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Coupling Coordination Relationship and Spatiotemporal Heterogeneity between Functional Diversification and Settlement Evolution in Traditional Mountain Areas (2000–2020): A Case Study of Fengjie County, China

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Abstract: Since the socio-economic reform in 1978, rural China has undergone drastic spatial restructuring, and the trend of multifunctional development and dynamic evolution of settlements in the countryside have become increasingly obvious. Functions and settlements are the important parts of rural areas. Rural multifunction is a new perspective to explore the diversified development paths of the countryside, and rural settlements provide basic support for rural multifunction. Clarifying the complex coupling coordination relationship between rural functional diversification (RFD) and rural settlement evolution (RSE), and identifying the spatial heterogeneity of their interactions is the key to promoting the rural revitalization strategy. This study analyzes the spatiotemporal changes in rural functions and rural settlements at the township level, alongside assessing various forms and the extent of coupled development. Therein, we consider the advantages of different coupling types of townships and propose four development paths for rural settlements to improve the adaptability of rural functions and settlements. The results show that: (1) The functions and settlements in the study area are characterized by significant spatial and temporal dynamics, indicating that the traditional mountainous countryside is in a process of rapid development and change. (2) The coupling coordination degree of RFD and RSE increases yearly, generally transitioning from the moderate imbalance to the basic coordination stage, and the coordinated townships have obvious spatial agglomeration. (3) Based on the elasticity coefficient model, this paper summarizes four coupling models of RFD and RSE to guide the optimization of rural settlement development paths. This research provides scientific guidance for developing countries in the spatial planning of rural territories and the optimization of rural settlements.

Keywords: rural multifunction; settlement evolution; coupling relationship; spatiotemporal difference

Citation: Zhao, W.; Li, Y.; Wang, Q.; Shao, J. Coupling Coordination Relationship and Spatiotemporal Heterogeneity between Functional Diversification and Settlement Evolution in Traditional Mountain Areas (2000–2020): A Case Study of Fengjie County, China. *Land* **2024**, *13*, 1090. https://doi.org/10.3390/land13071090

Academic Editors: María L. Gómez-Moreno and Carmen Delgado-Viñas

Received: 2 July 2024
Revised: 16 July 2024
Accepted: 16 July 2024
Published: 19 July 2024

1. Introduction

With the development of industrialization and urbanization, the global economy is growing rapidly, but it is also causing the decline of the rural system and the increasingly severe "rural disease". Rural depopulation, waste of land resources, and inadequate development occur frequently.Especially since the 21st century, this issue has received increasing attention and many countries have begun to implement multiple strategies to revitalize the countryside [1]. Since the Second World War, European countries have begun to adopt multifunctional agriculture [2] and multifunctional village approaches [3] as rural development paradigms. The differentiated countryside has become a major feature of rural spatial change [4]. In central Europe, some marginal and problem villages (including declining villages) are showing signs of socio-economic revitalization in the form of changes in village function types [5]. In Spain, the mobility of labor and capital has accelerated the transformation of the rural industrial structure, leading to the development of non-farm functions [6].

In China, since the reform and opening up of China in 1978, the economic development of China has made worldwide remarkable achievements. For example, the urbanization rate has increased from 17% to 60%, and the average annual growth rate of industrial value added has reached 14.6%. With the emergence of the "Chinese Miracle", this traditional agricultural country has transformed from a native-rural society to an urban-rural society [7]. In the context of this transformation, their dominant advantageous functions are also quite different, which makes China's rural development present diversified and regionalized characteristics [8]. Therefore, more and more Chinese scholars have begun to pay attention to the development of multifunction in rural areas that have achieved fruitful results in elucidating the theory [9], classification [3,5], evolution process [10], and influence mechanism [11,12] of rural multifunction. Most of the research regions focus on the plains and other regions with a high urbanization level, such as the Yangtze River Delta [13,14] and Pearl River Delta [15] in China, the central plains of Europe [16,17], while less attention has been paid to mountainous areas with relatively backward socio-economic development. From the perspective of traditional development, mountainous areas have large undulations and fragmented landforms, resulting in their socio-economic development lagging behind plains areas [18]. However, the mountainous countryside's characteristic resources and ecological environment are generally better than that of the plain area [19]. With the support of the government for the development of mountainous areas, the use of superior resources to develop specialty industries has become an important method for rural revitalization [20,21]. At the micro level, many townships have gradually differentiated, with dramatic changes in the spatial organization, shape, and landscape of the settlements.

In the process of rapid industrialization and urbanization, the rural settlements in China are undergoing rapid differentiation and reorganization. The vast majority of rural settlements in Western China are located in ecologically sensitive mountain environments, and policy interventions in these areas have driven rapid changes in rural settlements over the decades [22]. Existing studies have revealed the spatiotemporal characteristics and dynamic mechanism of rural settlements in different geomorphic areas, and have found that the structural and functional evolution of rural residential land in mountain regions shows a typical pattern of "single composite differentiation-diversification", which is closely related to economic and social transformations and changes of farmers' livelihood strategies [23]. Rural settlements are the core spatial carrier of various socio-economic elements and activities within rural areas, also the material space carries the multiple functions of rural areas [24]. Changes in their size, composition, and structure reflect the multifunctional development characteristics of the rural land system [25]. Rural settlement distribution has the strongest correlation with agricultural production function, followed by industrial manufacturing and service supply functions, and the weakest correlation with ecological leisure function [4]. Those involved in the restructuring of rural settlements should pay special attention to multifunctional development and its formation mechanism so that they can accommodate a larger population and better adapt to future industrial development.

However, most existing research separates rural functions from settlement evolution, neglecting the relationship between the realization of multiple values and the evolution of rural settlements [26]. A theoretical framework for the coupling of RFD and RSE has not been established, and the corresponding case validation is lacking, unable to reveal the coupling response models for the coupling evolution of rural functions and settlements. Moreover, most of the current research scales on rural development are based on county-level units, but there are large geographic differences in rural areas within counties, so it is difficult to scientifically grasp regional differences when research is conducted at the spatial scale of counties [4]. Therefore, it is urgent to construct a theoretical model and methods for the coupling relationship between RFD and RSE at a small scale (township scale) and conduct case validation to explore how to guide the optimization of rural settlements according to local conditions.

Three Gorges Reservoir Area (TGRA) is a typical ecological fragile area integrating rural, mountainous, and migrant conditions [20]. With the development of industrialization and urbanization, as well as the implementation of the ecological migration policy, the rural functions and settlements in the reservoir area have undergone great changes. On the one hand, the reservoir area's socio-economic level and ecological environment have significantly improved with the regional function evolving from a single agricultural production system to a multi-functional rural system [27]. On the other hand, the settlement pattern has also evolved with the socio-economic development of the region [28]. Based on this, we raise the question: in TGRA, does the socio-economic development represented by RFD have an impact on the evolution of the size, shape, density, and agglomeration of rural settlements? Similarly, can the evolution degree of rural settlements reflect the level and direction of regional diversification of rural functions? Can the coupling relationship and spatiotemporal heterogeneity between RFD and RSE reveal the transformation of human–land relations in traditional countryside in TGRA? We think these questions deserve to be explored in depth.

To answer the above questions scientifically, based on the vital role of land use in reflecting the multifunctional development of rural areas, this paper constructs a theoretical framework for understanding the interaction between RFD and RSE in mountainous areas and conducts a quantitative analysis with 32 townships in Fengjie County, TGRA. This paper aims to address three pressing questions: (1) Explain the potential relationship between RFD and RSE, and construct a theoretical framework. (2) To analyze the spatial-temporal evolutionary characteristics of rural functions and settlements. (3) Explore the coupling response models of RFD and RSE, reveal the coupling paths, and put forward pertinent suggestions. The results of this study can provide scientific guidance for the development of rural functions and the optimization of settlement spatial layout in other similar mountainous townships across the globe.

2. Theoretical Framework

2.1. Rural Multifunctional Evolution

Rural functions are the ability of rural elements to provide various products and services to both urban and rural residents [29]. The understanding and utilization of rural multifunction have gone through a process from simple to complex. Rural multifunction originated from the theory of multifunctional agriculture. Initially, scholars believed that the agricultural function was the rural function, and the identification of rural function was single and only [30]. With the acceleration of industrialization and urbanization, the countryside has entered a new stage of development, and the relationship between urban and rural areas has changed dramatically [31]. The rural areas have not only become an ideal place to ease the accumulation of urban capital, but also the strongest factor in attracting urban residents to spend their leisure time [32], and the vitality of the rural areas has been stimulated. The diversified demands of urban and rural residents for rural production, consumption, and ecology are continuously driving the evolution of rural functions [33]. The single function of agricultural production is constantly being surpassed, industrial production, leisure tourism, and other functions are gradually becoming an indispensable part of rural functions, and the diversified features of rural functions are continuously increasing [34].

