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Spatial-Temporal Characteristics of Green Development Level in River Basin

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Abstract

The Tuojiang Basin accounts for 30.8% of Sichuan Province's GDP, but the total water resources account for only 3.5%, resulting in increasing problems of water shortage, environmental deterioration and pollution, which further affects green development in the Basin. The objective of this paper is to investigate the green development of the Basin, expose deficiencies and ultimately unravel the path toward green development in the river basin of China. This paper was based on a green development measurement system under Economy-Nature-Resource-Society-Pollution perspectives and used Crtic method to calculate the weights of system indicators. Then Gray Correlation-Topsis evaluation model was used to measure green development level from 2009 to 2020. Finally, spatial evolution of green development in Tuojiang Basin was analyzed through Moran Index. The results showed that economy and pollution are the important factors of green development. And overall green development level was showing a trend of decreasing first then rising, which reached the lowest in 2014 and highest in 2019. Moreover, all cities in Tuojiang Basin except Ziyang reached a high level of green development in 2020. This paper added various pressure indicators produced by environmental pollution to the index system and enriched the evaluation index system for green development.

Keywords: Green Development; GC-TOPSIS; Spatial-Temporal Differentiation; Dynamic Evolution.

1. Introduction

While "black development" has created great wealth in the world, resource depletion and environmental pressure are also increasing, and problems such as pollution caused by urban development and sub-health of urban residents are gradually emerging [1]. The United Nations held the Sustainable Development Summit and emphasized that the three pillars of sustainable development - the economy, society and the environment are indivisible, and the development of the economy must follow the laws of nature and reduce the cost of the natural environment [2]. The economy has developed rapidly in China, and the GDP in 2021 increased by 8.1% over 2020. However, the rapid economic growth has increased China's resource and environmental costs for many years, resulting in serious ecological problems, such as serious environmental pollution, high environmental risks and large ecological losses. The construction of China's ecological civilization lags behind economic and social development, so the realization of green, green development is the priority.

Green development of Basins is considered to be a process of social, economic, and overall betterment that maintains a flexibility for future options and simultaneously conserving natural resources [3]. As an important

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support for the ecological construction zone of the Yangtze River Economic Belt and the economic development of Sichuan Province, the green development of Tuojiang Basin has attracted much attention. The amount of water resources in Tuojiang Basin only accounts for 3.5% of Sichuan Province, but it supports more than 20% of the population and GDP of the province, leading to the highest level of water resources development in all Basins of the province, which is difficult to support the sustainable development of social economy. About 42% of the heavily polluted rivers in Sichuan Province are located in Tuojiang Basin, but the urban sewage treatment rate is 64%, while the construction rate of township sewage treatment plants is only half of the urban sewage treatment rate. It can be seen that the pollution control system in Tuojiang Basin is not strong [4]. Above these problems restrict the social and economic development of the Basin, so it is important to consider from the perspective of the overall situation of the Basin and the multiple elements of green development [5].

As a hot topic of academic discussion, "*green development*" has attracted much attention from many researchers and can be divided into four categories: (1) Some scholars have analyzed the concept of green development and noted that green development is the path to high economic, social and environmental development [6, 7], in which the green economy is an important part of green development [8, 9]. (2) Green development efficiency is measured by two methods: index system evaluation and production efficiency measurement. Index system evaluation methods include the OECD Green Growth Assessment Framework [10], the United Nations Environment Program (UNEP) Green Economy Measurement Model [11], and the Beijing Normal University Green Development Index Assessment Mode [12]. They have explored the measurement of green development from different perspectives, such as economy [13], society [14], ecology [15] and integration [16]. It can be seen from the past literature that the economy [17] and environment [18] are the most important influencing factors, followed by ecological construction [19] and social policies [20]. In addition to the positive feedback, there are also negative impacts, most of which are directly reflected in the pollutant emissions caused by human production and life. Therefore, it is necessary to include the negative pollutant discharge of Tuojiangr Basin in the environmental impact on green development. Efficiency measurement methods include the traditional radial DEA model [21], EBM [22] and TOPSIS method [23]. (3) Evolutionary characteristics and influencing factors : Scholars have focused on evaluating green development from global [24], national [25], provincial [26], and municipal [27] perspectives. The GIS spatial analysis method [28, 29] and obstacle degree model [30] are commonly used methods. (4) Improvement measures: Zheng & Li [31] believe that the economic environment, policy system and other factors restrict regional green development. Chen et al. [32] emphasized that cultivating a green development system and strengthening urban hardware guarantees can improve the quality of urban development.

Based on previous studies, this paper finds that, first, the traditional green development considers the symbiotic relationship between the economic system, the natural system and the social system, which cannot fully adapt to the characteristics of different regions in Tuojiang Basin. This paper constructs an evaluation index system covering economic growth, natural conditions, resource utilization, social response and environmental pollution. Second, the green development system involves not only positive feedback, but also negative effects, most of which are directly reflected in the emissions of pollutants caused by human production. Therefore, this paper adds various pressure indicators produced by environmental pollution to the index system. Third, Tuojiang Basin flows through many cities, so there are many differences in resource allocation, social response, and environmental pollution in each city. It is necessary to combine multiple evaluation methods, overcome the limitations of extensive economic developement models, and integrate the spatial analysis and temporal analysis into the evaluation model, which can undergo a transition from an extensive economic development model to a green economic development model in Tuojiang Basin.

The contributions of this paper are as follows: (1) This paper identifies the key factors affecting the green development of Tuojiang Basin, which is conducive to guiding the development coordination among the factors of economy, society, resources, environment, etc. (2) To fully consider the regional characteristics and differences of Tuojiang Basin, this paper measures the overall and subsystem green development levels. This paper analyses the actual obstacles and excellent achievements in the process of green development, and strengthens the research on the differences in green development levels in Tuojiang Basin. (3) This paper explores the spatial differentiation pattern and agglomeration of green development levels in Tuojiang Basin through spatial correlation analysis and proposes policy suggestions for coordinated green development to further promote the economic and social growth of Sichuan Province and protect the natural ecological environment of the basin.

In order to solve the environmental pollution problem of Tuojiang Basin and improve green development level, this paper explores green development of Tuojiang Basin from 2009 to 2020 under Economy-Nature-Resource-Society-Pollution perspectives. Spatial-temporal evolution of green development in Tuojiang Basin is evaluated by Gray Correlation-TOPSIS evaluation model with combination weight determination. Based on the spatial correlation analysis of five typical cities, this paper discusses the results and puts forward some policy suggestions.

2. Study Area and Data

2.1. Study Area

The study area is a tributary of the upper Yangtze river which located in southwest of China, central Sichuan Province. The study area is oblong which total length of the watershed is 712 kilometers, and has a drainage area of approximately 32,900 km². It is composed of mountain area, plain and hill, and has a mild climate, with an annual average temperature of 17.1℃, abundant rainfall and an annual average precipitation of 1010mm. It is a non-closed Basin, and the runoff mainly comes from precipitation. Tuojiang Basin flows through 31 counties (districts) in 5 cities, including Deyang, Ziyang, Neijiang, Zigong, Luzhou. The geographical location of Tuojiang Basin and the location of five cities are shown in Figure 1.

