model[11]. Firstly, the coupling degree index is calculated, then the comprehensive index of land ecological security and rural revitalization is computed, and subsequently the coupling coordination degree index is obtained. Thus, the coupling and coordinated development degree of the two systems can be determined. The formula is as follows:

$$C = \frac{2\sqrt{U_1 \times U_2}}{U_1 + U_2} \tag{5}$$

$$T = \alpha \cdot U_1 + \beta \cdot U_2 \tag{6}$$

$$D = \sqrt{C \times T} \tag{7}$$

In the formula, C represents the coupling degree of the two systems, which ranges [0, 1]. U_1 and U_2 are the comprehensive indices of land ecological security and rural revitalization. T represents the comprehensive index of the two systems, reflecting their synergy. α and β are undetermined coefficients, and $\alpha + \beta = 1$, with $\alpha = \beta = 0.5$. D represents the coupling coordination degree between the land ecological security and the rural revitalization system, with the range being [0, 1]. By using the coupling coordination degree model, the mutual influence and interactive dependence between the two

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systems can be measured. Calculating the coordination degree can reflect the degree of correlation between the systems, and further comprehensive analysis of the coupling coordination level between the systems can be conducted.

3.6 Classification of Grades

In order to more accurately identify and evaluate the security development levels and coupling coordination states among different regions, and to explore the complexity of rural revitalization and land ecological security, this study, based on the analysis of other studies[12-13], adopted the natural breakpoint method for classification and divided each state (Tables 3 and 4).

Table 3 Comprehensive Evaluation Grades for Land Ecological Security and Rural Revitalization

Land ecological security Rural revitalization	Unsafe	Relatively Unsafe	Critical Safety	Relatively Safe	Ideal Safety
	[0,0.2)	[0.2,0.4)	[0.4,0.6)	[0.6,0.8)	[0.8,1)
Land ecological security	Low level of development	Relatively low level of development	Average level of development	Relatively high level of development	High level of development
	[0,0.2)	[0.2,0.4)	[0.4,0.6)	[0.6,0.8)	[0.8,1)

Table 4 Classification Table of Coupling and Coordination Levels

NO.	Coupling Coordination Coefficient	Coupling Coordination Degree Grade	NO.	Coupling Coordination Coefficient	Coupling Coordination Degree Grade
1	[0,0.1)	Extreme imbalance	6	[0.5,0.6)	Primary coordination
2	[0.1,0.2)	Severe imbalance	7	[0.6,0.7)	Mild coordination
3	[0.2,0.3)	Moderate imbalance	8	[0.7,0.8)	Moderate coordination
4	[0.3,0.4)	Mild imbalance	9	[0.8,0.9)	Good coordination
5	[0.4,0.5)	Borderline coordination	10	[0.9,1.0]	High coordination

4. Results and Analysis

4.1 Analysis of the Comprehensive Level of Land Ecological Security

Based on the established indicator system (Table 1), after standardizing and obtaining the weights of the original indicator data, the comprehensive level of land ecological security in the Chishui River Basin is analyzed according to Equations (1) -(3), as shown in Table 5.

Table 5 Land Ecological Security Evaluation and Rural Revitalization Index Evaluation

	Land ecological security assessment			Assessment of rural revitalization development		
	2012	2017	2022	2012	2017	2022
Zhaotong	0.2606	0.3710	0.4508	0.2365	0.3452	0.4621
Bijie	0.4485	0.4436	0.5684	0.5766	0.7215	0.8260
Zunyi	0.5628	0.5434	0.6277	0.6065	0.7661	0.7949
Luzhou	0.5413	0.6996	0.8686	0.4287	0.5282	0.6747

4.1.1 Time Evolution Characteristics

During the ten-year period from 2012 to 2022, the comprehensive index of land ecological security in the Chishui River Basin exhibited a three-stage evolutionary pattern: "low-level stagnation—local breakthrough—overall improvement". In 2012, the region was characterized by dominant pressure factors, a fragile environmental state, and weak response capacity, with all indices falling within the low-value range. Particularly in Zhaotong City, due to its complex terrain and inherently fragile ecological conditions, the comprehensive index was only 0.24, categorizing the area as "relatively unsafe". By 2017, with increased regional investment in ecological governance, variations in the growth rates of the indices became evident. The pressure index generally declined, while the state-response index showed slight improvement in Zhaotong and a significant increase in Luzhou, marking the first-level transition node. Luzhou's safety index reached 0.7, meeting the threshold for "relatively safe". By 2022, driven by the ecological priority strategy, the pollution prevention and control campaign, and the cross-border collaborative mechanism for mine restoration, the three-dimensional indicators—pressure, state, and response—achieved synchronized improvement for the first time. This led to an overall enhancement of ecological security across the basin. Luzhou reached an ideal safety level, indicating that the land ecological security of the Chishui River Basin had

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entered a new phase characterized by accelerated restoration and a positive feedback cycle.