2.2. A Theoretical Framework for the Coupling Relationship between RFD and RSE

The rural area is a complex system composed of natural, ecological, social, and economic subsystems, in which the coordinated development of society, economy, ecology, and population is the basis for enhancing the vitality of rural development and promoting sustainable development [35]. Some studies have represented social-ecological systems in terms of population, economy, and environment to reflect the evolution of regional social-ecological system relationships [36]. There are also studies to reveal the rural population-land-industry coupling relationship through settlements, sloping farmland, and orchards [37]. This paper selects rural functions and settlements as objects to analyze the coupling relationship of rural society–economy–ecology–population based on the following: rural functions mainly focus on the functions and effects of the economy, society, culture, and ecology in rural areas, which are the centralized embodiment of socio-economic and ecological protection [38]. The settlements are the main space of production and living for the rural population, which can reflect the evolutionary characteristics of the rural population. Relationships between rural functions and rural settlements may be synergistic or trade-offs, resulting in townships showing different degrees of vigor or decline. On the one hand, RFD has a conductive effect on RSE. On the other hand, RSE has a feedback effect on the development of rural functions [39]. Therefore, we propose a coupling theoretical framework between RFD and RSE on the basis of social-ecological system transformation [40], rural land use transformation [41], and multifunctional development of the countryside [42] (Figure 1).

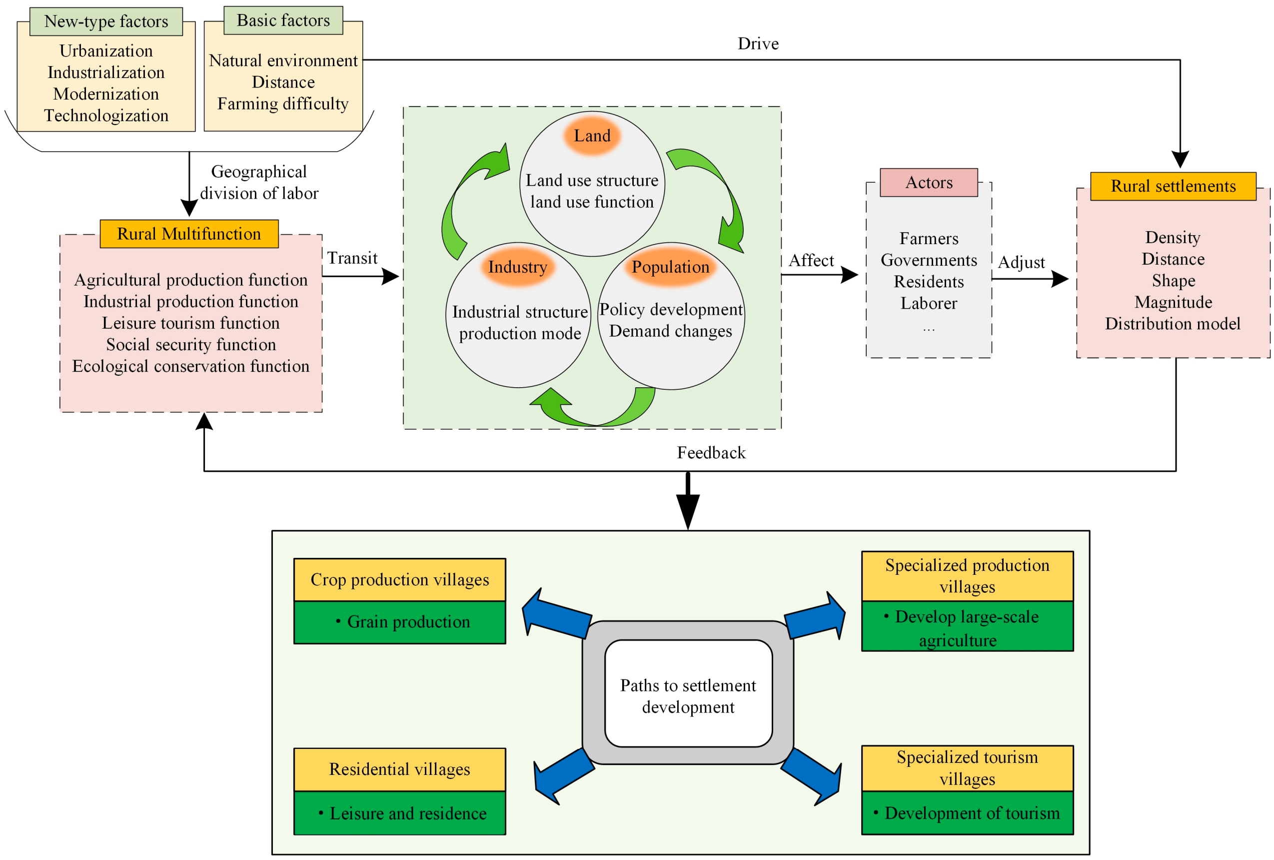

Figure 1. Analysis framework for the coupling relationship between RFD and RSE.

In the traditional agricultural period, the main demand of farmers was agricultural production to satisfy food and clothing; thus, residents' demand for rural settlements at this time was mainly to meet production needs. Influenced by the terrain, most cultivated land in mountainous areas was fragmented and dispersed [43]. The non-concentration of cultivated land resources and the finiteness of agricultural work radius determined the dispersive distribution of rural settlements [44]. At this time, the mountain settlements were mainly distributed around the cultivated land to facilitate production and improve labor efficiency. The settlement structure was scattered and small in size.

In the modern transition period, the rural areas' original single agricultural production model was changed, industrial production developed along with the rise of industrialization, and the overall regional economic level was significantly raised [45]. The living standards of rural residents have improved, and their demand for rural settlements has changed from the original demand for production to the demand for living and development. The type and structure of rural land use have changed, especially in the mountainous areas, where some farmers have taken advantage of their geographic location to build agritainment and develop eco-tourism. Functions such as recreation and health services have emerged in the countryside. Meanwhile, the dependence of rural settlements on cultivated land resources in mountainous areas declined, and the distribution of rural settlements was gradually attracted by transportation and public service facilities [46]. The rural settlements in high-elevation areas gradually shifted to the plains, which provided convenient transportation and living conditions. Sloping cultivated land farther away from the settlement tended to be abandoned and transformed into woodland or grassland, and the ecological function of the rural area was strengthened. Currently, the land use, spatial pattern, and functional structure of mountainous areas in China are in the stage of post-production transformation and diversified development, it is urgent to use the theory of rural multifunction to guide the layout optimization of rural settlements [47].

With the diversified development of rural functions, the urban-rural mobility of resources, population, and economy has led to the continuous evolution and development of rural settlements. In addition to agricultural cultivation, the countryside has a variety of natural resources and beautiful natural spaces that towns do not have. Therefore, the development paths of rural settlements under the background of RFD can be roughly categorized into four ways: firstly, food production villages which mainly engage in traditional food production. The second is the specialized production villages that concentrate on large-scale agriculture and agricultural product processing. Third, specialized tourism villages mainly utilize the natural scenery to develop tourism. Fourthly, residential villages, where public facilities are well established closer to towns can form large-scale new countryside.

The coupling research object and theoretical framework of this paper is a further deepening of previous related research, which has strong theoretical significance.

3. Data and Methods

3.1. Study Area

Fengjie County is situated in the hinterland of the TGRA core zone (109°1′17″ E~109° 45′58″ E, 30°29′19″ N~31°22′33″ N), covering an area of 4087 km^2 (Figure 2). The landform type is mainly mountains and hills, and the area with a slope above 6° accounts for 90.33% [48]. According to the Seventh National Census Bulletin results, by the end of 2020, Fengjie County had a total resident population of 744,800, of which 50.48% lived in rural areas. In recent years, the rural economy of Fengjie County has developed rapidly and gradually forms an economic model mainly based on agricultural cultivation, industrial production, and tourism services, and the rural functions tend to be diversified. Meanwhile, after the construction of the Three Gorges Project, with the implementation of the immigration project and the acceleration of the urbanization process, the urbanization rate of Fengjie County has increased from 13.5% in 2000 to 49.53% in 2020, and the settlements in the region have changed significantly. Therefore, this paper chooses Fengjie County as the study area, which will help reveal the general law of the coupling response between RFD and RSE in TGRA.