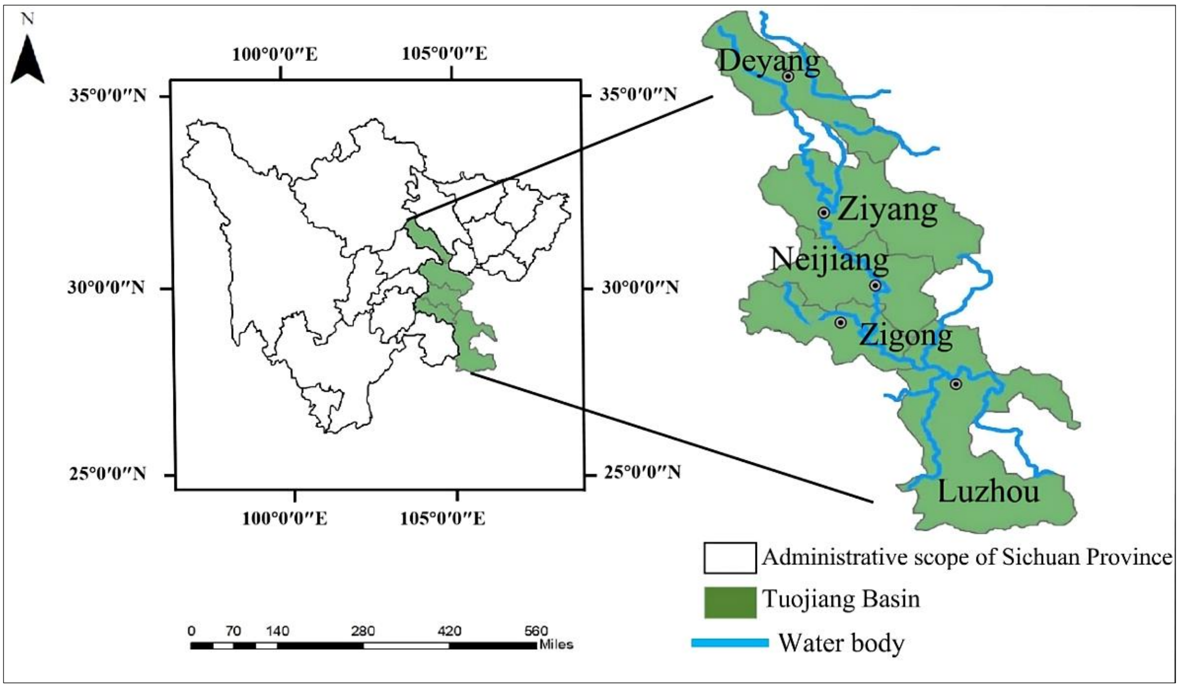


Figure 1. Tuojiang Basin geographical location

3. Index System

3.1. Interaction Mechanism of Green Development

As green development is a highly intricate system composed of economic, social, and ecological environments, many factors should be considered in its evaluation [33]. Figure 2 shows that the rapid social and economic development of the Basin has brought about increases in both the economy and population. Economic growth can promote the growth of GDP, the urbanization rate and environmental protection investment, which will have a positive impact on social response.

However, an increase in population leads to an increase in total water consumption, which has a negative impact on environmental protection. Economic development achieves the goal of ecological environment development through social response. At the same time, the consumption of resources also leads to environmental pollution. Therefore, economic development needs to consider the interactions among the natural environment, resources, social response and environmental pollution at the same time.

3.2. Construction of Evaluation Index System

China's National Development and Reform Commission formulated the Green Development Indicator System in 2016, which mainly includes five indicators including resource utilization, environmental governance, environmental quality, ecological protection, growth quality and green life. Through the Green Development Indicator System in 2016 and the internal mechanism of green development, the study has refined five subsystems (Economy-Nature-Resource-Society-Pollution).

Based on the above five subsystems of green development in Tuojiang Basin, the study combines the international indicators selected by OCED and refers to China's green development index system to determine the green development evaluation index system composed of 20 detailed indicators in Table 1.

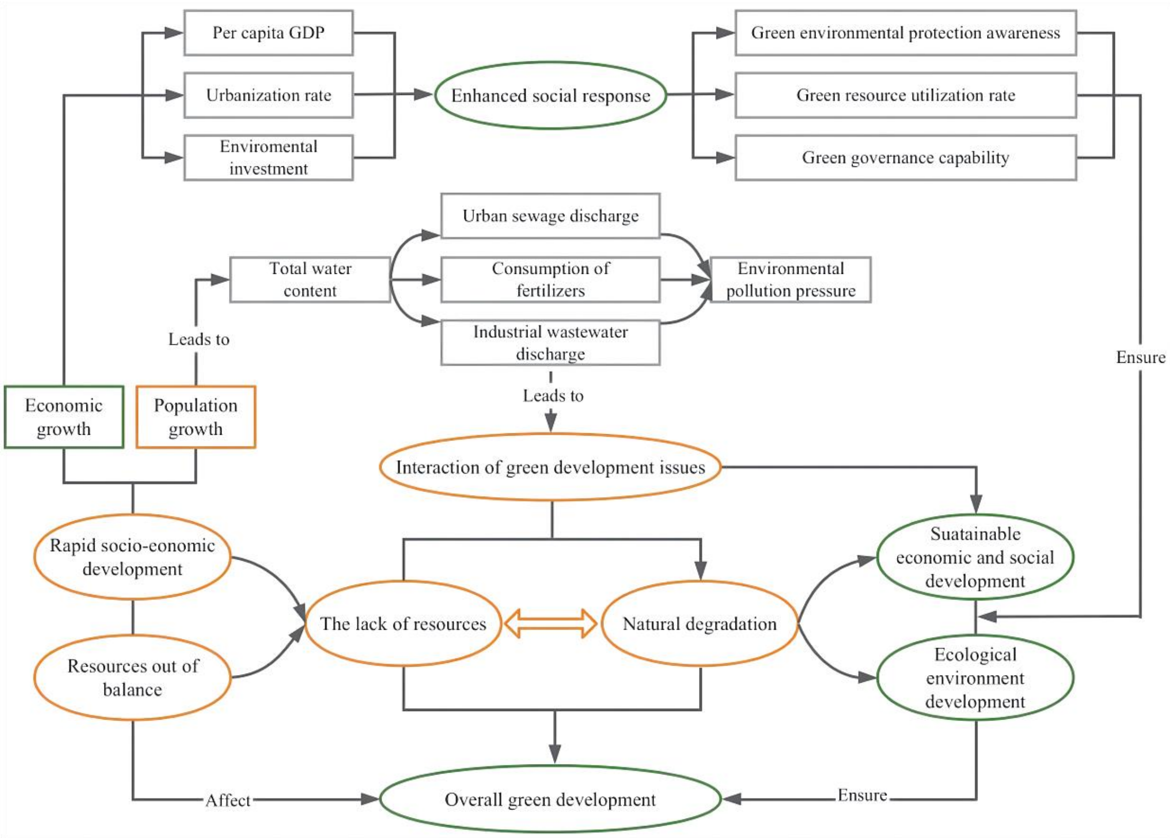


Figure 2. The internal interaction mechanism of green development

Table 1. Evaluation index system of green development in Tuojiang Basin

System	Evaluation indicator	Calculation formula	Indicators meanings
Economy (E)	E_1: Per capita GDP	Total GDP/total population	People's economic level
	E_2: Urbanization rate	Non-agricultural population/total population	The level of urban progress
	E_3: Growth rate of industrial added value	Industrial added value/In the same period of numerical	The running trend of industrial economy
	E_4: Proportion of investment in energy conservation and environmental protection in GDP	Energy conservation and environmental protection investment/Gross Domestic Product	Harmonious relationship between environmental protection and economic development
Nature (N)	N_1: Precipitation	Natural monitoring data	Basin healthy state
	N_2: Mean pH value of precipitation	Natural monitoring data	Precipitation and atmospheric pollution
	N_3: Average annual concentration of inhalable particulate matter (PM_{10})	Air quality monitoring data	Air quality state
	N_4: Average relative humidity	Natural monitoring data	Basin healthy state
Resource (R)	R_1: Proportion of effective irrigation area	Effective irrigation area/total cultivated area	Agricultural production and water resources utilization
	R_2: Per capita water consumption	Total water resources/total population	Availability of water resources
	R_3: Forest coverage rate	Forest area/total land area	Level of forest resources
	R_4: Energy consumption per unit output value	Total energy consumed/gross domestic product	Regional energy consumption level
Society (S)	S_1: Urban water conservation reuse rate	The total amount of sewage recycled/total amount of sewage treatment	Utilization of sewage resources
	S_2: Per capital annual R&D expenditure	Intramural Expenditure on R&D/total number of researchers	Basin protection awareness
	S_3: Sewage treatment rate	Amount of treated sewage/total sewage discharged	The extent of urban sewage treatment
	S_4: Greenery coverage of urban area	Urban green coverage/construction land area	Level of urban green space development
Pollution (P)	P_1: Urban sewage discharge	Amount of domestic sewage	The pollution from city life
	P_2: Industrial wastewater discharged	Amount of industrial wastewater	The pollution from industry
	P_3: Average chemical fertilizer application rate	Total fertilizer use/sown area	The pollution from agriculture
	P_4: Success rate of monitoring section water quality	Class III or above water quality/total measured water quality	Current situation of Basin water quality