4.1.2 Spatial Differentiation Pattern

The river basin shows a gradient distribution feature of "fragile upstream - transitional middle section - excellent downstream". The spatial differentiation pattern map of ArcGIS was generated based on the coupling coordination degree (Figure 2).

(a) 2012 *(b) 2017* *(c) 2022*

Figure 2 Land ecological security level map of each area in the Chishui River Basin

The upstream towns of Zunxiang County, Weixin County, and Suoyong County contain karst stone desertification-sensitive areas characterized by elevations exceeding 1500 meters and sloping farmland with gradients greater than 25 degrees. These regions have long remained at a "relatively unsafe to critical safety" level in terms of ecological security. In the middle reaches, the evergreen coniferous and broad-leaved mixed forest zones in Guixi County, Renhuai County, and Jinsha County are impacted by topographic fragmentation, mining activities, and agricultural expansion. Their ecological safety index ranges from 0.40 to 0.63, indicating a state of "critical safety" to "relatively safe." Downstream, the humid evergreen broad-leaved forest areas in Hejiang County and Chishui County benefit from favorable climatic conditions, including an annual average temperature above 18℃ and annual precipitation exceeding 1100 mm. These regions possess the most favorable ecological background and achieved the "relatively safe" threshold as early as 2017, advancing to "ideal safety" by 2022. Overall, cross-provincial ecological compensation mechanisms, joint law enforcement efforts, and mine restoration initiatives have reinforced the gradient restoration strategy of "downstream leadership, middle reaches following, and upstream catching up." While spatial heterogeneity is gradually decreasing, it remains substantial[6].

4.2 Analysis of Comprehensive Level of Rural Revitalization

Based on the established indicator system (Table 2), after standardizing and obtaining the weights of the original indicator data, and according to Equations (1) (2) (3), the comprehensive level of rural revitalization in the Chishui River Basin is analyzed (Table 5).

4.2.1 Time Evolution Characteristics

From 2012 to 2022, the comprehensive index of rural revitalization in the Chishui River Basin exhibited an evolutionary trajectory characterized by "initial foundation consolidation — mid-term leap — late-term stability." At the beginning of the study period, the average values of all five criterion layers across the region were only 0.46, indicating an overall moderate level of development. The primary constraints were the underdeveloped industrial prosperity and weak governance effectiveness. By 2017, the region had entered a phase of accumulating momentum for rapid growth, marked by increased policy support and a 25% rise in the index. However, significant structural disparities persisted. Improvements in living standards and rural culture progressed more rapidly compared to industrial prosperity and ecological livability. After 2022, the region entered a phase of sustained acceleration, with the index continuously rising at a growth rate of 21%. The synergy among the five criterion layers was notably enhanced: characteristic industrial clusters were established, digital rural infrastructure was expanded, cross-border ecological compensation mechanisms were implemented, and the grassroots governance point-based system was comprehensively promoted. These developments drove the overall comprehensive index of the region to exceed 0.69 by 2022, reflecting a relatively high level of rural revitalization and signifying a transition from isolated progress to a new stage of systematic and coordinated development.

4.2.2 Spatial Differentiation Pattern

The spatial differentiation of rural revitalization in the river basin is presented as an arch-shaped

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curve under the interaction of the industrial and economic background. The spatial differentiation pattern map in ArcGIS (Figure 3) is generated based on the coupling coordination degree data.