3.2. Data Sources and Processing

The rural areas referred to in this paper are primarily all territories outside the cities, strictly speaking beyond the built-up areas of the cities [49]. This study used Google Earth's high-definition remote sensing image as the data source, and the spatial resolution in 2000, 2010, and 2020 is 5 m. ArcGIS 10.2 software was used to transform the projection and geometric correction for multisource remote sensing images in the study area. Based on the standard of "Land Use Status Classification" (GB/T21010-2017) [50] in China, the land use vector data of Fengjie County in three stages were obtained by using human-computer interaction interpretation. The land use types were divided into 12 types. To verify the accuracy of land use classification, the team took 10 villages in Fengjie County, including Longguan Village, Tianping Village, and Shima Village, as sampling points in May 2021, and randomly selected samples of the interpretation results for field verification. The accuracy of land use type interpretation reached more than 90%. The road network data came from the 1:250,000 basic geographic database of the National Center for Basic Geographic Information (NCBGI) (http://www.ngcc.cn/ngcc/ (accessed on 18 July 2024)). Socio-economic data such as food production, population data, and insurance participation rate were obtained from the Fengjie Yearbook from 2000 to 2020. Tourism-related data were partly from the Fengjie Yearbook and the Fengjie WeChat official accounts. Missing data were obtained using methods such as substitution of similar years, proportion of relevant indicators, and mean value method.

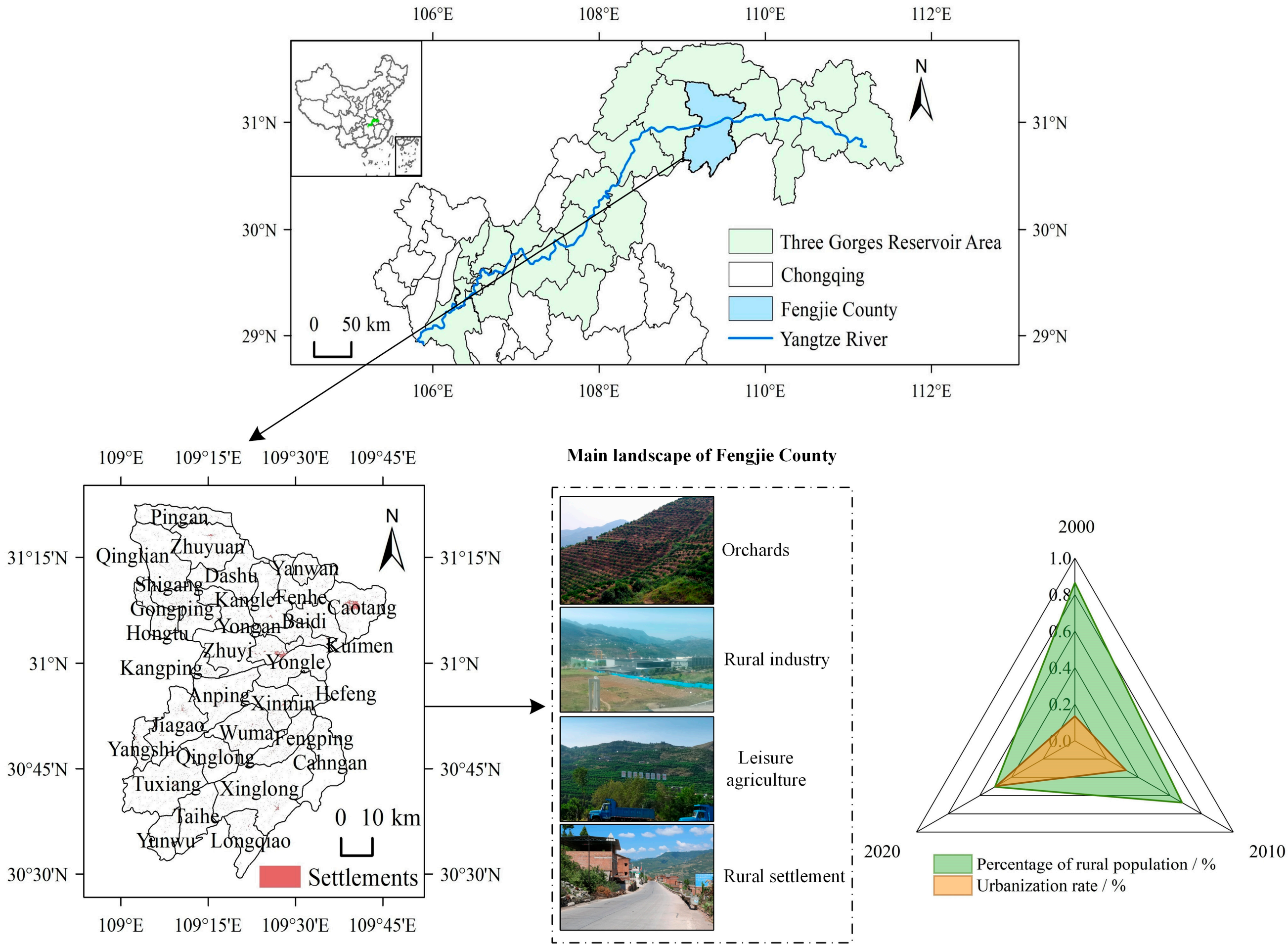

Figure 2. Location map of the study area.

3.3. Research Methods

3.3.1. Construction of the Evaluation System

(1) RFD evaluation system

Combining the actual development of Fengjie County and data availability, based on the production function, living function, and ecological function, 21 indicators were selected from five dimensions: agricultural production function (APF), industrial production function (IPF), leisure tourism function (LTF), social security function (SSF), and ecological conservation function (ECF) (Table 1).

APF. Based on the reality of Fengjie County's agricultural production ranking, this paper selected three indicators to reflect the output capacity of cultivated land: per capita grain production, economic fruit forest production, and rural livestock production value [51]. Meanwhile, most of the agricultural production needs to be carried out on cultivated land, so the per capita cultivated land area is selected to reflect the cultivated land ownership rate of farmers [45].

IPF. This paper selected four indicators to characterize: the number of industrial enterprises, industrial output value, per capita industrial and mining land area, and the number of industrial employees. The number of industrial enterprises can measure the number and scale of rural industries. Industrial output value expresses the output of rural industry in monetary form. The per capita industrial and mining land area and the number of industrial employees represent the participation degree of rural residents in industrial production.

LTF. We selected four indicators to characterize the LTF: the number of farmhouses, the number of major scenic spots, the number of annual visits, and the proportion of public facilities. Among them, the number of farmhouses, the number of annual visits, and the proportion of public facilities reflect the service capacity of the countryside [52]. Scenic spots are the basis for the development of tourism, and the higher the number of scenic spots, the better the development prospects of the LTF.

SSF. Employment is the basis for the existence of social security, and the rural employment rate was chosen to represent employability. Residents' living standards can largely reflect the perfection of regional social security, therefore, we selected per capita disposable income, social insurance participation rate, per capita food security rate, and road network density to measure the living standard of rural residents [53].

ECF. Compared with urban areas, rural areas are less developed and can maintain ecosystem stability, soil conservation, and vegetation preservation [54]. Therefore, this paper selected four indicators to characterize the ECF of rural areas: soil conservation capacity, average ecosystem service value, forest cover, and biological abundance index.

Table 1. Rural function evaluation index system.

Functional Layer		Specific Indicators	Unit	Average Weights
Production function	APF	Per capita cultivated land area	hm^2/person	0.016
		Per capita grain production	kg/person	0.020
		Rural livestock production value	yuan	0.069
		Economic fruit forest production	kg/person	0.026
	IPF	Number of industrial enterprises	n	0.051
		Industrial output value	yuan	0.051
		Per capita industrial and mining land area	hm^2/person	0.016
		Number of industrial employees	person	0.051
Living function	LTF	Number of farmhouses	n	0.076
		Number of major scenic spots	n	0.044
		Number of annual visits	person	0.076
		Proportion of public facilities	%	0.158
	SSF	Per capita disposable income	yuan	0.029
		Per capita food security rate	%	0.016
		Social insurance participation rate	%	0.016
		Rural employment rate	%	0.013
		Road network density	km/km^2	0.106
Ecological function	ECF	Soil conservation capacity	$t/(hm^2 \cdot a)$	0.024
		Average ecosystem service value	yuan	0.013
		Forest cover	%	0.116
		Biological abundance index	—	0.013

Note: Calculation methods for soil conservation capacity, average ecosystem service value, and biological abundance index are described in references [55–57], respectively.

(2) RSE evaluation system

The changes in the spatial pattern of rural settlements can reflect the specific characteristics of regional settlement evolution. The landscape pattern index is highly condensed landscape information, a quantitative indicator reflecting landscape structure composition and spatial pattern characteristics, and can better quantify the evolution characteristics of settlements [58]. Therefore, we selected four landscape pattern indexes from four dimensions: area, shape, density, and aggregation to quantitatively analyze the evolutionary characteristics of the settlement in each township. The specific evaluation system is shown below (Table 2).