4. Methods

4.1. CRITIC Method

CRITIC method is an objective weighting method proposed by Diakoulaki et al. [34]. The specific calculation steps are as follows:

Step 1: Normalize the initial data matrix.

Positive indicators: $x_{ij} = (X_{ij} - Xminmax_{\min})$ (1)

Revers indicators: $x_{ij} = (Xijmin_{max_{max}})$ (2)

Step 2: Correlation of indicators: calculate the standard deviation.

$$\mathbf{v}\sigma_j = \sqrt{\frac{\sum_{i=1}^{n}(x_{ij}-\overline{x}_j)^2}{n-1}} \tag{3}$$

where $\overline{x}_j$ is the mean of indicator, which quantifies the contrast intensity of the corresponding criterion.

Step 3: Conflict of indicators: calculation of the correlation coefficient.

$$R_j = \sum_{i=1}^{n}(1 - r_{ij}) \tag{4}$$

where r_{ij} is the correlation coefficient.

Step 4: Calculate the amount of information, $\boldsymbol{C_j}$ emitted by the j^th criterion.

$$C_j = \sigma_j * R_j \tag{5}$$

Step 5: Calculate the weight of the j^th criterion.

$$W_c = \frac{C_j}{\sum_{j=1}^{m} C_j} \tag{6}$$

4.2. Entropy Method

Step 1: Normalize the initial data matrix.

Positive indicators: $x_{ij}^{'} = (x_{ij} - min\{x_{ij}\})/(max\{x_{ij}\} - min\{x_{ij}\})$ (7)

Reverse indicators: $x_{ij}^{'} = (max\{x_{ij}\} - x_{ij})/(max\{x_{ij}\} - min\{x_{ij}\})$ (8)

Step 2: Calculate the proportion of indicators.

$$p_{ij} = x_{ij}^{'}/\sum_{i=1}^{m} x_{ij}^{'} \tag{9}$$

Step 3: Define the entropy.

$$e_j = -\ln(m)^{-1}\sum_{i=1}^{m} p_{ij}\ln p_{ij} \tag{10}$$

Step 4: Calculate the coefficient of variation.

$$g_j = 1 - e_j \tag{11}$$

Step 5: Acquisition of the weight.

$$w_e = g_j/\sum_{j=1}^{n} g_j \tag{12}$$

4.3. Combination Weights of Indicators Method

The paper uses Song's et al. [35] weighting method to achieve objective integration of indicator information weights . The formula is as follow:

$$W_{ij} = \frac{(\sigma_j+e_j)\sum_{i=1}^{n}(1-r_{ij})}{\sum_{j=1}^{m}(\sigma_j+e_j)\sum_{i=1}^{n}(1-r_{ij})} \tag{13}$$

4.4. Gray Correlation-TOPSIS Method

In order to improve the accuracy of the evaluation conclusions, the paper integrats TOPSIS Method and Gray Correlation Method. The proposed GC-TOPSIS has the following steps:

Step 1: Calculate the normalized weighted decision matrix based on the combination weights.

a: Calculate the normalized decision matrix.

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{j=1}^{n} x_{ij}^2} \tag{14}$$

b: Build weighted normalized decision matrix.

$$v_{ij} = w_{ij} r_{ij} \tag{15}$$

Step 2: Calculate the positive-ideal and negative-ideal solutions.

$$V^+ = \{v_1^+, \dots, v_n^+\} = \left\{(\max_i v_{ij} | j \in J), (\min_i v_{ij} | j \in J')\right\} \tag{16}$$

$$V^- = \{v_1^-, \dots, v_n^-\} = \left\{(\min_i v_{ij} | j \in J), (\max_i v_{ij} | j \in J')\right\} \tag{17}$$

where J is associated with benefit criteria and is associated with cost criteria.

Step 3: Calculate the separation measures to the positive-ideal and negative-ideal solutions (Euclidean distance).

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}, i = 1, \dots, m. \tag{18}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, i = 1, \dots, m. \tag{19}$$

Step 4: Calculate the GC coefficient between the ith alternative and positive-ideal and negative-ideal alternative about the jth index.

a): The gray correlation coefficient of the ith alternative to the positive ideal solution and the negative ideal solution about the jth index is calculated as follow:

$$r_{ij}^+ = \frac{\min_i \min_j \left|z_j^+ - z_{ij}\right| + \rho \max_i \max_j \left|z_j^+ - z_{ij}\right|}{\left|z_j^+ - z_{ij}\right| + \rho \max_i \max_j \left|z_j^+ - z_{ij}\right|} \tag{20}$$

$$r_{ij}^- = \frac{\min_i \min_j \left|z_j^- - z_{ij}\right| + \rho \max_i \max_j \left|z_j^- - z_{ij}\right|}{\left|z_j^- - z_{ij}\right| + \rho \max_i \max_j \left|z_j^- - z_{ij}\right|} \tag{21}$$

where ρ is the resolution coefficient, $\rho \in [0,1]$, we choose $\rho = 0.5$ in this study.

b): The GC coefficient matrix between each alternative and the positive-ideal alternative and negative-ideal alternative are obtained:

$$R^+ = \begin{bmatrix} r_{11}^+ & r_{12}^+ & \cdots & r_{1m}^+ \\ r_{21}^+ & r_{22}^+ & \cdots & r_{2m}^+ \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1}^+ & r_{n2}^+ & \cdots & r_{nm}^+ \end{bmatrix} \quad R^- = \begin{bmatrix} r_{11}^- & r_{12}^- & \cdots & r_{1m}^- \\ r_{21}^- & r_{22}^- & \cdots & r_{2m}^- \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1}^- & r_{n2}^- & \cdots & r_{nm}^- \end{bmatrix} \tag{22}$$

c): The gray correlation degree between the ith alternative and the positive and negative ideal alternative are obtained:

$$R_i^+ = \frac{1}{m} \sum_{j=1}^{m} r_{ij}^+, (i \in \{1,2, \dots, n\}) \tag{23}$$

$$R_i^- = \frac{1}{m} \sum_{j=1}^{m} r_{ij}^-, (i \in \{1,2, \dots, n\}) \tag{24}$$

Step 5: Normalize R_i^+, R_i^-, D_i^+, and D_i^- :

$$\tilde{M}_i = \frac{M_i}{\max M_i}, (i \in \{1,2, \dots n\}) \tag{25}$$

where $M_i \in \{R_i^+, R_i^-, D_i^+, D_i^-\}$.

Step 6: Calculate the integrated closeness index which considers Euclidean distance and GC coefficient.

$$C_i = \frac{\alpha D_i^- + \beta R_i^+}{(\alpha D_i^- + \beta R_i^+) + (\alpha D_i^+ + \beta R_i^-)} \tag{26}$$

where α and β are preference coefficients, reflecting the preference of shape and position, satisfying $\alpha + \beta = 1$, $\alpha, \beta \in [0,1]$, this study takes $\alpha = \beta = 0.5$.