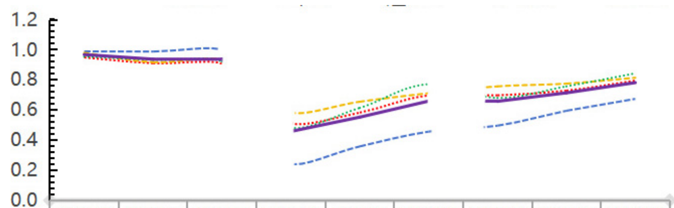
(a) 2012 *(b) 2017* *(c) 2022*

Figure 3 Rural Revitalization Levels in Each Region of Chishui River Basin

The upstream Zhaotong base index was only 0.24, indicating a relatively low level of development. This situation is attributed to the poor transportation infrastructure and the single-structured industrial pattern in the high-altitude karst region. With continuous investment in green industrial clusters—such as apple, ginseng, and pepper cultivation on the plateau and the advancement of digital rural construction[14], the index rapidly increased to 0.46, achieving a "lowland rebound." In the middle reaches, Bijie and Zunyi leveraged the dual drivers of the "three transformations" reform[15] and red tourism culture[16-17], with the index rising from 0.58 and 0.61 to 0.83 and 0.79, respectively. This progress brought both regions to high and relatively high levels of development, forming a peak within the Chishui River Basin. The downstream city of Luzhou benefits from a trillion-yuan liquor industry chain and advantageous river transportation along the Yangtze River and Chishui River. However, due to an initially single-industry structure and ecological constraints, its index stood at 0.43, reflecting a "tail-end downward trend." In recent years, through industrial chain extension, the establishment of modern agricultural demonstration parks, and fiscal resource reallocation, the index has risen to 0.67, reaching a higher development level and completing the "tail-end lifting" process.

4.3 Coupling and Coordination Analysis of Land Ecological Security and Rural Revitalization in the Chishui River Basin

When constructing the coupling and coordination model for land ecological security and rural revitalization, based on formula(5) -(7), the coupling degree and coordination degree of the two systems were analyzed from the temporal dimension. The coupling degree C, comprehensive coordination index T and coupling coordination degree D for each region in each year were calculated (Figure 4).



	C2012	C2017	C2022	T2012	T2017	T2022	D2012	D2017	D2022
Zhaotong	0.989	0.988	0.994	0.249	0.358	0.456	0.496	0.595	0.674
Bijie	0.949	0.911	0.907	0.513	0.583	0.697	0.697	0.728	0.795
Zunyi	0.980	0.918	0.932	0.585	0.655	0.711	0.757	0.775	0.814
Luzhou	0.954	0.933	0.922	0.485	0.614	0.772	0.680	0.757	0.843
Study Area	0.968	0.937	0.939	0.458	0.552	0.659	0.658	0.714	0.782

Figure 4 Each region CTD index

4.3.1 Coupling Coordination Time Analysis

From the perspective of the time dimension, the coupling and coordination relationship between land ecological security and rural revitalization in the Chishui River Basin from 2012 to 2022 generally exhibited the characteristics of "high coupling, slow coordination, and significant regional disparities". Firstly, the coupling degree C remained stable at approximately 0.9, indicating a strong and stable interaction between the land ecological security system and the rural revitalization system, with a high level of interdependence. There was no significant decoupling over the ten-year period, suggesting that the two systems were consistently operating in a state of "high-level integration". However, the interannual variations in the comprehensive coordination index T and the coupling coordination degree

