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Comprehensive Evaluation and Spatial-Temporal Pattern of Green Development in Hunan Province, China

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Abstract: Hunan Province in China is in the initial stage of green development. Human activities and urban construction lead to ecological environmental problems. Based on the physical geography, environmental quality and socio-economic data from 2005 to 2020, this study established a green development evaluation system based on the DPSIR model by analyzing the logical relationship of green development in Hunan Province. In addition, we explored the change characteristics of the green development level, and evaluated the green development in Hunan Province from the time and space dimensions. The results showed that there are significant spatial differences in the green development level of counties in Hunan Province, showing a pattern of "strong in the east, weak in the central and western regions". In addition, from 2005 to 2020, the county's green development index showed agglomeration distribution. The driving forces and pressure systems have a significant role in promoting the green development of the county, while the state and impact systems also have a certain role in promoting the green development of the county. Based on the evolution mechanism of green development in Hunan Province, this paper studied the new green development evaluation system and proposed green development policy recommendations, aiming to provide a scientific basis for the construction of ecological civilization in the region.

Keywords: comprehensive evaluation; spatial-temporal pattern; green development level; spatial heterogeneity; Hunan province; DPSIR model

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1. Introduction

Green development is an inevitable choice for human development. It is a deep-seated exploration of the harmonious coexistence mode between humans and nature in response to global resources and environmental problems [1]. Green development is a new development model combining the economy, society, and ecology and has important guiding significance for social policy adjustment and development focus correction. As one of the fastest growing emerging industrialized countries, China's gross domestic product (GDP) increased from CNY 367.9 billion in 1978 to CNY 11400 billion in 2021. China's rapid development depends on the rapid growth of its industrial level, but the traditional extensive manufacturing mode has caused great pressure on China's resource supply and environment. There is an urgent need to adjust the corresponding green development strategy to achieve efficient, balanced, and harmonious development [2–4]. At present, the research on China's green development is mostly based on the first-tier, second-tier cities, or township areas with obvious particularity [5–8], lacking universal research on the existing large number of small and unobvious county characteristics [9]. Therefore, in order to cope with the environmental pollution and resource depletion caused by the gradual expansion of the county's economy, it is urgent to put forward corresponding countermeasures for the county's green development.

Hunan Province is located in south-central China, rich in natural resources and humanistic color. It puts forward the goal of 'promoting ecological civilization and building a beautiful Hunan', and its green development policy is gradually improving. Based on the good local natural resources, various regions of Hunan Province have formed green development forms with local characteristics [10]. With the rapid development of agriculture and industry in recent decades, problems such as a shortage of resources, environmental damage, and ecological degradation have led to a reduction in the environmental capacity in Hunan Province, thus affecting the green development of the region. Agriculture is the main industry in the northeastern part of Hunan Province, and the disturbance of the environment by human activities is more serious. Therefore, the green development index in Hunan Province showed a downward trend from 2005 to 2020, and the index in the northeast was the lowest. It is urgent to formulate new policies to achieve green development.

Research on the evaluation of urban green development evaluation can be divided into the evaluation index selection [11–14], the index weight setting [15–24], the green development framework's construction and model evaluation [25–31], and the spatial-temporal change and driving mechanism of green development [32–36]. The evaluation index selection is a key factor affecting the conclusion of urban green development evaluation. The United Nations Commission on Sustainable Development (UNCSD) has designed a system for sustainable development covering 134 indicators in the economic, social, and environmental fields [37]. The World Bank takes national wealth as the basis for measuring sustainable development and builds a sustainable development index system composed of natural capital, artificial capital, human capital, and social capital. In addition, countries have actively explored and practiced sustainable development index systems at different scales [38–41], such as the European urban sustainable development index system, the Manuka New Zealand sustainable development index system, and the United States Seattle community sustainable development index system, etc. [42]. Therefore, the three-pillar model combining social systems, economic systems, and environmental systems is widely used because of its simple and comprehensive characteristics [11–13]. Chinese scholars believe that social systems, economic systems, and environmental systems are the three elements of urban green development. Yuan, Li et al. constructed a sustainable development index system including the economy, society, and the environment to evaluate the sustainable development capacity of municipalities and provincial capitals in China [43,44]. In addition, some researchers choose green GDP [45,46], green economic efficiency [47–49], or green economic indicators [50,51] as indicators of urban green development. However, most studies focus on national provinces and municipalities, and few studies exist on green development evaluations from a county perspective [52,53]. Wei et al. applied resources and environmental carrying capacities (RECC) to explore the relationship between regional economic development and environmental carrying capacity, analyzed the specific characteristics of each functional area in the county, and provided a reference for optimizing the spatial pattern of land and further deepening green development [54]. She et al. studied the constraints of infrastructure sustainability to effectively improve the sustainability effect and provide a reference for the long-term green development of counties [55]. In addition, Cheshmehzangi et al. realized a dual-carbon management plan through comprehensive evaluations such as SWOT analysis and fluid dynamics (CFD) simulation, providing a reference for the county's low-carbon transition and sustainable energy planning [56].

The index weight setting is also an important part of urban green development evaluation, which can be divided into subjective weighting methods [15], objective weighting methods [16,17], and combined weighting methods [18–20]. Subjective weighting methods, such as the Delphi method [21], the Analytic Hierarchy Process (AHP) method [22], etc., reflect the subjective judgment and intuition of the evaluators. The Delphi method was used to determine the index entropy to evaluate the green economy differences in different provinces and cities in China [25]. However, the objectivity and reproducibility of these methods are relatively poor. Objective weighting methods, such as the entropy weight method [23], deviation maximization method [24], etc., adopt relatively perfect mathematical theories and methods but do not consider the subjective information of the evaluator.

Gang et al. used multiple linear regression analysis to analyze the development of the green economy in 30 provinces in China and found that the overall development was good, but the regional polarization was severe [57]. Yin et al. used the entropy weight method to study the green economy level of 30 provinces in China in 2015 and found significant regional differences [58]. Although these methods can comprehensively elucidate the development of a regional green economy, they cannot fully reveal the internal development constraints. In order to embody the advantages of the above two methods at the same time, a combined weighting method is proposed and widely used.

Various mature analysis frameworks and measurement methods have been formed for the construction and evaluations of green development frameworks. Kim et al. conducted a cross-country comparison of green growth in 30 countries by using the OECD assessment framework [26]. Based on the Green Growth Knowledge Platform, Lyytimäki et al. constructed a series of key green growth indicators for Finland [27]. Xu et al. used SEA technology to improve the efficiency of municipal solid waste treatment and ensure the sustainable development of urban economic, social, and environmental coordination [59]. LI et al. developed the Full Permutation Polygon Synthetic Indicator method (FPPSI) to comprehensively evaluate and give recommendations for different stages of urban development [60]. Zhou et al. improved the urban sustainability evaluation system and further improved the accuracy and pertinence of their conclusions by incorporating the attitude indicators of decision makers [61]. Zhu et al. established an object–subject–process framework system and analyzed the global green development practice and policy effect evaluation model [29]. Wu et al. used the DPSIR model to evaluate urban green development in Beijing, taking into account resource depletion, environmental damage, and ecological benefits [30]. Guo et al. used the Urban Development Index (CDI) framework to evaluate the sustainable development of China's municipalities from five dimensions: infrastructure, waste treatment, health, education, and urban output [28,30,31]. Na and Martin et al. used SEB, DEA-BCC, and other models to analyze the green economic efficiency of Chinese cities in different years, and found that technological progress is the main driving force restricting the development efficiency of the urban green economy [48,49].