4.5. Spatial Correlation

Step 1: Global spatial auto-correlation.

$$Moran'sI = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(Y_i-\overline{Y})(Y_j-\overline{Y})}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\sum_{i=1}^{n}(Y_i-\overline{Y})} \tag{27}$$

where W_{ij} is the combination weight, and Y_i and Y_j are the green development level of region i and j.

Step 2: Local spatial auto-correlation.

$$I_i = \frac{(Y_i-\overline{Y})}{S^2}\sum_{i\neq j}^{n} W_{ij}\left(Y_j - \overline{Y}\right) \tag{28}$$

where I_i is the local Moran's I of region I.

5. Results and Analysis

5.1. Key Factors of Green Development in Tuojiang Basin

The objective combination weighting of Equations 2 to 13 is used to calculate the weights of each index and five subsystems in this study. Among the research uses Song's et al. [35] weighting method to achieve objective integration of indicator information weights, Equation 13 is the formula combining CRITIC method and Entropy method which can overcome the shortcoming of single weighting method to a certain extent, avoid one-sidedness and improve the scientificity of weighting. The calculated data results are shown in Table 2. We can see the key systems and factors in green development of Tuojiang Basin through the weights data.

Table 2. The index weight of green development evaluation in Tuojiang Basin

System	Index name	Combination weight	System weight
Economy (E)	E_1	0.0291	0.3981
	E_2	0.0313	
	E_3	0.1932	
	E_4	0.1444	
Nature (N)	N_1	0.0185	0.1190
	N_2	0.0301	
	N_3	0.0595	
	N_4	0.0109	
Resource (R)	R_1	0.0773	0.1175
	R_2	0.0105	
	R_3	0.0146	
	R_4	0.0151	
Society (S)	S_1	0.0582	0.1466
	S_2	0.0503	
	S_3	0.0301	
	S_4	0.0080	
Pollution (P)	P_1	0.0196	0.2188
	P_2	0.0258	
	P_3	0.0805	
	P_4	0.0929	

As can be seen from Table 2, the ranking of the influence degree of the five systems on the green development of Tuojiang Basin is as follows: Economic system>Pollution system>Social system>Natural systems>Resource system. Among the 20 influencing indicators of the green development level in Tuojiang Basin, the five key factors with the highest weight are: Growth rate of industrial added value (E_3), Average chemical fertilizer application rate (P_3) and Proportion of effective irrigation area (R_1), among these five factors, there are two factors to measure the green economy situation of Basin, and two factors to measure the current situation of the environmental pollution, one factors about the carrying capacity of resources. Therefore, Economic and Pollution are the most significant in the five systems for improving the green development level in Tuojiang Basin.

5.2. Temporal Changes of Green Development in Tuojiang Basin

The Euclidean distances D_i^+ and D_i^- are calculated by using TOPSIS model, showing in Equations 14 to 19 in the study. Then Gray Correlation method is used to obtain the Gray Correlation Degrees R_i^+ and R_i^- between the i^{th} alternative and the positive and negative ideal alternatives by using Equations 21 to 24. In order to improve the accuracy of the evaluation results, the paper combines TOPSIS method and Gray Correlation method to evaluate the green development level of Tuojiang Basin and uses Equations 26 and 27 to calculate the comprehensive paste progress C_i. The closer the integrated closeness is to 1, the higher the level of green development is. The calculated data results are shown in Figure 3.

The overall green development of Tuojiang Basin from 2009 to 2020 shows a "V" shaped fluctuation trend, which is analyzed in four stages in this paper. During this period, the overall green development level of Tuojiang Basin fluctuated continuously under the influence of economic model transformation and environmental pollution control. From 2009 to 2014, the economic development under the traditional industrial model destroyed the natural environment, so excessive energy consumption, inadequate social policy response and the green development level declined. After 2014, the transformation of the green economy was on the right track, green technology investment and policy implementation from all walks of life complemented each other, environmental pollution was greatly improved and controlled, and the overall green development of the Basin has reached the best state under multiparty coordination.

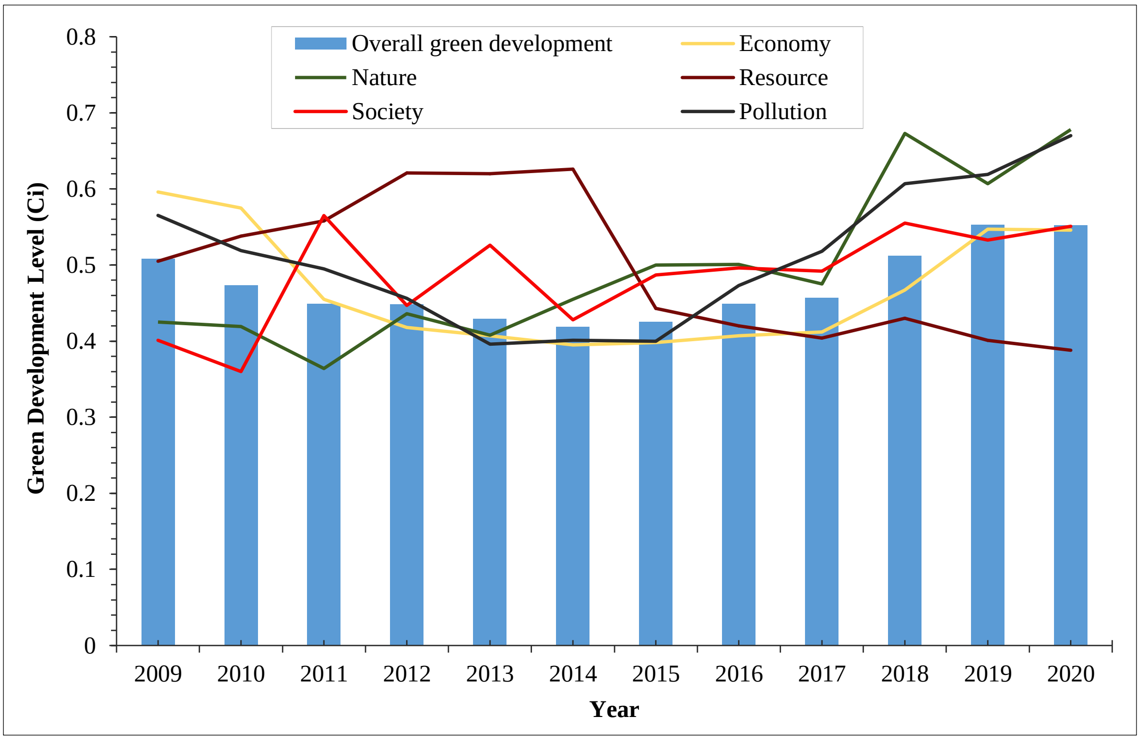


Figure 3. Green development of Tuojiang Basin from 2009 to 2020

(1) The first stage was a sharp decline from 2009 to 2011. Green development level in Tuojiang Basin declined rapidly, with a decrease of more than 5% every year. An Extensive economy is one of the important factors for the decline in the overall green development level of a Basin. At this time, the social policy response in Tuojiang Basin was in the embryonic stage, management measures remained at the suggestion level, and green development was negatively affected.

(2) The second stage is characterized by a slow decline from 2011 to 2014 and a low point in 2014. The overall green development level in Tuojiang Basin has slowed down. From 2011 to 2012, the green development of the Basin was almost stagnant, and the rate of decrease in the green development level from 4.2% to 2.3%. From 2012 to 2014, under the traditional growth model, energy-intensive polluting industries have been unable to provide green development momentum at the economic level, and environmental protection investment has also decreased, resulting in the lowest level of green development in Tuojiang Basin in 2014.