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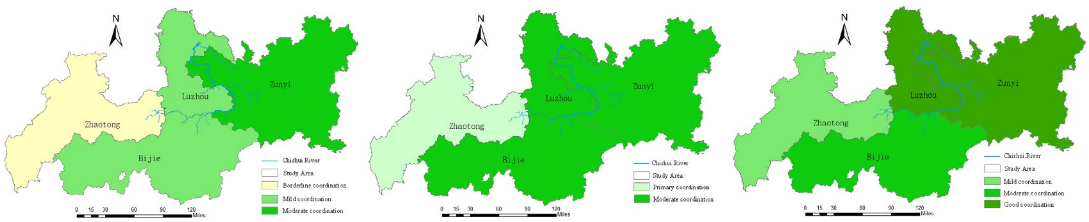
D displayed an overall increasing trend accompanied by regional differentiation. For instance, although the T value in Zhaotong City continued to rise, it remained below the regional average for a prolonged period, reflecting insufficient synergy among resource utilization efficiency, ecological protection investment, and rural revitalization policies. In contrast, Zunyi and Luzhou cities, which have stronger economic foundations and governance capabilities, maintained T values above 0.7, exhibiting a "first increasing and then stabilizing" pattern. The D value across the entire basin increased from 0.658 to 0.782, representing an average annual growth of less than 1.9 percentage points. The overall progress was relatively slow, and the system had not yet transitioned from "moderate coordination" to "good coordination". Zhaotong City started from the lowest baseline, with a coupling coordination degree of 0.496 in 2012. However, over the past decade, it experienced an average annual increase of approximately 1.8 percentage points, reaching 0.674 in 2022. This marks a substantial improvement, transitioning from "edge coordination" to "moderate coordination," representing the most notable progress among all regions. Nevertheless, its absolute level remains the lowest, making it the primary constraint on the overall development of the river basin. Bijie, Zunyi, and Luzhou had higher initial coupling coordination degrees, ranging from 0.68 to 0.76 in 2012. Among them, Zunyi and Luzhou achieved average annual growth rates of 1.6 and 1.7 percentage points, respectively, surpassing 0.8 by 2022 and entering the stage of "good coordination." In contrast, Bijie exhibited the slowest growth, with an increase of only 0.8 percentage points over the past ten years, maintaining the status of "moderate coordination." Overall, the pattern of "strong coupling but weak coordination" across the river basin has not been fundamentally altered. Therefore, future efforts should focus on enhancing ecological compensation mechanisms, optimizing industrial structures, and promoting institutional innovation to accelerate the realization of high-level coordinated development throughout the entire river basin.

4.3.2 Coupling Coordination Spatial Analysis

From the spatial dimension perspective, the coupling and coordination degree between land ecological security and rural revitalization in the Chishui River Basin exhibits a gradient differentiation pattern characterized by "downstream areas leading, middle reaches following closely, and upstream areas gradually catching up". This spatial pattern has remained relatively stable from 2012 to 2022, with only minor internal hierarchical adjustments. According to the ArcGIS spatial analysis results (Figure 5), the coupling and coordination hotspots are predominantly concentrated in the downstream areas of Luzhou, whereas the upstream regions of Zhaotong have consistently maintained low levels over time.



(a) 2012 *(b) 2017* *(c) 2022*

Figure 5 Spatial Differentiation of Coupled Coordination between Land Ecological Security and Rural Revitalization

Specifically, Zhaotong City, as the headwater region of the Chishui River, remained in a state of "low coordination" across its entire territory in 2012. By 2022, only a portion had advanced to "moderate coordination," while the overall level remained at the lowest tier within the river basin. The primary constraints included the extensive presence of high-altitude steep-slope farmland, high ecological fragility, and the limited diversity of rural industries. In the transitional zone between the upper and middle reaches, Bijie achieved "moderate coordination" in 2012 and maintained this level by 2022, with only minimal improvement. Spatially, it exhibited a pattern of "localized hotspots with generally low coordination," indicating that ecological conservation and rural revitalization policies have yielded uneven outcomes at the county level. This highlights the need for stronger cross-regional ecological compensation mechanisms and industrial collaboration. In the middle reaches, Zunyi City reached "moderate coordination" in 2012 and progressed to "good coordination" by 2022, becoming the only prefecture-level city in the basin to achieve a comprehensive improvement. The high-coordination areas are concentrated along the main stem of the Chishui River, benefiting from the synergistic development of the wine-tourism integration industry and ecological restoration projects. In the downstream region, Luzhou City, leveraging its geographical advantages, financial resources, and

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technological capabilities, already exhibited an initial state of "good coordination" in 2012, with over 70% of its areas reaching "good coordination" by 2022. Form an integrated protection and development pattern of "city - river - mountain".

5. Conclusion and Discussion

5.1 Conclusion

Ecological security serves not only as a green pathway for rural revitalization but also as its foundational basis. To achieve high-quality ecological and green development, it is essential to promote the coordinated advancement of both aspects, thereby providing a solid foundation and sustained momentum for ecological civilization construction. This study investigates the spatiotemporal evolution of the coupling and coordination between land ecological security and rural revitalization in the Chishui River Basin from 2012 to 2022. The findings aim to foster ecological-economic harmony within the region and support the sustainable development of the river basin.