Table 2. The evaluation system for RSE.

Level 1 Indicators	Level 2 Indicators	Calculation Method	Average Weight
Area	Mean patch size (MPS)	Calculated in Fragstats4.2	0.119
Shape	Landscape shape index (LSI)	Calculated in Fragstats4.2	0.146
Density	Patch density (PD)	Calculated in Fragstats4.2	0.184
Aggregation	Aggregation index (AI)	Calculated in Fragstats4.2	0.551

3.3.2. Comprehensive Evaluation Model

We utilize the comprehensive evaluation model to measure the level of RFD and the degree of RSE in Fengjie County and obtain the composite index of the two. The specific calculation formula is as follows.

$$u_1 = \sum_{i=1}^{m} a_i x_i \tag{1}$$

$$u_2 = \sum_{j=1}^{n} b_j y_j \tag{2}$$

where u_1 and u_2, respectively, represent the composite index of RFD and the composite index of RSE. The a_i and b_j represent the weights of the respective indicators for each subsystem, respectively. The x_i and y_j are the standardized values of each indicator.

3.3.3. Coupling Coordination Degree Model

We use the coupling coordination degree model to explore the coupling relationship between RFD and RSE. The specific calculation formula is as follows.

$$C = 2\sqrt{\frac{m_1 m_2}{(m_1 + m_2)^2}} \tag{3}$$

$$T = \alpha m_1 + \beta m_2 \tag{4}$$

$$D = \sqrt{C + T} \tag{5}$$

where m_1 and m_2 are the composite indices of RFD and RSE. C is the degree of coupling, and the value range is [0, 1], the higher the C value, the stronger the interaction between the RFD and RSE. T represents the index of coordination between the two elements. α and β are undetermined coefficients. Since this paper mainly studies the coupling coordination relationship between the two systems (variables), to ensure an equal relationship between the two systems in statistical measurement, based on the reference of existing studies [59], this study takes $\alpha = \beta = 0.5$. D represents the degree of coupling coordination, and a larger value of D indicates a stronger degree of coupling coordination between elements, $D \in [0, 1]$. We divided the coupling coordination degree of rural functional diversification and settlement evolution in Fengjie County into five intervals: $D \in [0, 0.2)$ as serious imbalance, $D \in [0.2, 0.4)$ as moderate imbalance, $D \in [0.4, 0.6)$ as basic coordination, $D \in [0.6, 0.8)$ as moderate coordination, $D \in [0.8, 1]$ as high coordination.

3.3.4. Spatial Autocorrelation Analysis

The degree of interdependence between attributes at a location and attributes at other locations can be measured by spatial autocorrelation. Global spatial autocorrelation was first utilized to explore the degree of spatial dependence of the coupling coordination between RFD and RSE. Next, local spatial autocorrelation analysis was used to test whether the coupling coordination between the two was characterized by local area agglomeration.

3.3.5. Elasticity Coefficient Model

We used the elasticity coefficient model to analyze the complex nonlinear relationship between RFD and RSE. The townships were divided into different coupling response models based on the relationship between the composite index of RFD and the composite index of RSE during the study period. The specific calculation formula is as follows.

$$W_i = \frac{\Delta E_i}{\Delta H_i} = \frac{(E_{it+1} - E_{it})}{(H_{it+1} - H_{it})} \quad (6)$$

where W_i is the elasticity coefficient for township i. ΔE_i and ΔH_i are the change in the composite index of RFD and the change in the composite index of RSE in township i, respectively. E_{it+1} and E_{it} are the composite indices of RFD at the end and beginning of the period in township i, respectively. H_{it+1} and H_{it} are the composite indexes of RSE at the end and beginning of the period in township i, respectively. Depending on whether W_i, ΔE_i, and ΔH_i are greater than 0, townships can be divided into four coupling response models. The specific division process is shown in Table 3.

Table 3. Coupling model division between RFD and RSE.

Coupling Relationship between RFD and RSE	ΔEi	ΔHi	Coupling Response Models
Synergistic relationships	>0	>0	Vibrant model
	<0	<0	Recessionary model
Trade-off relationships	>0	<0	Transitional model
	<0	>0	Traditional model

3.3.6. Geographic Detector

The natural and human geographic elements within the study area differ greatly, and the factors affecting the rural regional multifunction and the evolution of rural settlements have spatial heterogeneity. Therefore, we utilized the geodetector to quantitatively analyze the driving factors of the coupling change between RFD and RSE. According to the existing studies and the actual situation of the study area [60,61], we selected 12 influencing factors from natural environmental and socio-economic dimensions. K-mean clustering was used to discretize each factor value, and then geodetector was used to detect the selected factors. Specific indicators are shown in Table 4.

Table 4. Indicators of coupling factors of RFD and RSE.

Influence Factors	Variable
Natural factors	Average elevation (X1), average slope (X2), cropland area (X3), degree of topographic relief (X4), forest cover (X5)
Socio-economic factors	Distance to county government (X6), population density (X7), transportation convenience (X8), per capita GDP (X9), intensity of human activity (X10), land use degree (X11), rural employed population (X12)

Note: see references for calculation of the intensity of human activity [62] and the land use degree [63].

4. Results

4.1. Spatial and Temporal Changes in RFD

4.1.1. Spatial and Temporal Patterns of Different Rural Functions Change

In this paper, the magnitude (natural breakpoint method) of change in rural function values in the preceding and following periods was used to divide the townships (Figure 3). From 2000 to 2020, the townships with reduced APF were mainly located in the central river valleys in Fengjie County. The water and heat conditions in this area were good for the development of orchards, while agricultural activities such as food cultivation and animal husbandry were gradually reduced, resulting in a declining trend in the APF. The IPF of each township in the period of 2000–2010 mainly increased slightly, and the moderate and massive increased townships were concentrated in the central three streets and the surrounding area. During 2010–2020, the number of townships with moderate and massive increases increased significantly, and the industrial production capacity of Fengjie County was enhanced. The LTF in the 2000–2010 period mainly increased slightly and moderately, and the townships with larger increases were mainly distributed in the Baidi Scenic Area in the center and the Xinglong Scenic Area in the south. From 2010 to 2020, with the support of the Fengjie County government to the township leisure tourism industry, most of the townships were showing an increasing trend. The SSF and the ECF were the two most obvious functions of Fengjie County's development. This is closely related to the Fengjie County government's policy of emphasizing economic development and ecological construction in the past.