The spatial-temporal change and driving mechanism of green development have been concerned with the spatial heterogeneity of specific research objects. Similarly, the study of green development is bound to explore the occurrence, change, and impact of differences in green development. Zhang and Chen et al. used panel data to analyze regional green development levels, spatial relationships, and their heterogeneity characteristics in China [33,34]. Hasan et al. used the LMDI model to analyze the economic scale, industrial structure, and technological progress of German green development [35]. Cheng et al. used the projection pursuit evaluation model and the methods of Gini coefficient, coefficient of variation, spatial autocorrelation, and spatial measurement to analyze the temporal and spatial evolution trajectory and impact mechanism of green development in 30 provinces and cities in China [32,36].

In general, China's green development evaluation is still in its infancy, and the statistics department has not systematically conducted statistics on the relevant indicators of green development evaluation. The existing research results are quite different in the structural design of the index system. Therefore, it is urgent to establish a hierarchical index system reflecting the coupling of natural, economic, and social systems to reveal the continuous operation mechanism of the complex and giant system of regional development. At the same time, this method should be relatively easy to calculate, and the results are intuitive and easy for decision makers to understand and apply. Therefore, this paper takes 88 counties in Hunan Province, as the research object and uses principal component analysis, analytic hierarchy process, and ArcGIS spatial visualization to scientifically and objectively explore the spatio-temporal changes and limiting factors of green development in Hunan counties. The DPSIR model is used to construct a green development evaluation index system, define the connotation of green development, and reveal the constraints affecting regional green development.

2. Materials and Methods

2.1. Overview of the Study Area

Hunan Province is located in the central and southern part of China (24°38′–30°08′ N, 108°47′–114°15′ E), east of Jiangxi, west of Chongqing and Guizhou, south of Guangdong and Guangxi, and north of Hubei, with a total area of 2,118,000 square kilometers. Hunan has a subtropical monsoon humid climate with four clear seasons, sufficient heat, and concentrated rainfall. The annual average temperature is 16–18 °C, and the annual average precipitation is 1200 to 1800 mm. Based on the principle of data accessibility and unity, this paper selects 88 counties in Hunan Province to study (Figure 1).

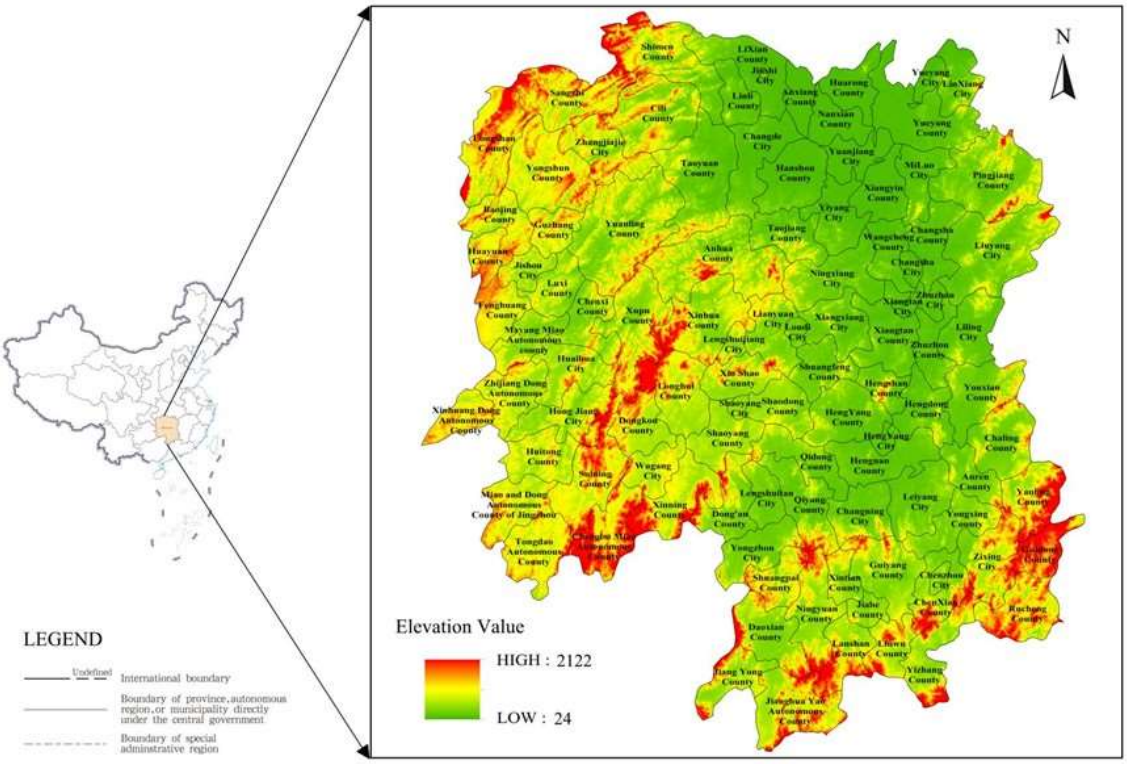

Figure 1. Overview of the study area.

2.2. Data Objects and Sources

The economic development data came from the 'Hunan Province County Statistical Yearbook' (2005, 2010 and 2015) and the '2020 National Economic and Social Development Statistical Yearbook'. Environmental data came from the 'China Urban Statistical Yearbook' (2005, 2010, 2015, and 2020), the county's 'environmental bulletin', and the China Air Quality Online Monitoring and Analysis Platform (https://www.aqistudy.cn/, accessed on 4 January 2022). Geospatial data came from the Resource and Environment Science and Data Center (http://www.resdc.cn/, accessed on 19 December 2021).

2.3. Evaluation Index System Construction

Under the guidance of the concepts of "green economy", "sustainable development", "resource cycle", and "environmental carrying capacity", this study draws a logical diagram of urban green development (Figure 2). Through the relationship diagram, we can see the interaction between resources, the environment, the economy, and society in urban development, which provides a reliable theoretical basis for the screening of indicators. This study used the DPSIR model (Figure 3) to establish a green development evaluation model in Hunan Province and used the subjective and objective combination method to calculate the weights. Population and economic development were used as the main driving force (D) and production pressure (P) on the environment, respectively, resulting in changes in regional sustainable state (S), which in turn have an impact (I) on the natural environment, human health, and socio-economic structure. Based on these impacts, society responds (R) to the stress state and the impact of the driving force to achieve the goal of promoting regional sustainable development. Combined with the existing research results [11–14] of the sustainable development index system at home and abroad and the development characteristics of Hunan Province, Table 1 constructs a green development evaluation index system including 25 indicators at three levels: the target layer, criterion layer, and index layer. The driving force system (D) reflects the driving effect of socio-economic development, population change and geographical factors on regional development. The pressure system (P) reflects the environmental pressure on the corresponding region under the direct effect of the driving force. The state system (S) reflects the result of the combined effect of internal pressure and external driving force in the region. The impact system (I) describes the impact of various factors on the development of regional systems from the aspects of medical level, industrial development level, and social infrastructure construction level. The response system (R) is the feedback of human beings on the state and impact of regional systems. Pressure includes indicators that put pressure on green development and therefore have a negative impact. The indicators included in Status, Impact, and Response form a positive feedback relationship with green development, so they are all positive impacts. For the driving force of green development, there are positive indicators, negative indicators, and neutral indicators.