(1) Natural conditions and human activities jointly drive the temporal and spatial variations in ecological security. From 2012 to 2022, the land ecological security index in the Chishui River Basin exhibited a phased evolution: transitioning from "low-level stagnation" to "local breakthrough" and finally to "overall improvement". Over this decade, the region progressed from a state of "relatively unsafe" to one approaching "ideal safety". The topography within the basin drops sharply from the Yunnan-Guizhou Plateau to the Sichuan Basin. Karst rocky desertification-prone areas, evergreen broad-leaved forest zones, and river valley alluvial plains are interwoven, forming a distinct natural ecological gradient. Furthermore, human activities such as steep slope cultivation, mining, soil and water conservation initiatives, and cross-provincial ecological compensation policies were implemented in successive stages. These interventions simultaneously enhanced the "pressure-state-response" tri-dimensional indicators over time and reinforced the spatial gradient pattern of "fragile upstream — transitional midstream — excellent downstream".

(2) Driven by diversification, remarkable achievements have been made in rural revitalization. From 2012 to 2022, the comprehensive rural revitalization index in the region advanced through three stages: from "foundation consolidation" to "growth" and finally to "establishment." In the upstream area of Zhaotong, green industrial clusters—such as plateau-grown apples and turmeric, combined with digital rural development—enabled a "recovery from a low point." In the middle reaches, Bijie and Zunyi leveraged the "three transformations" reform and the dual impetus of red tourism and cultural development, pushing the index above 0.8 and forming a regional peak. In the downstream area of Luzhou, the extension of the liquor industry chain, the construction of modern agricultural parks, and the decentralization of fiscal resources contributed to the "elevation of the lagging end." The five dimensions—agricultural industry prosperity, ecological livability, village cultural advancement, effective governance, and affluent living—coordinately advanced. These efforts not only directly elevated the level of rural revitalization but also enhanced land ecological security through industrial greening, infrastructure upgrading, and governance innovation, thereby establishing a positive feedback loop of mutual promotion between "revitalization and security."

(3) The level of temporal coupling and coordination has shown a consistent upward trend, although significant spatial disparities persist. From the perspective of the entire Chishui River Basin, there is a clear temporal pattern characterized by "high coupling, moderate coordination, and an overall improving trajectory." Spatially, the gradient pattern of "downstream leadership—middle reaches following—upstream lagging behind" has remained largely unchanged over the past decade. The upstream region, constrained by high elevation, steep terrain, and an economically narrow industrial base, has not yet achieved a high level of coupling and coordination. In contrast, the middle reaches have made notable progress through the synergistic development of wine tourism and ecological restoration. The downstream region maintains the highest level of coupling and coordination, supported by a more developed economy and comprehensive ecological protection strategies. These spatial disparities stem from the overlapping gradients of economic development, ecological sensitivity, policy implementation, and resource allocation, which collectively hinder the basin from advancing to a stage of high-level synergy. To address this, future efforts should focus on cross-regional collaborative mechanisms, including downstream support, middle-reach coordination, and upstream innovation, to promote an integrated and balanced development across the basin.

5.2 Discussion

(1) This study has restructured the indicator system for assessing land ecological security and rural revitalization. While research on land ecological security has reached a relatively mature stage, comprehensive evaluation studies on rural revitalization remain in their early exploratory phase. Rural revitalization is a complex system encompassing multiple key elements such as population, land, and industries. Consequently, its evaluation indicator system has not yet been fully standardized or perfected. Therefore, future research should prioritize the development of a more scientific, systematic, comprehensive, and practically applicable indicator framework to enhance the operational feasibility and policy relevance of such studies.

(2) The coupled and coordinated development of land ecological security and rural revitalization in the Chishui River Basin is influenced by a variety of factors, such as natural environmental conditions, regional levels of economic development, and the intensity of policy implementation. Future research should further examine the interactions among these factors and their combined impacts on coupled and coordinated development, as well as explore strategies to optimize these factors through integrated approaches, thereby promoting more balanced and sustainable regional development.

(3) From the perspective of data acquisition, this paper selected data at the prefectural-level city scale for analysis. Future research will collect refined data at the county and township levels through field investigations, questionnaire surveys, and interviews. This approach would facilitate a deeper understanding of the spatial disparities, temporal evolution patterns, and underlying driving mechanisms of the coupling and coordination between land ecological security and rural revitalization. The studies will offer both theoretical support and practical insights for local governments in implementing relevant policies, thereby demonstrating considerable theoretical and practical significance.

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