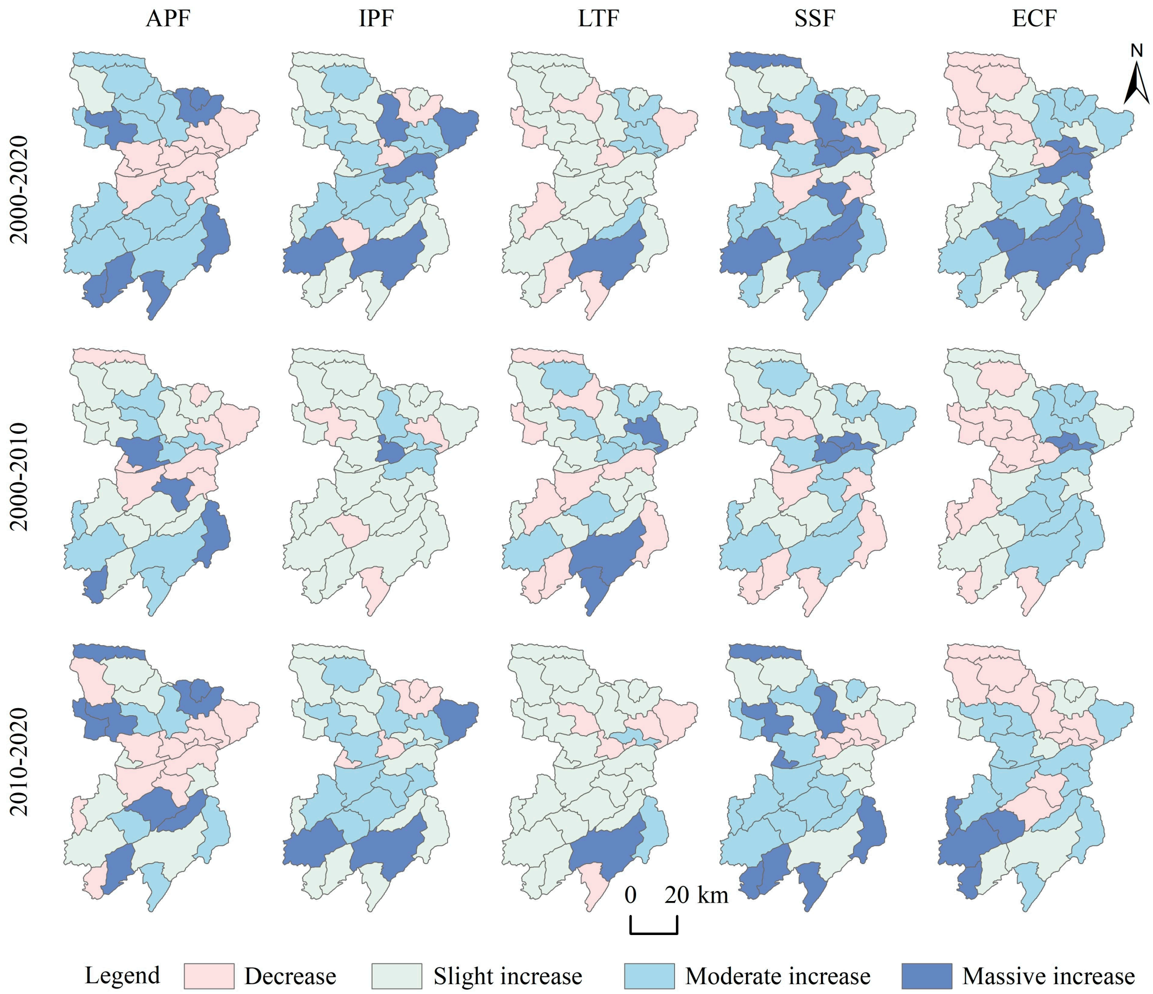

Figure 3. Characteristics of rural function change in Fengjie County townships.

4.1.2. Characteristics of Changes in the RFD

This paper utilized the composite index of rural functions in each township to measure the degree of RFD (Figure 4). In summary, the composite index of RFD increased in most of the townships from 2000 to 2020. The average composite index has risen from 0.222 in 2000 to 0.281 in 2020, and the level of functional diversification in the rural areas has enhanced, with comprehensive development of production, living, and ecological functions. Influenced by socio-economic development, the high-value townships were concentrated in the central and southern regions of Fengjie County, which were more developed.

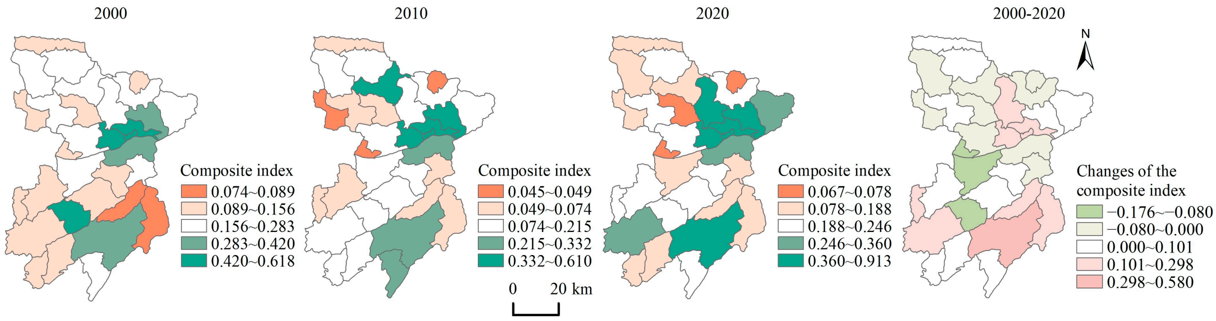

Figure 4. Spatial distribution of the composite index of rural functional diversity.

4.2. Spatial and Temporal Changes of Rural Settlements

4.2.1. Characteristics of Landscape Pattern Changes in Rural Settlements

The difference in landscape pattern index of rural settlements in the study area from 2000 to 2020 was obvious (Figure 5). The area of the PD index with high values has expanded. In 2000, the high-value areas were mainly located in the northern part of the county, while in 2010 and 2020, the high-value areas gradually expanded to the south. As a whole, the density of settlements in the study area increased. The LSI index decreased and the shape of the settlements tended to be simpler. The areas with high AI index values for settlements were expanded significantly, mainly in the northern and central parts of the study area which indicated the cluster of rural settlement patches regionally. Compared with 2000 and 2010, the MPS index increased significantly in 2020 and the size of settlements continued to expand, with the highest MPS regions mainly located in the urban areas along the Yangtze River.

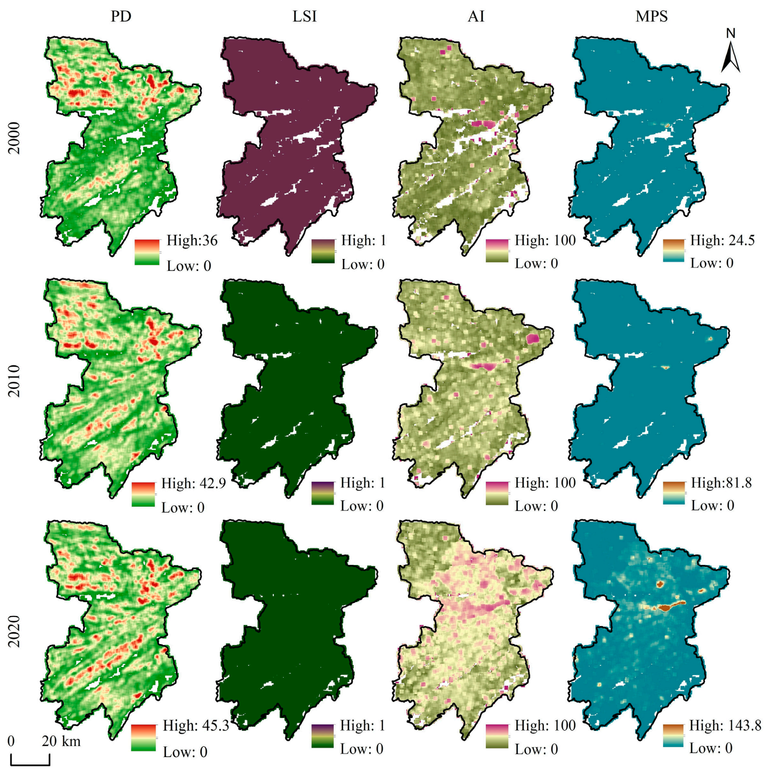

Figure 5. Spatiotemporal characteristics of settlement landscape index in Fengjie County.

4.2.2. Characteristics of Changes in the RSE

Based on the PD, LSI, AI, and MPS indices, a composite index of RSE was calculated for each township in Fengjie County (Figure 6). The dynamic evolution trend of rural settlements was obvious from 2000 to 2020, with the average composite index increasing from 0.184 in 2000 to 0.262 in 2020. It indicated that rural settlements' size, density, and degree of aggregation have changed significantly over time. Townships with high values of the composite index of RSE gradually spread from the central region to the south, and the townships with low values were mainly concentrated in the southern high-elevation areas due to the influence of topography.

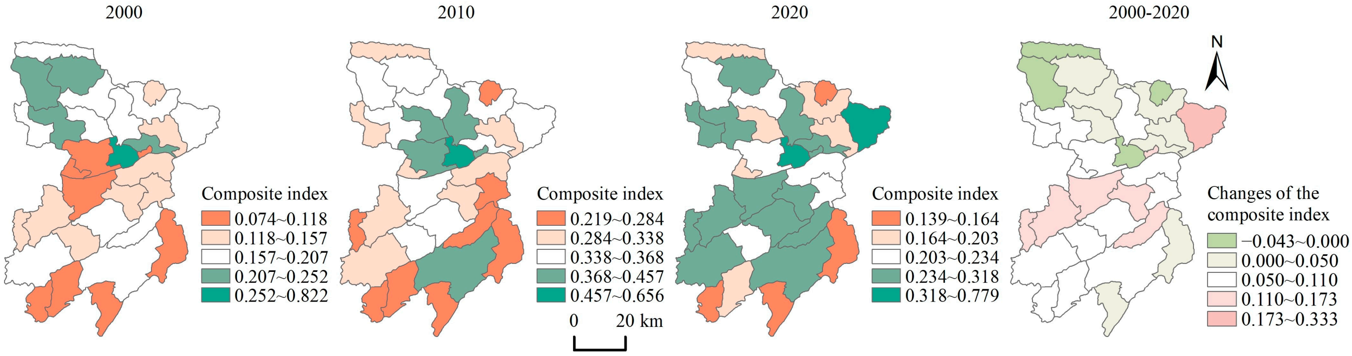

Figure 6. Spatial distribution of the composite index of RSE.