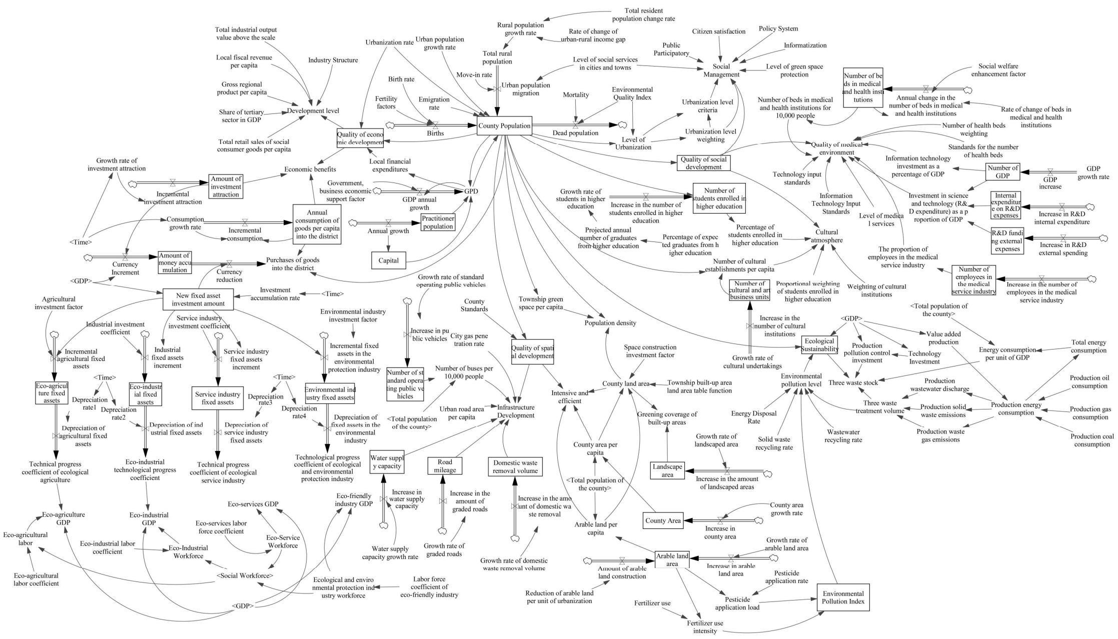

Figure 2. Logic diagram of urban green development.

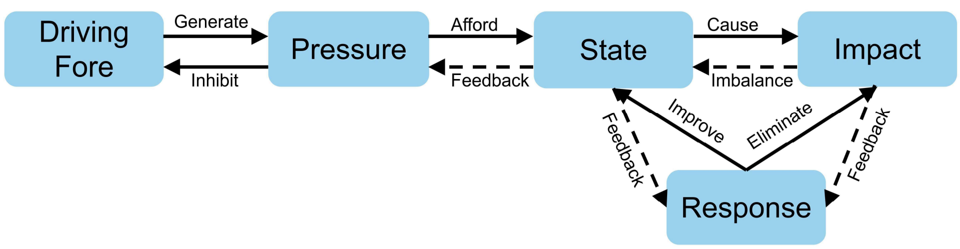

Figure 3. Schematic diagram of the DPSIR model.

Table 1. Green development evaluation index system of Hunan Province based on DPSIR model.

Target Layer	Criterion Layer		Index Layer	Unit	Index Types	Weight Value of Index Layer
Hunan Province Green Development Evaluation Index System	Driving force (D)	D1	GDP	CNY billion	Positive	0.121
		D2	regional GDP	CNY 10 thousand	Positive	0.139
		D3	household registrational population	Millions	Negative	0.123
		D4	population density	millions/km^2	Negative	0.115
		D5	total grain output.	tons	Positive	0.132
		D6	DEM		Positive	0.108
		D7	annual precipitation	L/m^2	Neutral	0.138
		D8	mean annual temperature	°C	Neutral	0.125
	Pressure system (P)	P1	industrial SO_2 emissions	tons	Negative	0.283
		P2	$PM_{2.5}$	tons	Negative	0.214
		P3	industrial soot emissions	tons	Negative	0.255
		P4	industrial wastewater emissions	tons	Negative	0.248
	State system (S)	S1	primary industry added value	CNY 10 thousand	Positive	0.184
		S2	second industry added value	CNY 10 thousand	Positive	0.203
		S3	completed urban fixed assets investment	CNY 10 thousand	Positive	0.206
		S4	road density	%	Positive	0.198
		S5	water system density	%	Positive	0.095
		S6	vegetation coverage	%	Positive	0.114
	Impact system (I)	I1	number of beds in medical and health institutions		Positive	0.304
		I2	number of industrial enterprises above scale		Positive	0.299
		I3	road distance	m	Positive	0.203
		I4	water distance	m	Positive	0.193
	Response system (R)	R1	human disturbance index	%	Positive	0.237
		R2	comprehensive ecological service value	CNY	Positive	0.381
		R3	land-use change rate	%	Positive	0.381

The weight value of the index layer of the green development evaluation index system in Hunan Province is calculated according to the principal component analysis method. According to the calculation results, the key factors that play a negative role in green development are land use change and ecosystem service value. The key factor for the development to play a positive role is industrial SO_2 emissions.

2.4. Comprehensive Green Development Index

In this paper, principal component analysis and the analytic hierarchy process were used to determine the objective weight and subjective weight, respectively, to obtain the comprehensive weight. The calculation method of the Comprehensive green development index is as follows:

1. Indicator data standardization:

$$\text{Positive indicator normalization}: \ Z_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{1}$$

$$\text{Negative index normalization}: \ Z_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{2}$$

where $x_{ij}(i = 1,2, \ldots, m; j = 1,2, \ldots, n)$.

2. Index weight through principal component analysis:

$$F_k = \frac{W_k}{\sqrt{\lambda_k}} \tag{3}$$

$$O_{ij} = \frac{\sum_{k=1}^{p} F_k V_k}{\sum_{k=1}^{p} V_k} \tag{4}$$

$$W_{ij} = \frac{O_{ij}}{\sum_{i=1}^{m} O_{ij}} \tag{5}$$

where W_k represents the loading number of the principal component k; λ_k represents the characteristic root of each principal component ($k = 1, 2, \ldots, p$); V_k represents the variance contribution rate of each principal component; F_k represents the obtained linear combination coefficient; O_{ij} represents the obtained comprehensive score model coefficient; and W_{ij} represents the obtained index weight coefficient.