(3) The third stage slowly improved from 2014 to 2017. The growth rate of the green development level in the Basin increased from 1.43% to 5.65%, and the improvement speed increased rapidly. In 2015, Sichuan Province established and improved the horizontal water environment and ecological compensation mechanism between the

upstream and downstream cities in Tuojiang Basin, and the concentration of pollution indicators decreased, marking an improvement turning point in the green development of Tuojiang Basin. From 2014 to 2017, a number of restoration measures were implemented to protect green space and natural vegetation in Tuojiang Basin, greatly improving the environment. Therefore, the green development level of the Basin has been significantly improved during this stage.

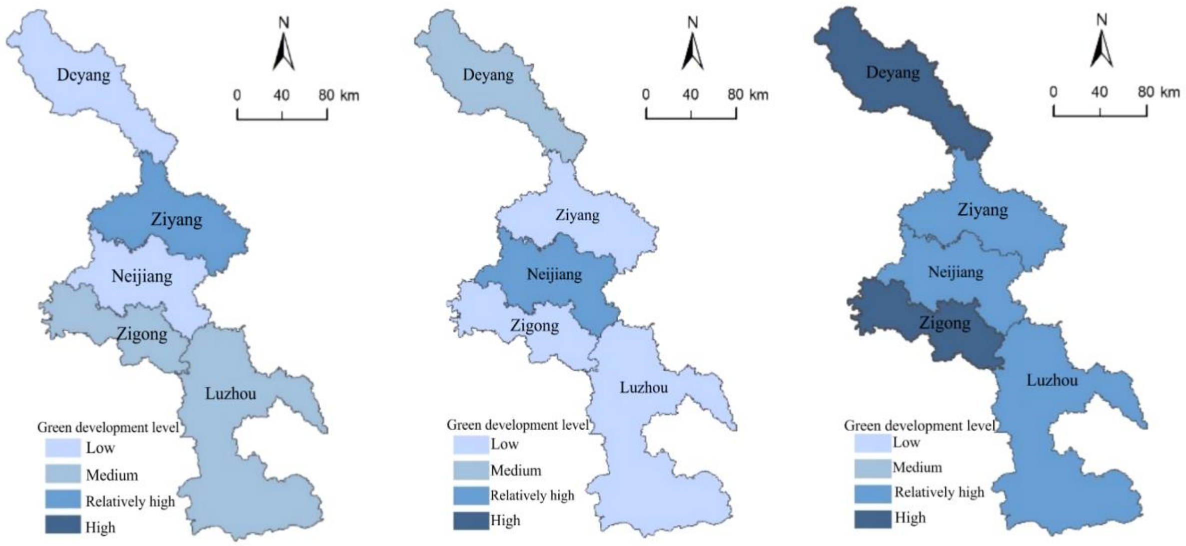
(4) The fourth stage was the steep increase stage from 2017 to 2020， and the peak occurred in 2019. After 2017, the development level of the green economy in Tuojiang Basin increased, and the economic model of the one-sided pursuit of GDP increase has been gradually phased out. In 2018, the social policy response in Tuojiang Basin reached its highest level, the air quality in Sichuan Province reached its best in history, and the water quality in Tuojiang Basin recorded best water quality in the past decade. At the same time, the environmental pollution of the Basin has been greatly controlled and improved. After 2019, all aspects of green development in Tuojiang Basin were optimized, and social policies are still being implemented.

Then, from the perspective of the green development level of Tuojiang Basin subsystem during 2009-2020, the green development trend of the economic and environmental system is almost consistent with the overall green development trend of the Basin, which means that the green economic transformation and green environment improvement within Tuojiang Basin have the greatest driving force on the overall green development level of the Basin. The green development of the natural and social system and the overall green development of the Basin show a fluctuating trend of intermittent overlap, which means that in the process of green development of the Basin, the natural system has been affected by the positive and negative effects of the social economy and environmental resources. Meanwhile, the promulgation and implementation of social policies have also experienced a process of large investment in environmental protection construction, long periods and slow effects. However, with the passage of time to achieve green coordination, the resource system and the overall green development of the Basin show the opposite trends. The green development of the Basin requires resource consumption as the premise, and the resource utilization within the Basin should be reasonable and moderate.

5.3. Spatial Difference of Green Development Level

5.3.1. Spatial Evolution of Overall Green Development

In order to further analyze the spatial dynamic evolution of the green development level in Tuojiang Basin, three time points were selected: 2009, 2014 and 2020. GC-TOPSIS model is used to calculate the overall green development level of each city. Then this paper use the visualization technology of ArcGIS10.1 software to analysis spatial evolution characteristics of green development level in 2009, 2014 and 2020, which is showing in Fingure 4. Among the paper processed the urban green development level of the three years and divided it into four sections, the high level area (0.5085~0.5430), the high level area (0.474~0.5085), the middle level area (0.4395~0.4740) and the low level area (0.4050~0.4395).



(a) 2009 **(b) 2014** **(c) 2020**

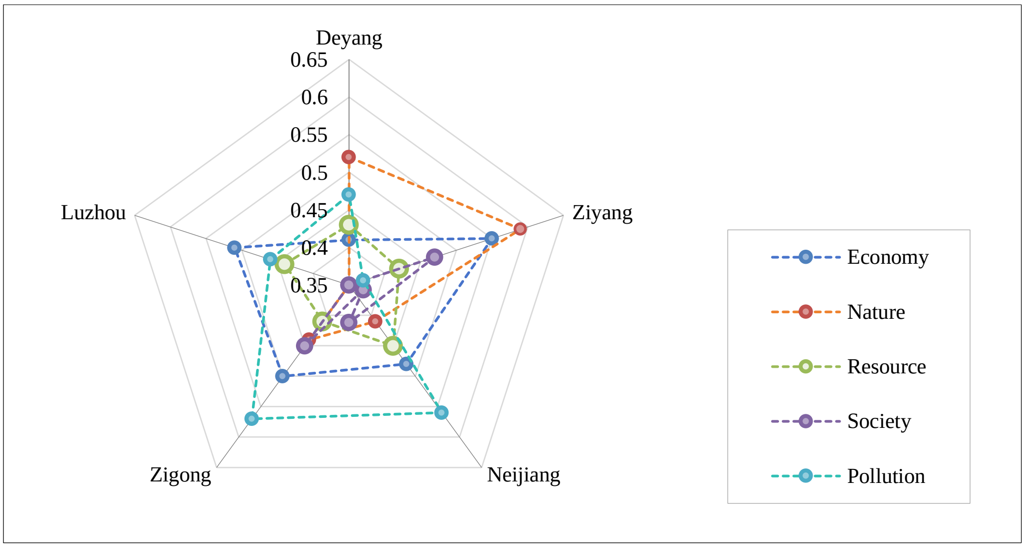
Figure 4. Spatial evolution characteristics of green development level in 2009, 2014,2020

From 2009 to 2014, the spatial pattern of green development level in Tuojiang Basin evolved: (1) The low level of green development in Tuojiang Basin gradually shifted from the upper reaches of the Basin to the middle and lower reaches that is, the green development advantage shifted from the middle and lower reaches to the upper reaches. (2) In 2014, Tuojiang Basin had the most low-level green development areas, including Zigong, Luzhou and Ziyang. (3) Deyang is in a stage of fluctuation and improvement of green development, Zigong is in a state of steady development, Luzhou is in the stage of low-level recession, and Ziyang and Neijiang have experienced the greatest fluctuations.