4.3. Evolutionary Characteristics of the Coupling Coordination Degree between RFD and RSE

4.3.1. Spatiotemporal Analysis of Coupling Coordination Degree

The coupling coordination degree showed an upward trend from 2000 to 2020 (Figure 7). In 2000, the coupling coordination degree between RFD and RSE was [0.145, 0.928]. Among them, 17 townships were in varying degrees of imbalance; most of them showed moderate imbalance, while the 15 townships in a coordinated situation were mostly in basic coordination. From 2010 to 2020, the coupling coordination degree increased significantly, with a value range of [0.179, 0.995] in 2010 and [0.124, 0.955] in 2020, and the number of townships at the imbalance level decreased gradually with the regional development.

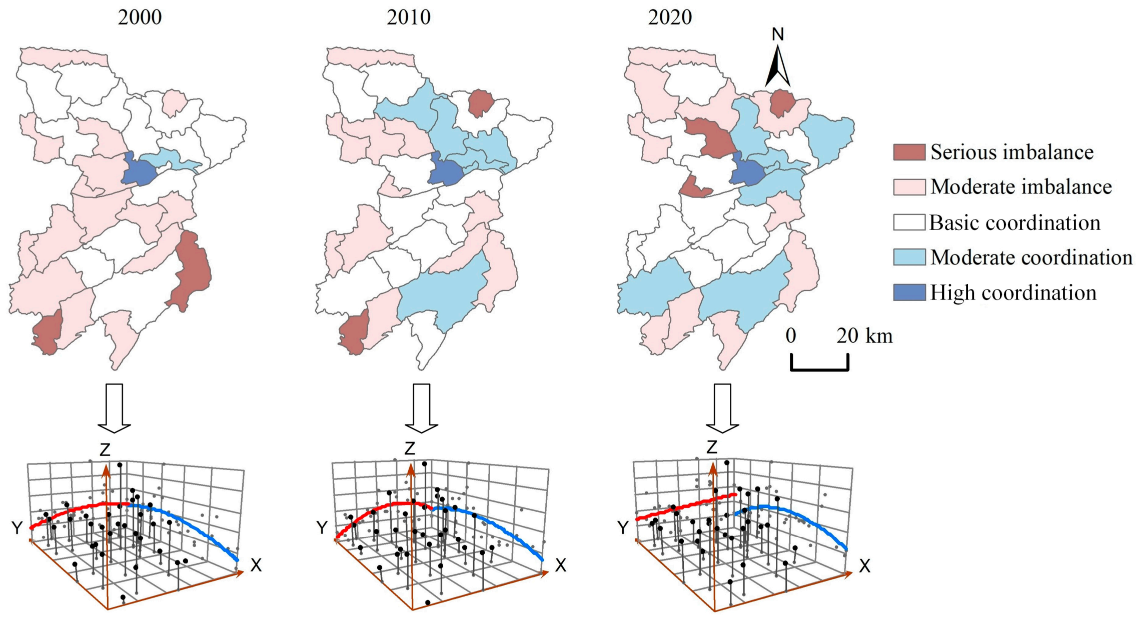

Figure 7. Spatial distribution of the coupling coordination degree between RFD and RSE.

Further, based on the trend surface fitting results, the spatial trend of the coupling coordination degree between RFD and RSE in Fengjie County from 2000 to 2020 was characterized. As can be seen from Figure 4, the spatial trend of the coupling coordination degree in the three years was similar, showing the feature of "low in the west and high in the east, low in the south and high in the north", but there were differences in the trend line increase in different directions. In 2000 and 2010, the east–west trend line was relatively steep, with the highest point occurring in the central region, while the north-south trend line was relatively flat. In 2020, the east–west trend line was relatively flat and the north-south trend line was relatively steep, with the highest point in the central region.

4.3.2. Spatial Clustering Characteristics of Coupling Coordination Degree

Moran's I for the three years in the study area were all greater than 0 (Table 5), indicating a positive correlation in the coupling coordination degree between RFD and RSE in each township and significant spatial clustering characteristics. In addition, the Moran's I did not differ much among the three vintages, indicating that this spatial feature remained relatively stable over a long period of time. As shown in Figure 8, the high-high clustering regions of the coupling coordination degree were mainly concentrated in the suburbs of the central towns, such as Yong'an Street, Yufu Street, and Kuimen Street. These regions have a solid economic foundation, convenient commuting conditions, and close urban-rural linkages, leading to obvious penetration of urban functions into rural areas. Meanwhile, good regional accessibility and socio-economic levels have brought a material foundation for rural settlement expansion. Therefore, the degree of diversification of rural functions and the evolution of rural settlements were more obvious than the rest of the townships in Fengjie County.

Table 5. Global Moran's *I* of the coupling coordination degree.

Year	Moran's I	*Z*-Value	*p*-Value
2000	0.57	4.53	<0.001
2010	0.59	4.57	<0.001
2020	0.46	3.57	<0.001

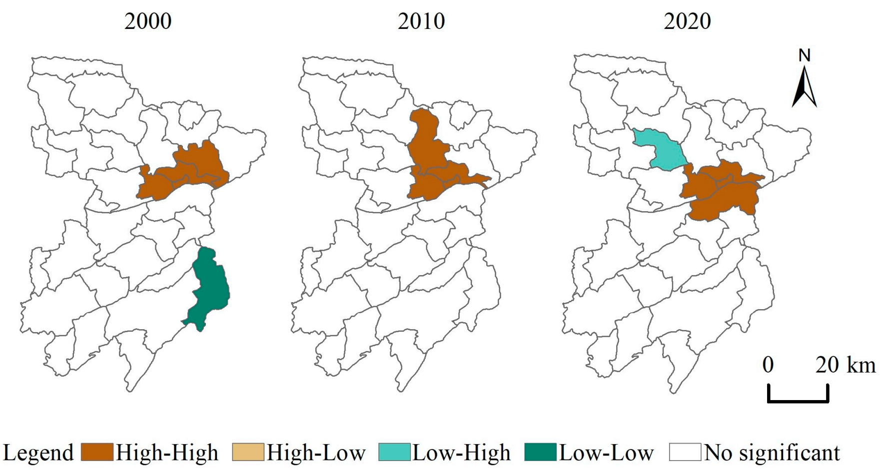

Figure 8. LISA cluster map of the coupling coordination degree between RFD and RSE.

4.4. Regional Differentiation in Coupling Response Models of RFD and RSE

According to the division criteria in Table 3, the coupling response models of RFD and RSE in Fengjie County were summarized (Figure 9). The synergistic development of both RFD and RSE is called the vibrant model. This model has the highest number, with townships accounting for 56.25% of the total, which is in line with the overall trend in rural villages at present. The composite index of RFD decreases while the composite index of RSE increases, which is called the traditional model. This model has the secondary number, with 31.25% of township units, mainly located in the central part of Fengjie County. The synergistic decrease of both RFD and RSE is called the recession model, which is small in number and is typified by Yanwan Township and Qinglian Township. The composite index of RFD increases while the composite index of RSE decreases, which is called the transitional model, typified by Ping'an Township.

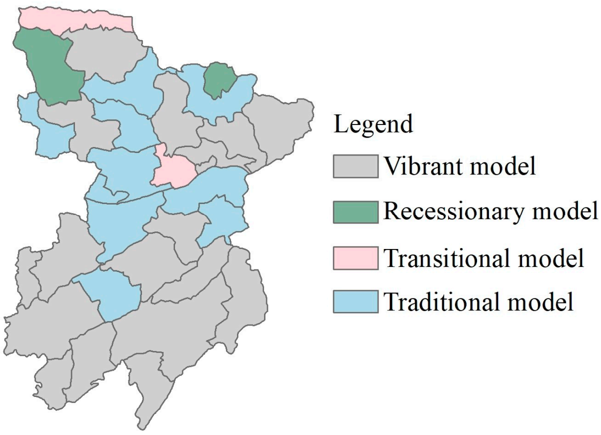

Figure 9. Distribution of the coupling response models of RFD and RSE.

4.5. Driving Factors of the Coupling Coordination Degree between RFD and RSE

4.5.1. Independent Influence of Each Factor

Factors such as population density, per capita GDP, and intensity of human activity had a higher influence on the coupling coordination degree in 2000 (Figure 10). In 2010, compared with 2000, per capita GDP and rural employed population had the greatest impact on coupling coordination degree, while the impact of the other factors decreased. In 2020, population density, intensity of human activity, and rural employed population had the greatest impact on it. In general, changes in the intensity of human activities in rural areas have contributed to the transition of regional land use. The original land use pattern has been disrupted, and industrial, facility, and settlement land are constantly enriched. Meanwhile, the increase in population density and employees in rural areas provides a sufficient labor force for developing rural industries, driving the diversified development of rural functions. The increase in per capita GDP enables farmers to improve their living conditions, and the number and size of settlements tend to increase, consistent with the research results of Tu Shuangshang [64].