3. Index weight through analytic hierarchy process:

$$B_m = \begin{pmatrix} a_{11} & \ldots & a_{1j} \\ \ldots & \ldots & \ldots \\ a_{i1} & \ldots & a_{ij} \end{pmatrix} \tag{6}$$

$$W_i = \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \ (i = 1,\ 2, \ldots,\ n) \tag{7}$$

$$W_i = \frac{W_i}{\sum_{j=1}^{n} W_{ij}} \ (i = 1,\ 2\,, \ldots,\ n) \tag{8}$$

$$\mathrm{CI} = (\lambda_{\max} - n)/(n-1) \tag{9}$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{10}$$

where a_{ij} represents the index data of the criterion layer; n represents the number of indicators; B_m represents the judgment matrix; W_{ij} denotes the normalized data of item j index; $\lambda_{\max}$ is the maximum eigenvalue; CI is the consistency index; and RI is the random consistency index.

4. Comprehensive green development index:

$$D = \sum W_{Dj} Z_{Dj};\ P = \sum W_{Pj} Z_{Pj};\ S = \sum W_{Sj} Z_{Sj};\ I = \sum W_{Ij} Z_{Ij};\ R = \sum W_{Rj} Z_{Rj} \quad (11)$$

$$\text{GDI} = \frac{SW_s \times RW_r}{Dw_d \times PW_p \times IW_i} \quad (12)$$

where GDI is the comprehensive green development index. D, P, S, I, and R represent the driving force index, pressure index, state index, impact index, and response index, respectively. W_{Dj} is the corresponding weight of the index j under the D criterion layer, Z_{Dj} is the standardized value of the index j under the D criterion layer, and W_D is the corresponding weight of the D quasi-lateral layer.

2.5. ArcGIS Spatial Analysis

In the analysis process, to more intuitively show the spatial differentiation of green development levels in Hunan Province, with the help of ArcGIS software, the natural breaking point method was used to divide the green development levels into five categories (very vulnerable area, extremely vulnerable area, medium vulnerable area, relatively vulnerable area, and non-fragile area). The overall spatial and local spatial autocorrelation characteristics of green development in the study area were analyzed by Global Moran's I index and Local Moran's I index:

1. Global Moran's I index:

$$I = \frac{n}{S_0} \times \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (y_i - \overline{y})(y_j - \overline{y})}{\sum_{i=1}^{n} (y_i - \overline{y})^2} \quad (13)$$

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \quad (14)$$

where n is the total number of space units, y_i and y_j represent the attribute values of the i and j space units, respectively, $\overline{y}$ is the mean value of the attribute values of all space units, and w_{ij} is the spatial weight value.

2. Local Moran's I index

$$I_i = \frac{Z_i}{S_2} \sum_{j \neq i}^{n} w_{ij} Z_j \quad (15)$$

$$Z_i = y_i - \overline{y};\ Z_j = y_j - \overline{y};\ S^2 = \frac{1}{\text{n}} \sum (y_j - \overline{y})^2 \quad (16)$$

where w_{ij} is the spatial weight, n is the total number of all regions in the study area, and I_i represents the local Moran index of the i region.

3. Results

3.1. Green Development Evaluation Results

In order to analyze the status of green development at different scales in Hunan Province, this study conducts a spatiotemporal analysis of green development from three perspectives: county, city, and province. Among them, county-level green development directly affects municipal-level green development and indirectly affects provincial-level green development.

3.1.1. Provincial Analysis

Based on the natural fracture method, this study divided the green development of Hunan Province into five levels. From Table 2, it can be seen that the area of the "very vulnerable" level showed a rapid upward trend in the four research years of 2005, 2010, 2015, and 2020, with growths of 4.9%, 48.1%, and 34.1%, respectively. This shows that the competitiveness of green development in Hunan Province is declining at an accelerated rate. Although the downward trend has eased after 2015, there is still a relatively large decline. The area of the "extremely vulnerable" level increased by a multiple in 2015, which is quite different from the other three research years. The "moderately vulnerable" area showed a downward trend as a whole. In addition, the "relatively vulnerable" and "not vulnerable" areas were higher in 2005 and 2010 and lower in 2015 and 2020. However, the change trend of green development level in recent years shows that the green development level of Hunan Province has declined, which indicates that Hunan Province urgently needs to change its mode of economic development and strengthen its ecological protection.

Table 2. Statistical table of the extent of green development at a provincial level in Hunan Province (km^2).

GDI	2005 (Year)	2010 (Year)	2015 (Year)	2020 (Year)
Very fragile	22.85%	23.97%	35.51%	47.60%
Extremely fragile	28.31%	26.24%	51.23%	34.18%
Moderately vulnerable	21.53%	17.52%	10.06%	10.51%
Relatively fragile	11.45%	15.02%	2.25%	4.04%
Not fragile	15.86%	17.25%	0.96%	3.67%

3.1.2. City Analysis

Figure 4, Tables 3 and 4 show that from the perspective of the city-level green development level and ranking, the cities with the highest green development level from 2005 to 2020 are Loudi, Hengyang, Xiangtan, and Yueyang. In general, the level of green development at the municipal level varies significantly. In addition, the dynamic changes in city-level rankings and the rate of change in green development levels show that Loudi, Yueyang, and Hengyang have relatively high green development levels, showing a steady upward trend. This shows that with the improvement in the economic development level and environmental protection level of Hunan Province, the economic development structure has evolved to a rational and advanced level, and the quality of economic growth has been continuously improved. Chenzhou City, Huaihua City, Shaoyang City, and Xiangxi Tujia and Miao Autonomous Prefecture have achieved remarkable results in green development construction, showing a fluctuating upward trend. It is worth mentioning that the ecological environment of Xiangtan City is fragile, the carrying capacity of resources and the environment is limited, and there has always been a contradiction between the needs for rapid economic development, resulting in slower changes in the level of green development and reflects the importance of improving green development. Overall, these cities need to rebalance economic development and environmental protection. It is necessary to focus on resource conservation while promoting economic expansion. In addition, it is also necessary to strengthen environmental governance to achieve the maximum economic development benefit with the minimum energy consumption and environmental pollution emissions.

3.1.3. County Analysis

Table 5 shows that the green development efficiency of Shuangfeng County is the highest in the study year, ranking almost in the top 10. Xinhua County, Lengshuijiang City, Lianyuan City, Zhuzhou County, Yanling County, Guzhang County, Shuangpai County, and Guidong County ranked in the top 10 twice. Among them, the green development level of Guzhang County and Yongxing County have changed the most and have made remarkable progress, indicating that these counties can better practice the green concept and implement the county green development system. However, the negative changes in the green development levels in Chaling County, You County, Yuanjiang City, Xiangxiang City, and Hanshou County are the most obvious. These counties face difficulties such as great changes in economic development and green development. It is necessary for these counties to adjust the development model in time and optimize the industrial structure and the green industry system. The green development level of Liuyang City, Cili County, Sangzhi County, Jishou City, Yongshun County, Ningxiang County, Liling City, Longhui County, Qiyang County, and Yuanling County are ranked at the end, indicating that there are problems such as pollution emissions, wastes of various resources, slow industrial upgrading, and industrial structures needing to be optimized. It is urgent to adjust measures to local conditions, develop characteristic green development paths, and accelerate the optimization and upgrading of industrial structures.