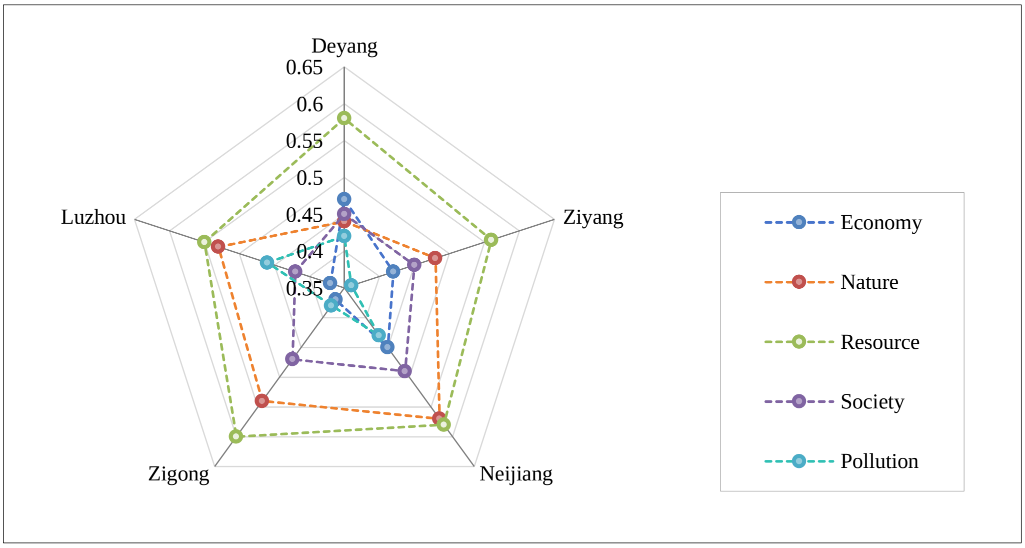
From 2015 to 2020, the spatial evolution trends of green development level in Tuojiang Basin were as follows: (1) In 2015, the low-level area of green development in Tuojiang Basin transiently shifted from the lower reaches to the upper reaches. (2) There was no low-level area in Tuojiang Basin after 2016. (3) From 2015 to 2020, the five cities were all in the state of green development, among which Luzhou, Deyang, Neijiang and Ziyang reached the optimal level in 2019, and Zigong reached the optimal level in 2020. (4) Ziyang and Luzhou have the best green development levels in the middle-level and high-level areas and do not have green development advantages in Tuojiang Basin.

5.3.2. Spatial Difference of Green Development Level among Subsystems

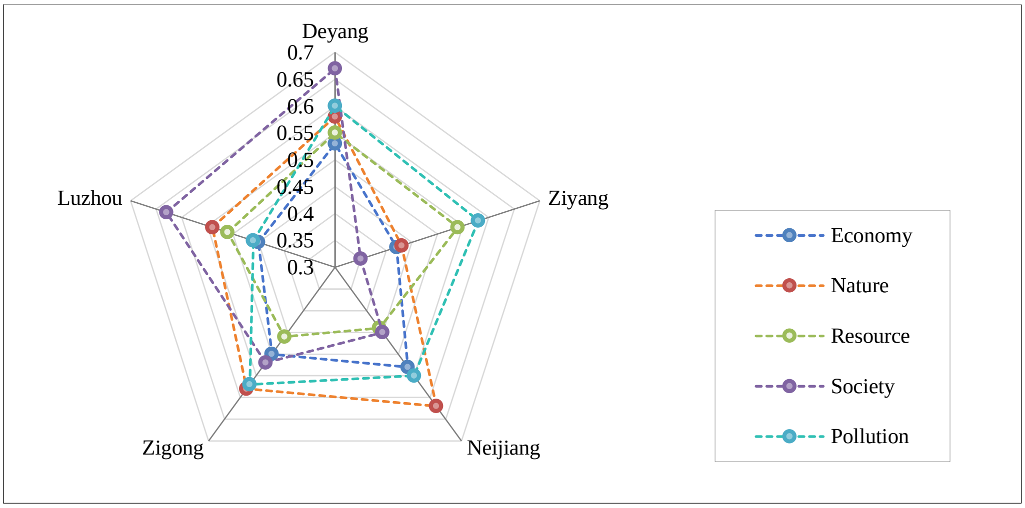
The study uses the visualization technology of ArcGIS10.1 software to draw a radar map of five urban green development subsystems, as shown in Figure 5.



(a) 2009



(b) 2014



(c) 2020

Figure 5. The level of green development in the five urban subsystems in 2009, 2014, 2020

The results show that Deyang has the highest level of green development, excellent economic development and natural reserve foundation, well-implemented policies, and the least obstacles. It has an overall advantage in terms of green development in Tuojiang Basin. Zigong has the second highest level of green development. The cultural industry, as the driving force of green economic growth, supports green development. However, due to the poor natural water resources, the acquired air quality needs to be further improved under policy regulation. The green development levels of Luzhou and Neijiang are similar, but the long-term and industrial-driven economic development model of Luzhou has made it necessary to transform the green development. At the same time, the implementation of social policies in Luzhou and Neijiang is not timely, the implementation rate is poor, and problems can be solved only when they occur. The policy sensitivity to green development problems is low, leading to significant improvement in the environmental quality of the two cities. The fundamental obstacle to the lowest level of green development in Ziyang is that the economic development is too backward, but the environmental level is superior.

5.3.3. Global Spatial Auto-correlation of Green Development

The study uses the spatial pattern map generated by ArcGIS software to substitute the overall green development level of cities in Tuojiang Basin in Geoda software, and then calculates the overall Moran's I. P-value represents whether Moran's I is meaningful. Only the P-values in 2009, 2014 and 2018 were lower than 0.1 (the significance level was lower than 10%), which was within the normal range. The calculated data results are shown in Table 3.

Table 3. Moran's I of green development level

Index/Year	2009	2015	2020
Moran's I	-0.828	-0.047	-0.472
Z (I)	-1.659	-1.786	-1.653
P-value	0.038	0.026	0.081

In 2009, 2014 and 2018, the Moran index of the green development level of Tuojiang Basin was negative, and the significance level at the three time points was lower than 10%. Through hypothesis testing, there was a negative spatial correlation between the green development levels of cities in Tuojiang Basin, indicating that the green development of cities in the Basin was in a state of spatial dispersion and differentiation. It is concluded that the causes of spatial heterogeneity are as follows:

(1) Compared with Deyang, Ziyang's industrial enterprises are scattered, and the traditional industrial development model is not suitable for long-term green development. Until 2018, Ziyang's economy had nearly doubled its GDP per capita compared with that in 2009, but it still did not have sufficient competitiveness. Therefore, the economic development of Ziyang is short and uneven, which makes it difficult to maintain high quality. Deyang has a solid industrial foundation, a variety of advantageous industries and stable economic development. As a major equipment manufacturing base in China, Deyang has domestic industrial enterprises, tothat continuously supply energy for GDP growth. During the peak period in 2018, the per capita GDP of Deyang is aboutwas approximately twice that of Ziyang, and the urbanization rate is higherwas greater than 10%. Deyang has an excellent economic foundation and a fastrapid development speed, but it has nonot made a green contribution to the whole Basin, leading to the spatial differentiation ofdifferences in the green development of the Tuojiang Basin.

(2) Zigong has a congenital shortage of water resources, insufficient water reserves and poor self-sufficiency. Zigong has a large population density, so human production and living pollution impose a large load on the natural environment. Zigong still has the problem of overbuilding upstream reservoirs in the Tuojiang Basin, which hinders the flow of water, reduces the water volume and has a long-term negative impact on the water quality of the Basin.

(3) Neijiang has focused on the treatment of water quality and air quality in the Tuojiang Basin, with a total investment of 15.281 billion CNY since 2016. Deyang has also vigorously promoted water pollution control in Tuojiang Basin over the years, and the annual average concentration of total phosphorus, a major pollutant, has decreased by 45.41%. On the other hand, Ziyang had the lowest investment in environmental protection and research due to the most backward level of green economic development in Tuojiang Basin and the lack of impetus.