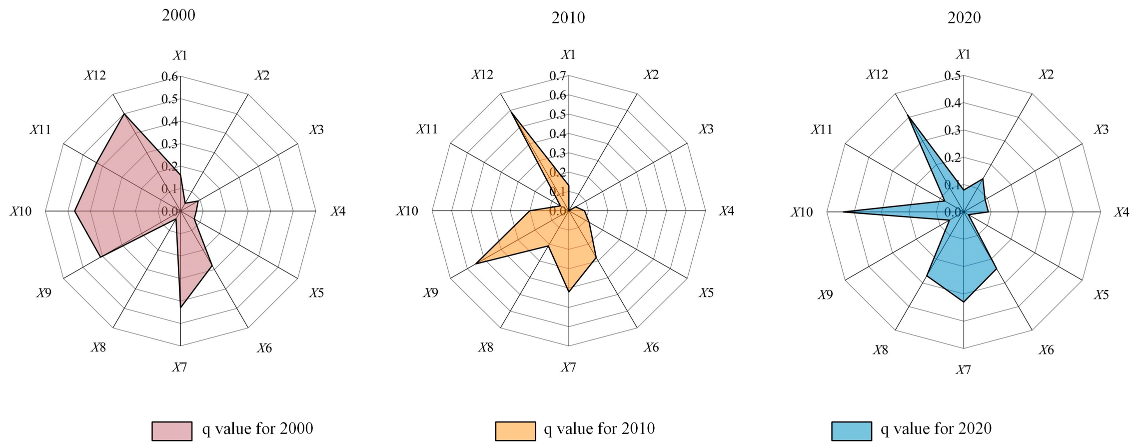

Figure 10. The single factor q value of the coupling coordination degree between RFD and RSE.

4.5.2. Interaction Effects of Each Factor

12 driving factors were used for interaction detection (Figure 11). The interaction factors with the greatest explanatory power from 2000 to 2020 were land use degree/cropland area (0.796), rural employed population/transportation convenience (0.812), and intensity of human activity/cropland area (0.7), respectively. Among them, the interactions of per capita GDP, intensity of human activities, and land use degree with the rural employed population in 2000 showed a non-linear enhancement effect, respectively. Cropland area, degree of topographic relief, and transportation convenience had mutually reinforcing

effects with the intensity of human activities in 2020. This shows that natural factors have a certain influence on rural functions and rural settlements development and change, but socio-economic factors such as economic development, social status quo, and human activities are the key driving factors for the coupling coordination changes of RFD and RSE.

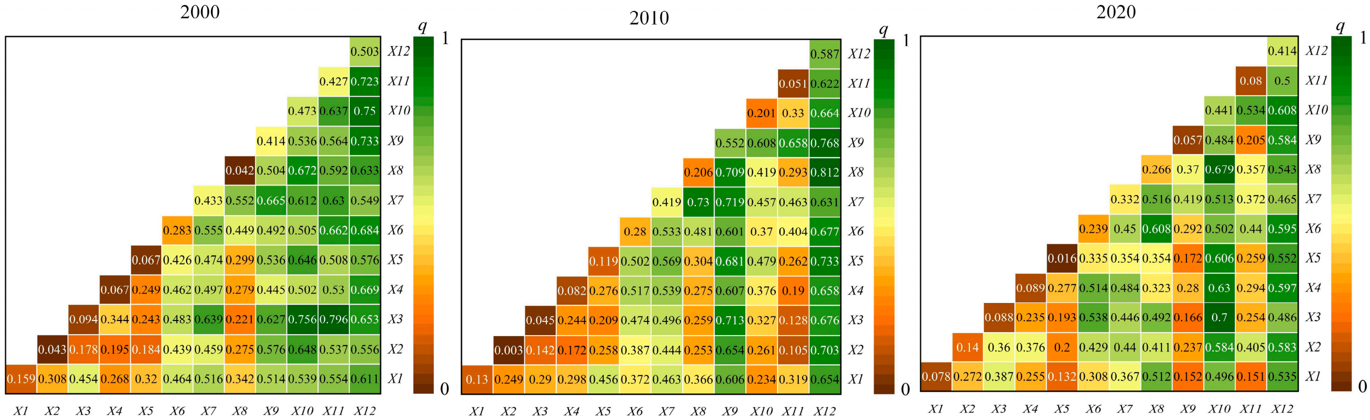

Figure 11. Interaction detection of driving factors in coupling coordination degree between RFD and RSE.

5. Discussion

5.1. Coupling Response Paths of RFD and RSE in Mountain Areas

The spatiotemporal evolution of rural functions and settlements in the study area from 2000 to 2020 showed significant diversity in their coupling responses, and the interrelationships between rural functions and settlements in different coupling models were also distinctive (Figure 12).

Vibrant model townships: the composite index of rural functions has increased, showing a trend of diversification, which can satisfy the diverse demands of residents. With the rapid development of the market economy, farmers' production space continues to expand, and their living space tends to be dense, gradually clustering near public facilities and transportation facilities. In addition, the interaction between rural functions and settlement functions has increased, functional spaces such as rural industry and commerce have appeared, and the landscape of the settlements has become diversified and functionally compounded. The mobility between various elements of the rural system has increased, and the vitality of rural development is strong.

Transitional model townships: this model improves the overall functional level of the rural areas. The dominant position of rural agriculture is challenged; agricultural production is no longer the main objective but is transitioning towards urbanization, resulting in a transformation of rural industrial structure. The development of rural urbanization and industrialization has promoted the functional differentiation of existing settlements, and commercial space, industrial space, and leisure space in settlement land have emerged constantly. Meanwhile, rural settlements with development advantages take the lead in growing up and developing into central villages or towns, and the form of rural settlement tends to cluster.

Traditional model townships: on the one hand, these areas are the main traditional agricultural production areas in Fengjie County, with widespread cultivation of citrus, walnuts, and medicinal herbs, and there are still many rural settlements with near-cropland layouts. On the other hand, the socio-economic development of the countryside has led to the construction of "household roads", making it possible for these settlements to enjoy convenient travel without deliberately clustering near transportation facilities. This model is more conducive to protecting and improving the rural environment, maintaining the beauty and character of the countryside.

Recessionary model townships: the degree of RFD decreases, and the number and size of the settlements have also become smaller, with a tendency for the countryside to decline.

The serious population loss in the rural areas has gradually reduced the number of villages and caused the problem of "hollowing out". The phenomenon of arable land abandonment is widespread, leading to the recession of rural agricultural production functions, and the settlements originally close to arable land tend to disappear. The reduction of the labor force makes the development of the market economy slow, which not only hinders the development of rural industrial production function and leisure tourism function but also hinders the enhancement of the settlement structure.