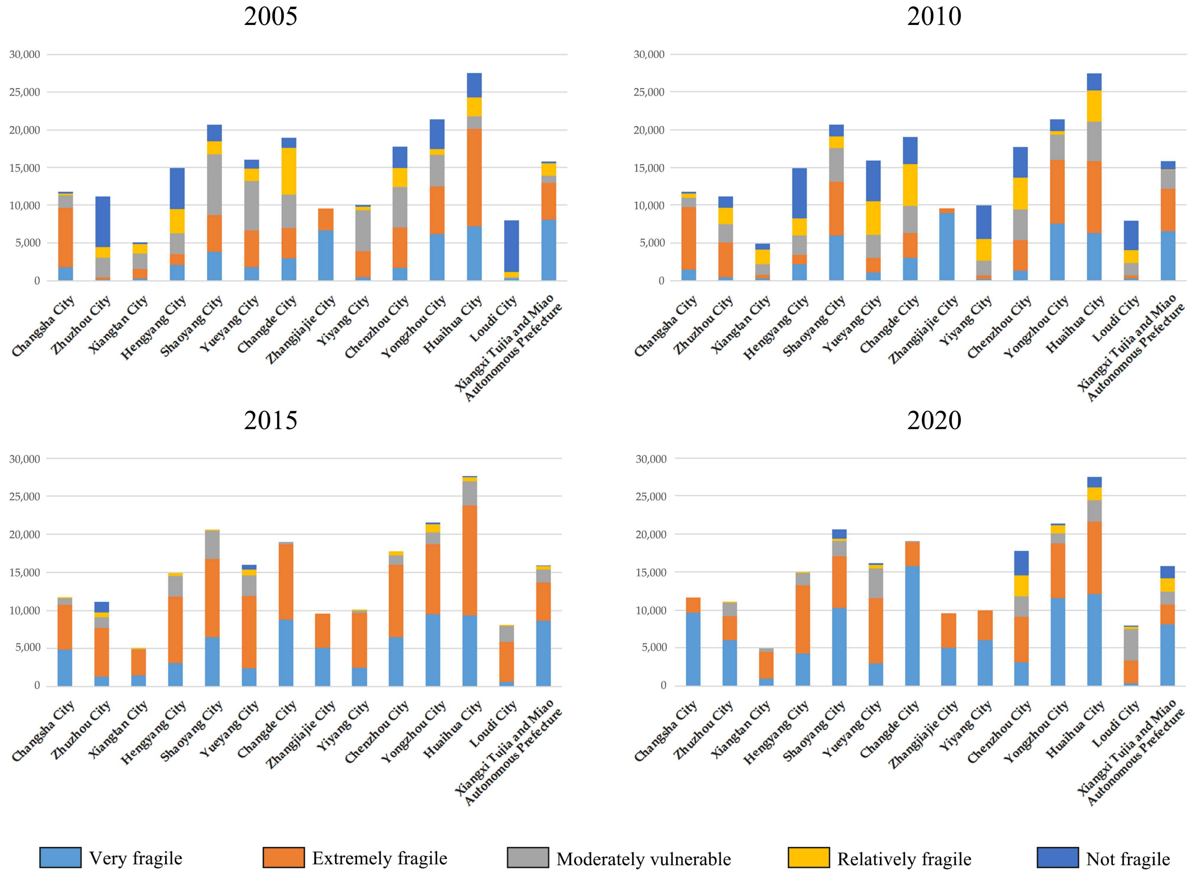

Figure 4. Changes in green development levels in 88 counties at the municipal level in Hunan Province from 2005 to 2020.

Table 3. Results of the evaluation of the green development level of 88 counties in the municipal area of Hunan Province from 2005 to 2020.

Ranking	2005		2010		2015		2020	
	City	Index	City	Index	City	Index	City	Index
1	Loudi City	0.038	Yiyang City	0.071	Zhuzhou City	0.689	Loudi City	0.422
2	Zhuzhou City	0.045	Loudi City	0.093	Loudi City	0.736	Chenzhou City	0.511
3	Hengyang City	0.234	Xiangtan City	0.164	Yueyang City	0.742	Xiangxi Tujia and Miao Autonomous Prefecture	0.681
4	Xiangtan City	0.315	Yueyang City	0.191	Hengyang City	0.795	Yueyang City	0.722
5	Changde City	0.369	Hengyang City	0.229	Shaoyang City	0.813	Huaihua City	0.786
6	Yiyang City	0.39	Chenzhou City	0.302	Huaihua City	0.865	Zhuzhou City	0.822
7	Chenzhou City	0.395	Changde City	0.33	Xiangxi Tujia and Miao Autonomous Prefecture	0.865	Shaoyang City	0.827

Table 3. *Cont.*

Ranking	2005		2010		2015		2020	
	City	Index	City	Index	City	Index	City	Index
8	Yueyang City	0.415	Zhuzhou City	0.452	Yongzhou City	0.876	Yongzhou City	0.879
9	Shaoyang City	0.423	Huaihua City	0.579	Chenzhou City	0.902	Hengyang City	0.889
10	Yongzhou City	0.588	Shaoyang City	0.636	Changsha City	0.927	Xiangtan City	0.915
11	Huaihua City	0.732	Yongzhou City	0.751	Yiyang City	0.968	Changde City	0.999
12	Xiangxi Tujia and Miao Autonomous Prefecture	0.82	Xiangxi Tujia and Miao Autonomous Prefecture	0.773	Changde City	0.987	Changsha City	1
13	Changsha City	0.826	Changsha City	0.827	Xiangtan City	0.987	Zhangjiajie City	1
14	Zhangjiajie City	1	Zhangjiajie City	1	Zhangjiajie City	1	Yiyang City	1

Table 4. The dynamic rate of change in green development level in 88 counties within the municipal area of Hunan Province from 2005 to 2020.

City	Very Fragile	Extremely Fragile	Moderately Vulnerable	Relatively Fragile	Not Fragile
Changsha City	0.674	−0.500	−0.145	−0.025	−0.004
Zhuzhou City	0.509	0.252	−0.064	−0.105	−0.592
Xiangtan City	0.130	0.469	−0.337	−0.255	−0.007
Hengyang City	0.142	0.513	−0.076	−0.211	−0.367
Shaoyang City	0.313	0.091	−0.292	−0.069	−0.043
Yueyang City	0.072	0.234	−0.168	−0.071	−0.066
Changde City	0.678	−0.047	−0.233	−0.327	−0.070
Zhangjiajie City	−0.176	0.176	0.000	0.000	0.000
Yiyang City	0.562	0.047	−0.546	−0.040	−0.024
Chenzhou City	0.081	0.035	−0.150	0.009	0.024
Yongzhou City	0.252	0.039	−0.135	0.016	−0.172
Huaihua City	0.181	−0.127	0.042	−0.033	−0.064
Loudi City	0.010	0.375	0.498	−0.054	−0.828
Xiangxi Tujia and Miao Autonomous Prefecture	0.000	−0.139	0.045	0.008	0.086

Table 5. Ranking of 88 counties in Hunan Province in terms of green development level (Due to a large number of counties, only the top 30 counties are ranked in the level of green development).