5.3.4. Local Spatial Correlation of Green Development

The adjacent cities in the Tuojiang Basin may have atypical characteristics different from those of the overall distribution. Geoda software was used to construct a Molan scatter plot of the green development level of the Tuojiang Basin in 2009, 2015 and 2020. To further observe the agglomeration intensity among cities in the Tuojiang Basin, the LISA agglomeration maps for 2009, 2015 and 2020 are shown in Figure 6. From 2009 to 2015, the low-level area of green development in the Tuojiang Basin gradually shifted from Deyang and Ziyang in the middle and upper reaches to Luzhou in the lower reaches. Neijiang and Zigong in the middle reaches maintained relatively moderate, moderate and high fluctuations.

After 2014, all the cities entered the stable development stage of medium level and above. Deyang was the first city to enter the high-level area, Luzhou city was stable at the medium-high green development level, and Ziyang, Neijiang and Zigong all maintained a steady improvement. In 2020, Deyang and Zigong reached a high level of green development, and other cities reached a medium to high level. In the early stage of green development, Deyang did not invest enough power in overall green development, which is economic. Therefore, the amount of sewage, wastewater and agricultural fertilizer in Deyang is much greater than that in Ziyang. Adequate watershed green management measures were not implemented in Neijiang. Ziyang has a high level of green development due to its late development, low internal consumption of resources and low environmental pollution. Because it has not developed its own green development advantages, it is not enough to play a role in promoting the coordinated green development of surrounding cities.

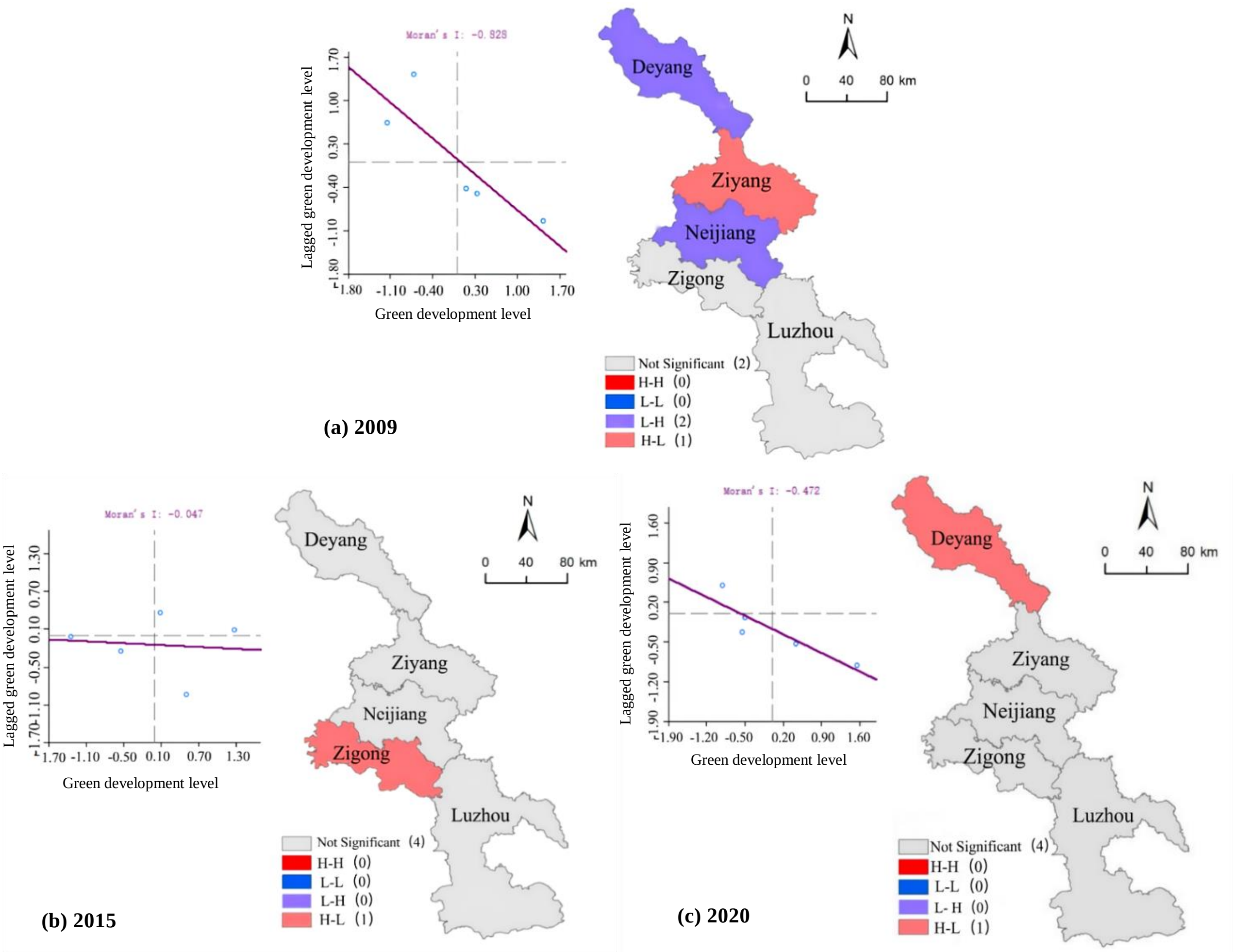


Figure 6. Local autocorrelation LISA clust map of green development level of Tuojiang Basin in 2009, 2015, and 2020

6. Discussion

The paper measures the green development level of Tuojiang Basin. Despite the rapid growth of scientific knowledge about the causes and effects of Basin pressure, effective management policies lag behind in most cases. Therefore, the paper explores the key points of green development and puts forward four key points that can be discussed:

(1) The results show that the economy is the most important factor for promoting the green development of the whole Basin, and extensive industry has been gradually eliminated in the green development process of cities. The long-term economic growth in the Tuojiang Basin is based on the premise of sacrificing natural resources and the environment. One-sided attention to industry and GDP growth has little effect on promoting high-quality green development in the Basin. Therefore, the Tuojiang Basin should combine the advantages of traditional industries and new development concepts to form a circular economy chain of kinetic energy transformation, reduce the pressure on natural resources and the environment, and improve the high-quality development of the green economy.

(2) The distribution of water resources in the Tuojiang Basin is uneven, industrial and agricultural production are limited, and high-energy-consuming industries consume large amounts of resources. It can be seen from the results of the paper that high energy consumption production is more unsustainable and has a negative impact on resource waste and pollution emissions when promoting the economy. All regions in the Tuojiang Basin should promote the development, utilization and recycling of renewable resources, and enterprises should invest in low-carbon, efficient and economic production models. Renewable energy should be encouraged to be the first resource used in the Tuojiang Basin in the future, renewable energy should be introduced, chemical fuels such as coal mines should be reduced, resource utilization should be improved, and pollution emissions should be reduced. The capacity resources of the Tuojiang Basin should be effectively utilized to promote the process of urban industrialization and urbanization.

(3) Green development requires the support of green innovation and environmental policy. The peak period of the overall green development of the Tuojiang Basin shows that the input and communication of watershed management and decision-makers to green innovation is an important breakthrough for urban enterprises in the Basin to achieve green transformation or the emergence of green awareness among the public under the guidance of science and technology. In terms of agricultural production, we should use innovative green irrigation technology, optimize the agricultural layout, update and replace large machinery with high production capacity, and improve agricultural production efficiency. Innovative technology can also be used to make a scientific cycle of water resources in production and life. The nonpoint source pollution caused by agricultural chemical fertilizer should be filtered and screened by technology to improve the green development ability of agriculture in the Basin.