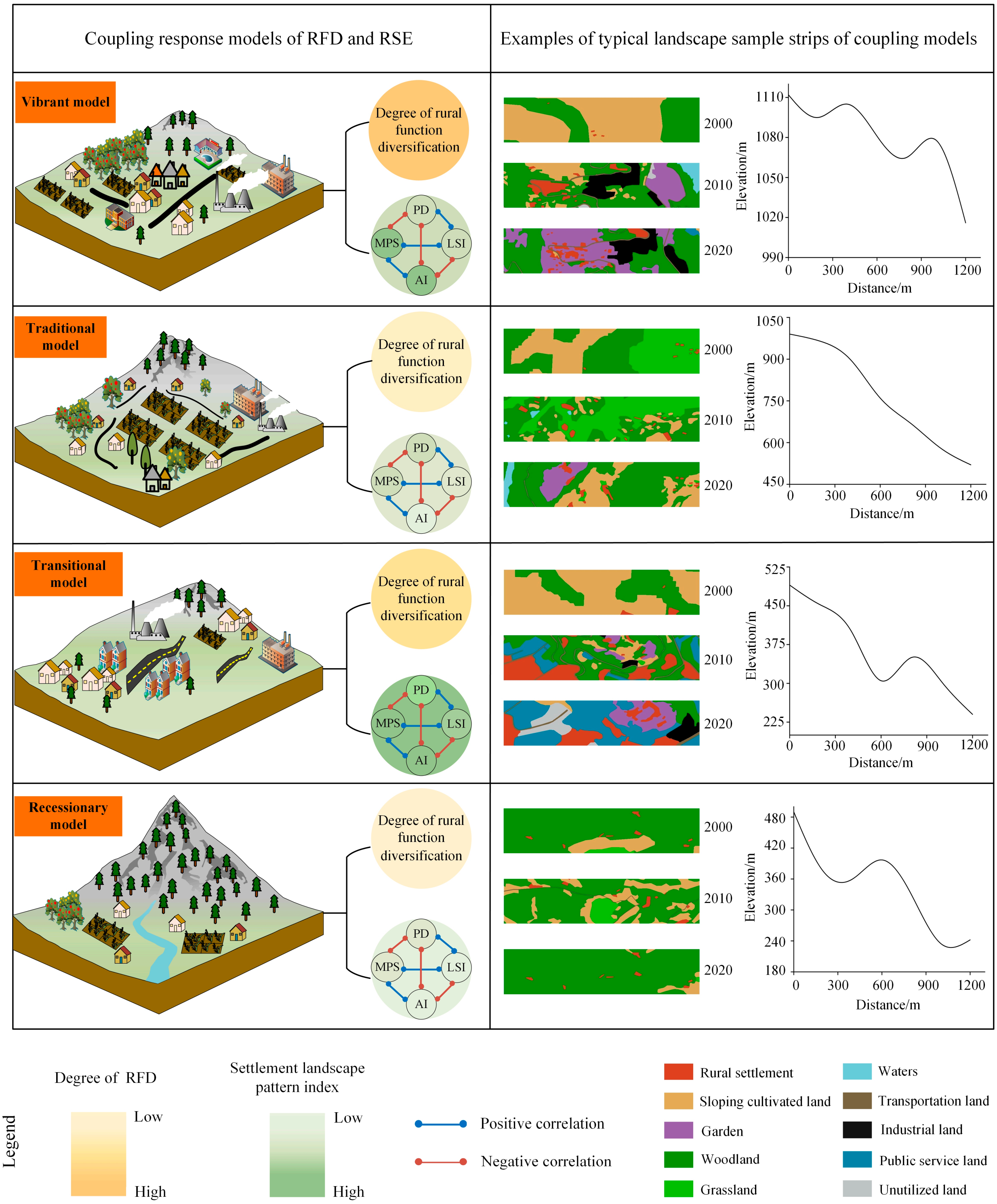

Figure 12. The coupling response path of RFD and RSE in mountainous areas.

5.2. Comparison with Research in Other Regions

Similar to the characteristics of rural functional development in the Jianghan Plain region [65], the middle reaches of the Yangtze River [66], and the Qinba Mountains [67], the study area shifted towards synergistic development of production, living, and ecological functions from 2000 to 2020. In terms of rural settlements, consistent with karst mountainous areas [68] and coastal areas [69], the size, quantity, and intensity of rural settlements in Fengjie County increased over time.

However, the development of rural functions and the evolution of settlements is a very complex process, and different research perspectives and regions will present different characteristics. The coupling relationship between the two also has significant differences. Compared to mountainous areas, due to the advantages of topography and rapid economic development, RFD started earlier in the plains, and the development degree and growth rate are mostly faster than those in mountainous areas, with stronger synergistic effects between functions. The accessibility in plain and coastal areas is high, and terrain conditions do not limit them, the settlements gradually tend to be randomly distributed [70]. The differences in the natural environment significantly impact settlement distribution in mountainous areas, where rural settlements tend to cluster in regions with flat terrain, good economy, and transportation conditions. Therefore, from the perspective of the coupling relationship between RFD and RSE, the coupling coordination degree in the plains is theoretically higher, and the spatial distribution of coordinated townships is more random. In contrast, the degree of coupling coordination in mountainous areas is relatively low, and the coordinated townships show a centralized distribution.

5.3. Influence on Development Planning in Rural Areas

In China, to promote rural revitalization, it is urgent to strengthen the comparative advantages of villages and optimize the layout of townships to promote the equal exchange of factors between urban and rural areas [71]. However, the Chinese government has only implemented major function-oriented zoning at the national and provincial levels to promote coordinated regional development and form an orderly spatial structure [4]. In the past, the pursuit of economic development in urban areas led to the neglect of the functions of rural areas, resulting in the loss of identity of rural areas. At the 20th Congress of the Communist Party of China (CPC), China's central government proposed a rural revitalization strategy, emphasizing the integration of primary, secondary, and tertiary industries and multifunctional development. However, existing studies state that conflicts exist between different production functions in rural areas, making it difficult to implement multiple functions as a whole [72]. Specific townships should develop their dominant functions based on local comparative advantages, rather than developing all functions indiscriminately [73]. The above analysis has shown that the coupling response models of RFD and RSE can be summarized into four types: vibrant model, traditional model, transitional model, and recessionary model. Therefore, differentiated development strategies should be adopted for townships with different coupling response models.

(1) Vibrant model: rural settlements in this model should be developed into specialized production villages to cultivate and process agricultural sideline products, extend the industrial chain, and give full play to the township's advantages of development vitality. (2) Recessionary model: this model needs to integrate fragmented rural settlement patches and moderately develop them into grain production villages. It is necessary to enhance the connectivity between settlements and improve their living, food production, and ecological functions to promote the multifunctional level of the villages. (3) Transitional model: rural settlements in this coupling model need to undergo rural transition based on their comparative advantages. There are two main transition paths, one is to transform into specialized tourism villages to develop tourism mainly by utilizing the natural scenery or the leisure tourism function of farmland. The second is to transform into residential villages, where some places closer to cities and towns have good public facilities to form large-scale new rural villages. (4) Traditional model: rural settlements in this coupling

model can be developed into food production villages for traditional food production, and can also be interplanted with cash crops to increase the economic benefits of agricultural cultivation. Meanwhile, it is necessary to do a good job in the sale and publicity of agricultural products to promote the development of agricultural production functions while driving the development of other rural functions.

5.4. Limitations and Prospects

The research results provide a theoretical reference for the policy formulation of rural spatial optimization and functional coordinated development in TGRA. However, it should still be pointed out that current research is more focused on the coupling relationship between rural functions and rural settlements in macro-typical regions. In the future, more attention should be paid to exploring the relationship between each rural function and settlement evolution at the micro level, as well as the systematic linkage in the process of coupling development. Meanwhile, due to limited data access, the evaluation system for the RFD needs to be further improved, and the regional culture and the security of homesteads should be emphasized. In addition, since the rural settlement vector patches in this paper are obtained by manual visual interpretation, it may have some impact on the measurement of rural settlements in Fengjie County. Nevertheless, the research results of this paper objectively reflect the coupling relationship between RFD and RSE in the study area, which can provide reference value for related research in other mountainous areas.

6. Conclusions

This paper constructed a theoretical framework for the coupling relationship between RFD and RSE and took Fengjie County in the hinterland of TGRA as a case study area to divide the coupling response models of RFD and RSE. It revealed the general law in mountainous areas and explored the driving mechanism of the coupling evolution. The main conclusions we draw are as follows:

(1) From 2000 to 2020, the average composite index of RFD in Fengjie County increased from 0.22 to 0.28, indicating that rural functions tended to diversify. The average composite index of RSE grew from 0.18 to 0.26, and the shape, scale, and area of the settlement evolved. With the improvement of the regional development level, the coupling coordination degree of RFD and RSE showed an upward trend, and the number of imbalanced townships decreased.

(2) From 2000 to 2020, the coupling coordination degree between RFD and RSE at the township scale showed a trend of "low in the west and high in the east, low in the south and high in the north". Meanwhile, the coupling coordination degree has a positive correlation, showing obvious spatial agglomeration, and the high-high cluster areas were mainly concentrated in the suburbs of the central towns.

(3) According to the relationship between the composite index of RFD and the composite index of RSE, we divided the townships into four coupling response models: vibrant model, recessionary model, transitional model, and traditional model. The interrelationships between rural functions and settlements in different coupling models were distinctive.

(4) Socio-economic factors such as population density, per capita GDP, and intensity of human activity were the dominant factors that influenced the coupling coordination degree of RFD and RSE. The interaction drivers with greater explanatory power were land use degree/cropland area, rural employed population/transportation convenience, and intensity of human activity/cropland area.

In the process of rural revitalization, it is necessary to promote the positive interaction between rural functions and rural settlements, enhance the adaptability of rural settlement transformation, and promote the sustainable and healthy development of rural areas.

Author Contributions: W.Z.: Writing—review and editing, Writing—original draft, Data curation, Conceptualization. Y.L.: Supervise, investigate, fund acquisition, perform formal analysis, and conduct data curation. Q.W.: Visualization, Software. J.S.: Resources, Project administration, Funding acquisition. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Major Program of the National Social Science Foundation of China (Grant number 20ZD096) and the Scientific Research Innovation Project of Graduate School of Chongqing Normal University (Grant number YKC24006).

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the ongoing nature of the research.

Acknowledgments: We are grateful to the scholars for their contributions to the production of land use data, and to the anonymous reviewers and editors for their valuable comments on improving the quality of the paper.

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

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