County Name	2005	County Name	2010	County Name	2015	County Name	2020	Ranking
Shuangfeng County	0.000	Leiyang City	0.017	Guzhang County	0.149	Guzhang County	0.138	1
Xinhua County	0.000	Xinhua County	0.022	Shuangpai County	0.202	Shuangpai County	0.208	2
Lengshuijiang City	0.000	Anhua County	0.038	Yanling County	0.274	Guidong County	0.253	3
Lianyuan City	0.000	Taojiang County	0.043	Yueyang County	0.324	Zixing City	0.294	4
Zhuzhou County	0.011	Xiangyin County	0.059	Suining County	0.337	Luxi County	0.303	5
Chaling County	0.015	Yuanjiang City	0.059	Zhuzhou County	0.357	Lengshuijiang City	0.304	6
Hengyang County	0.023	Lianyuan City	0.062	Guidong County	0.379	Shuangfeng County	0.330	7

Table 5. *Cont.*

County Name	2005	County Name	2010	County Name	2015	County Name	2020	Ranking
Youxian County	0.030	Xiangxiang City	0.064	Hengshan County	0.417	Rucheng County	0.331	8
Yanling County	0.049	Shuangfeng County	0.071	Hengdong County	0.438	Linwu County	0.333	9
Hengnan County	0.082	Hanshou County	0.083	Tongdao Dong Autonomous County	0.445	Yongxing County	0.334	10
Leiyang City	0.111	Hengyang County	0.086	Jingzhou Miao and Dong Autonomous County	0.453	Tongdao Dong Autonomous County	0.347	11
Liling City	0.114	South County	0.087	Shuangfeng County	0.467	Chengbu Miao Autonomous County	0.347	12
Qidong County	0.135	Yueyang County	0.094	Luxi County	0.498	Anren County	0.355	13
Shuangpai County	0.161	Hengnan County	0.109	Lengshuijiang City	0.517	Baojing County	0.356	14
Hengdong County	0.165	Hengdong County	0.120	Chengbu Miao Autonomous County	0.526	Suining County	0.365	15
Taoyuan County	0.178	Qidong County	0.125	Jinshi City	0.636	Lianyuan City	0.379	16
Hengshan County	0.190	Lixian County	0.126	Youxian County	0.642	Hongjiang City	0.383	17
Lanshan County	0.190	Guzhang County	0.132	Jiangyong County	0.685	Fenghuang County	0.391	18
Xiangtan County	0.194	Xiangtan County	0.139	Xiangyin County	0.696	Yanling County	0.410	19
Hanshou County	0.198	Guiyang County	0.157	Linxiang City	0.699	Jingzhou Miao and Dong Autonomous County	0.421	20
Guidong County	0.228	Hengshan County	0.165	Lianyuan City	0.722	Linxiang City	0.435	21
Linwu County	0.234	Miluo City	0.171	Dongkou County	0.724	Yueyang County	0.444	22
Anhua County	0.253	Pingjiang County	0.178	Dongan County	0.748	Xinhua County	0.459	23
Chengbu Miao Autonomous County	0.258	Taoyuan County	0.180	Changsha County	0.753	Jiangyong County	0.471	24
Zixing City	0.275	Zixing City	0.187	Wangcheng County	0.763	Huayuan County	0.488	25
Jiangyong County	0.281	Shuangpai County	0.191	Zhijiang Dong Autonomous County	0.790	Hengshan County	0.498	26
Anren County	0.282	Linwu County	0.216	Huitong County	0.809	Zhuzhou County	0.513	27
Guiyang County	0.282	Lengshuijiang City	0.221	Hengnan County	0.821	Huitong County	0.578	28
Suining County	0.284	Linxiang City	0.236	Huayuan County	0.831	Jinshi City	0.636	29
Luxi County	0.293	Yanling County	0.236	Linwu County	0.847	Jiahe County	0.652	30

In general, the green development efficiency of most counties is at a low level, and the city with the lowest green development level index is Yongshun County. In addition, the green development level of 88 counties and cities in Hunan Province shows a bipolar state, and there are few medium-low and medium-high efficiency cities. Among them, the index difference between the cities with the highest level of development and the cities with the lowest level of development is close to 1, indicating that the imbalance of green development levels within the counties of Hunan Province in 2020 is relatively obvious. This result also shows that counties must cooperate in green development. High level of green development cities such as Shuangfeng County should play a leading role in driving the surrounding counties to improve the level of green development. Cities with a low level of green development such as Liuyang City, Cili County, Sangzhi County, Jishou City, and Yongshun County should adopt advanced green production technology and gradually improve the balance of green development in Hunan Province.

As shown in Figure 5, to further explore the impact of the various sub-systems of green development on the overall green development of the county, the top-ranked high-quality green development counties and the lower-ranked low-quality green development counties were selected for comparative analysis. The results show that the pressure system (P) index of low-quality green development counties is significantly higher than that of high-quality green development counties. Both the state system (S) and the impact system (I) show fluctuating changes. In addition, the driving force system (D) index of high-quality green development counties is smaller than that of low-quality green development counties, and there is no significant difference in the response system (R) index. Therefore, it can be shown that the synergy of the pressure system and the driving force system has a greater impact on the green development of the county and that the economic development of each county has a certain negative impact on the urban resources and the environment. The development of the city is realized on the basis that the environment is under greater pressure. In addition, the state system and impact system have a certain impact on the green development of the county, indicating that the environmental governance of each county has a certain effect, but new problems will continue to arise. However, without the formation of early warning and pre-control mechanism, it is impossible to effectively avoid environmental pollution and destruction. The response system index shows a stable and high trend, indicating that the county governments have formulated and adopted positive countermeasures and policies in the process of promoting urban sustainable development, which alleviates the pressure of urban green development. The state of resources and the environment tends to improve, but the results achieved are still very limited.