(4) Through the analysis of the green development level of the Economy-Nature-Resource-Society-Pollution subsystem, this paper finds that economic foudation, resource endowment, social policy and geographical location play different roles in influencing the green development level of the five major cities in terms of the distribution of water resources in the Tuojiang Basin. The speed of economic development of cities in the Tuojiang Basin is quite different. Deyang has a strong industrial foundation, a variety of advantageous industries, and stable economic development. As a major equipment manufacturing base in China, Deyang has domestic ndustry enterprises, which continue to supply energy for GDP growth. Although Deyang has an excellent economic foundation and fast development speed, it has no green contribution to the whole river Basin, which also leads to the final spatial differentiation of the green development of cities in the Tuojiang Basin.

The cities in the Tuojiang Basin have different natural resource conditions. Compared with other cities, Zigong has the problems of congenital water resource shortages, insufficient water resource reserves and poor self-sufficiency. Zigong has a large population density, and the pollution of human production and life places a large load on the natural environment. In addition, there is also the problem of the overconstruction of upstream reservoirs in the Tuojiang Basin, which obstructs the flow of water and reduces the amount of water, which has a negative impact on the water quality of the Basin in the long term. Although most of the enterprises in Zigong meet the emission standards, due to the lack of geographical conditions, the emission standards of enterprises are inconsistent with the self-sufficiency of the Basin, which is not perfect compared with other cities. Therefore, the difference in natural resource carrying conditions is an inevitable problem for achieving coordinated green development in a Basin.

The social policies of the cities in the Tuojiang Basin are different. Since 2016, Neijiang has focused on water quality and air quality problems in the Tuojiang Basin, with a total investment of 15.281 billion CNY to carry out major projects such as ecological restoration, pollution control and environmental supervision. Deyang has also vigorously promoted the treatment of water pollution for many years, and the annual average concentration of total phosphorus, a major pollutant, in the Deyang section of the exit section decreased by 45.41% compared with that in the same period last year.

(5) Previous studies on the green development level of water resources in the Tuojiang Basin revealed that the level of opening to the outside world, technological progress, water use structure, government control intensity, and water resource endowment had significant impacts [36]. In addition, some studies on the level of agricultural green development in the Tuojiang Basin have shown that the level of agricultural green development in the whole Basin and the upper, middle and lower reaches has improved, there are differences in the level of agricultural green development, and the degree of agglomeration has decreased [37]. This paper revealed that economic and environmental pollution are among the most important green development indicators, while support for urban industrial economic development, financial investment in energy conservation and environmental protection, water quality in the Tuojiang Basin section and agricultural pollution are important factors affecting the green development level of the Tuojiang Basin. This finding also validates the conclusion of other studies on green development in the Basin that government control intensity, water resource endowment, and agricultural pollution have significant effects on the green development level in the Tuojiang Basin.

7. Policy Recommendation

***Determine the functions of the five cities and allocate resources*:** Zigong should deploy the water resources in Tuojiang Basin to combine the needs of production and life, such as adding water storage facilities in key enterprises and population gathering areas. Neijiang should focus on improving the air quality of monitoring points in Tuojiang Basin, such as publicly ranking the air quality data in the Basin, and guiding the environmental awareness of all sectors of society. Luzhou also needs to improve the urban water saving rate, such as increasing the investment in the construction of urban water supply and drainage pipelines. Secondly, for cities with outstanding competitive advantages in green development, the government can establish cross-administrative partnerships to make resources flow and promote the integrated development of the region.

***Promote the transformation of green agricultural production*:** The urban agricultural production in Tuojiang Basin can not only occupies most of the economic share, but also has high ecological efficiency. The whole Basin is a carrier of agricultural production, and the agricultural department should avoid the non-point source pollution caused by large amounts of chemical fertilizers and avoid the secondary pollution caused by the internal flow of the Basin. Municipalities in Tuojiang Basin can focus on improving the scope of agricultural productivity to ensure the optimal use efficiency of agricultural land, water and other agricultural infrastructure inputs. At the same time, the five cities should reduce the joint impact of soil and water loss on the Basin, and implement the return of farmland to the forest.

***Strengthen exchanges and cooperation among the five cities*:** Different cities in Tuojiang Basin has different development results due to its own advantages and shortcomings. Among them, Zigong has insufficient natural water resources, Ziyang has no pillar economic advantages, Neijiang and Luzhou have poor durability and implementation in social policy formulation and response, and Deyang has not exerted its advantageous position in green development to drive common development in the Basin. In terms of economy, the cities in Tuojiang Basin should first form a situation of economic investment, industrial technology cooperation and environmental assistance among the cities according to the advantages and disadvantages of their own green economic development under the drive of high-level cities; In terms of ecological environment, the cities in Tuojiang Basin can jointly establish and distribute ecological protection economic taxes and incentives, and allocate funds according to the proportion of GDP and the degree of water resources development and utilization in accordance with the pressure of each city on the resources and environment in Tuojiang Basin, so as to ensure the common development of the economy and environment in the whole Basin.

8. Conclusion

This paper explores the green development level of the Tuojiang Basin under five economy-environment-resource-society-pollution systems and determines the weights of subsystems and indicators via the CRITIC method and entropy method. The system with the largest weight is the economic development system, and the weight value is 0.398. The second is the environmental pollution system, with a weight value of 0.219. The coordinated development of the economy and environment is an important topic of green development in the Tuojiang Basin. The weight calculation results of detailed indicators show that the index with the largest weight is the growth rate of industrial added value (E_3), and the weight value is 0.193. The second index weight is the proportion of energy conservation and environmental protection investment in GDP (E_4), and the weight value is 0.144. The index weights rank second in the water quality monitoring compliance rate (P_4) and fertilizer application intensity (P_3) sections. Among the five systems used to improve the green development level of the Tuojiang Basin, economic and environmental pollution are among the most important green development indicators, while the support of urban industrial economic development, financial investment in energy conservation and environmental protection, water quality in the Tuojiang Basin section and agricultural pollution are important factors for evaluating the green development level.

The overall trend of the green development level in the Tuojiang Basin from 2009 to 2020 fluctuated roughly in a "V" shape, and the ranking on the time scale was 2019>2020>2018>2009>2010>2017>2016>2011>2012> 2013>2015>2014. The valley value of green development in the Tuojiang River Basin was 0.419. After 2014, the overall green development trend in the Tuojiang River Basin increased and reached a peak value of 0.553 in 2019. The Tuojiang Basin gradually entered the green development stage, from the initial stage of green development to the intermediate stage of decline, and finally showed good growth and a steady improvement stage.

The green development level of the Tuojiang Basin exhibited a negative spatial correlation. The agglomeration intensity among cities is weak, and the green development agglomeration of Luzhou in the lower reaches has been in an inconspicuous state. In 2009, Ziyang, a high-level area of green development, was surrounded by Deyang and Neijiang, a low-level area. However, Ziyang's own green development power was insufficient and did not play a leading role. In 2015 and 2020, Zigong and Deyang exhibited an "H-L" spatial trend, while the other four cities exhibited no significant change. The aggregation of the five cities was weak, and it was impossible to achieve a coordinated and unified green development situation in the Basin.

9. Declarations

9.1. Author Contributions

Conceptualization, H.Z. and H.T.; methodology, D.H.; software, H.Z.; validation, H.Z., H.T., and D.H.; formal analysis, H.Z.; investigation, H.H.; resources, H.H.; data curation, H.H.; writing—original draft preparation, H.Z.; writing—review and editing, H.T.; visualization, Q.S.; supervision, Q.S.; project administration, Q.S.; funding acquisition, H.Z. All authors have read and agreed to the published version of the manuscript.

9.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

9.3. Funding

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9.4. Institutional Review Board Statement

Not applicable.

9.5. Informed Consent Statement

Not applicable.

9.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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