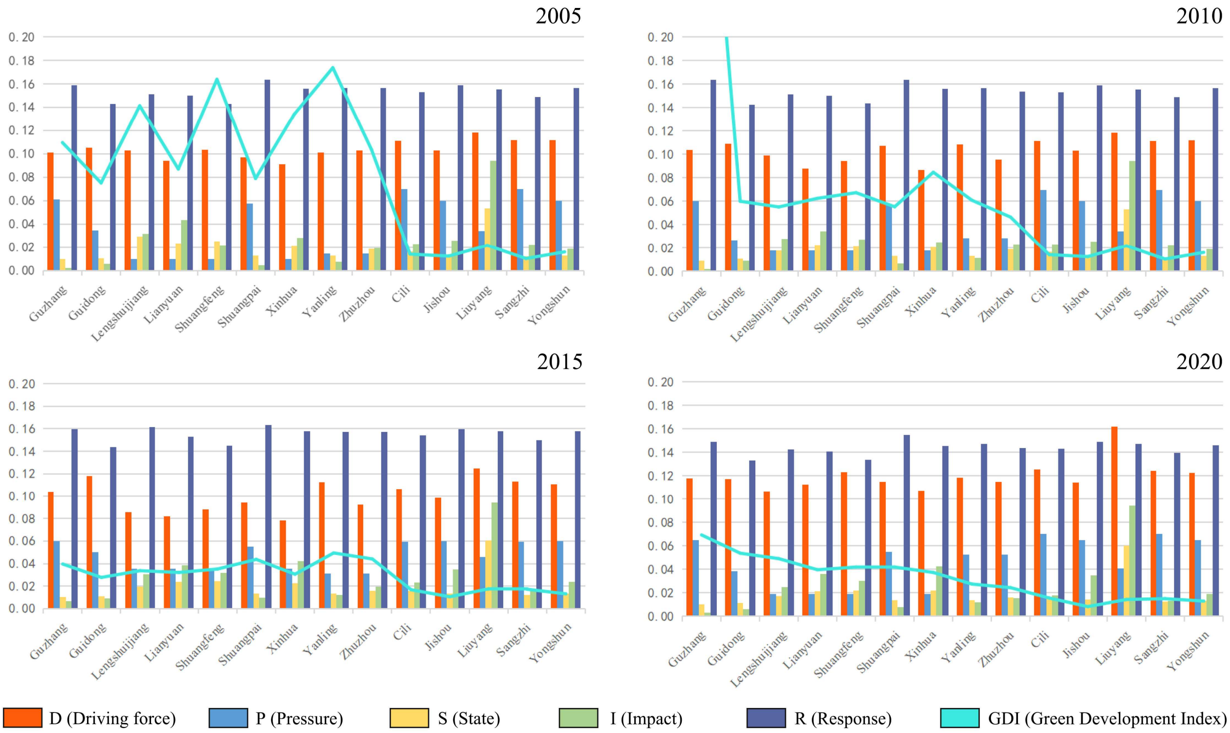

Figure 5. Green Development Subsystem Evaluation Analysis of Top-Ranked Counties and Bottom Ranked Counties on Annual Average 2005–2020.

3.2. Spatial Autocorrelation

Global spatial autocorrelation is measured by Moran's I and implemented by Space/ univariate Moran's I in Geoda. There are three modes: the spatial agglomeration mode, the spatial divergence mode, and the spatial random mode. When $p < 0.05$ and Z score higher than 1.96, the spatial distribution pattern is an agglomeration distribution. When $p < 0.05$ and Z score is less than -1.69, it is in the divergent mode. When $p > 0.05$, it is a random pattern. Table 6 shows the global spatial autocorrelation analysis of the green development index from 2005 to 2020. It shows that the Moran's I value is greater than zero from 2005 to 2020, indicating that China's green development index has a positive correlation in space, and the green development index has a positive spatial autocorrelation process, which is characterized by spatial agglomeration. In addition, with the passage of time, the spatial dependence gradually decreased from 2005 to 2015. Global Moran's I value decreased from 0.785 in 2010 to 0.744 in 2015. The green development index showed a slight trend of spatial diffusion and increased from 0.744 in 2015 to 0.787 in 2020. The degree of spatial agglomeration increased. Table 6 shows that the Moran's I value from 2005 to 2020 is greater than zero, indicating that the green development index has a positive spatial correlation, showing the characteristics of spatial agglomeration. Furthermore, from 2005 to 2015, this spatial dependence gradually decreased, with Global Moran's I decreasing from 0.785 in 2010 to 0.744 in 2015. The green development index showed a slight trend of spatial diffusion, rising from 0.744 in 2015 to 0.787 in 2020, indicating an increase in the degree of spatial agglomeration.

Table 6. Global Moran's I index of green development level of counties in Hunan Province, 2005–2020.

Year	2005	2010	2015	2020
Global Moran's I index	0.785	0.761	0.744	0.787

To distinguish the local spatial aggregation degree of each county in Hunan Province and analyze the similarity and spatial differentiation characteristics of the green development level of a county unit and its adjacent county units, ArcGIS 10.7 and Excel 2016 were used to draw the scatter plot of the Moran's I indices for the green development level of counties in Hunan Province from 2005 to 2020 (Figure 6). The "high-high" (HH) and "low-low" (LL) quadrants in the Moran scatterplot indicate that the overall green development at the county-level regional level in Hunan Province has a strong positive spatial correlation. The 'high-low' (HL) and 'low-high' (LH) quadrants correspond to strong negative spatial correlations, indicating spatial heterogeneity (discrete distribution patterns) in green development levels at the county-level regional level. It can be seen from Figure 6 that there are more counties in the HH and LL quadrants than in the HL and LH quadrants. The overall green development level also has a high regional concentration, with high values in the middle and east and low values in the west. The HH quadrant corresponds to counties with relatively high overall green development levels. These counties are close to each other and are mainly distributed in the central and eastern coastal areas and the northeast. The LL quadrant corresponds to counties with a low overall green development level. These counties are also close to each other, mainly in the west, northwest, and southwest of China. The LH quadrant contains local low-value anomalies: these counties correspond to lower levels of overall green development but higher levels in neighboring counties. On the contrary, the HL quadrant contains high-value outliers: the overall green development level of these counties is higher, but the level of adjacent counties is lower.

In conclusion, there is an obvious spatial dependence on the green development level of counties in Hunan Province; that is, the green development level of most counties in Hunan Province shows aggregation characteristics with adjacent areas. Furthermore, Figure 7 shows the LISA plot of the Moran's I indices of the green development level of counties in Hunan Province from 2005 to 2020. It can be seen from Figure 7 that the green development level of counties forms two different agglomeration areas in space. One is the "low-low" low-speed growth area of green development, which is composed of Longshan County, Yongshun County, Sangzhi County, Cili County, Yuanling County, Baojing County, and Guzhang County. These areas are located in the remote northwest, with vast territory, sparsely populated areas, relatively slow development of industrialization, and insufficient innovation power for green development. Another is the 'high-high' diffusion effect area of green development, which is composed of Xinhua County, Xupu County, Lianyuan City, Xiangxiang City, Shuangfeng County, Hengyang County, Hengshan County, Hengdong County, Hengnan County, Shuangpai County, Lanshan County, Ningyuan County, Xintian County, Jiahe County, Yanling County, Guidong County, and Rucheng County. Most of these areas are located in the middle east and eastern coastal areas. In addition, in the study area, there are few polarization effects, such as 'high-low' concentration areas and the transition's 'low-high' concentration areas at the a 0.05 significance level.

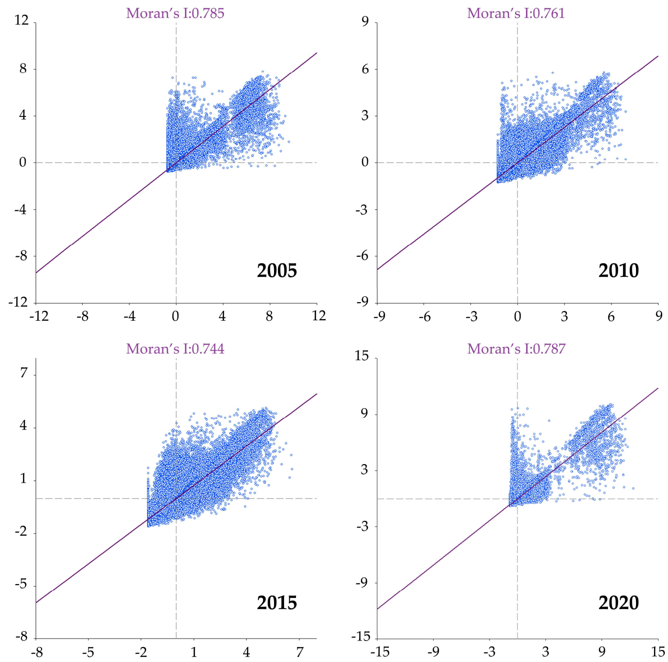

Figure 6. Scatter plot of Moran's I index for green development level of counties in Hunan Province, 2005–2020.

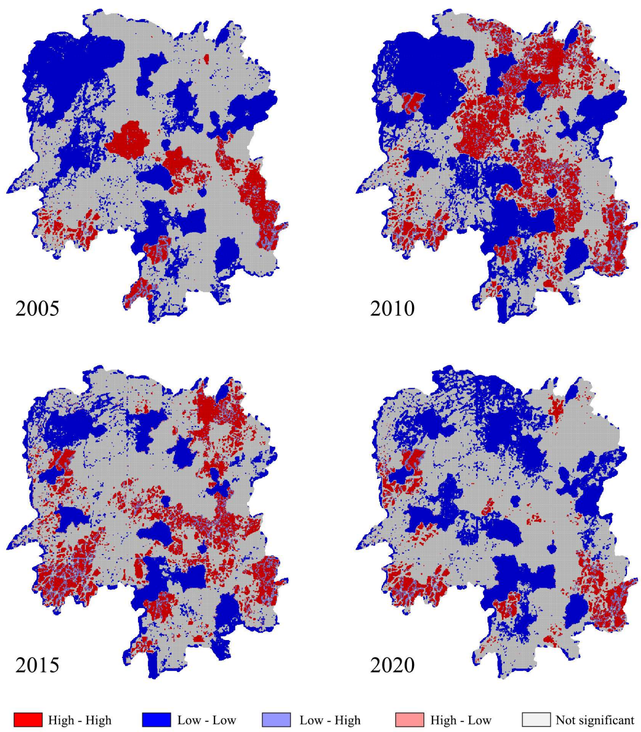

Figure 7. LISA plot of Moran's I index of green development level of counties in Hunan Province, 2005–2020.

3.3. Spatial Heterogeneity Analysis

From Figure 8, it can be seen that there are obvious spatial differentiation characteristics in the green development level of each county in Hunan Province. The details are as follows: In 2005, the overall spatial pattern of green development showed the characteristics of being high in the middle and east and low in the west. In 2010, the overall spatial pattern of green development showed the characteristics of being high in the east, low in the middle, and low in the west. In 2015, the overall spatial pattern of green development showed an overall sluggishness, with a slight increase in the east. However, the overall spatial pattern of green development in 2020 has strong spatial locking characteristics, with stable high-value areas in the east and relatively stable low-value areas in the central and western regions. From the perspective of the evolution process of spatial differentiation within the research period, the high-value areas gradually spread to the northeast of Hunan Province from 2005 to 2010, and the green development level of the northeast was enhanced. From 2010 to 2015, the level of green development in the whole county showed an obvious downward trend, and green development was restricted and hindered, which indicates that it is necessary to improve the quality and efficiency of economic development and promote the green transformation of economic development. In addition, the level of green development from 2015 to 2020 has been further enhanced, and the agglomeration features are remarkable. There is a significant spatial difference between the central region and the west and east, and the development trend of polarization is obvious. It can be seen that the green development level of each county in Hunan Province has undergone great changes during the study period. It is urgent to optimize the economic development structure and environmental protection methods, improve the quality of economic development and environmental protection, and change the excessive intake mode of resources and the environment in economic development.

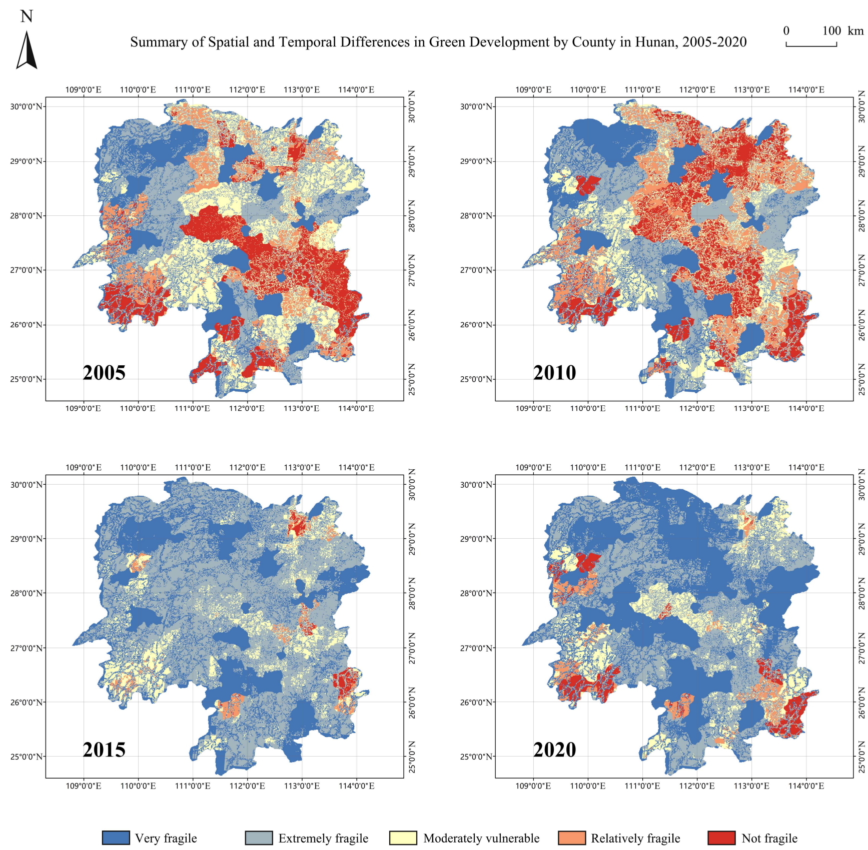

Figure 8. Summary of Spatial and Temporal Differences in Green Development by County in Hunan, 2005–2020.

4. Discussion

In this paper, the interaction factors of each link are considered, and green development indicators are set based on the DPSIR model. In addition, combining PCA and AHP to determine the index weights avoids the uncertainty of subjective weighting methods such as the Delphi method [21]. At the same time, with the support of ArcGIS and Geoda software, spatial visualization analysis is carried out. The results show the spatial differences in green development in the counties of Hunan Province and some factors that cause these differences. There are still differences in the green development models among the counties in Hunan Province, which still need to learn from each other to improve. The level of green development in the coastal areas of China is relatively high, while the level of green development in the northwest region is relatively lagging [57,58,62]. The research conclusions of Deng et al. [10] are similar to the evaluation results of this paper, both concluding that stable ecosystem development is needed in Hunan Province. It can be seen that the development trend of the green development index in Hunan Province is almost the same as that in China's inland provinces. However, there is variability in the results for the spatial distribution of development levels. Starting from a micro perspective, this paper takes each county as the unit of research and identifies problems such as the slowing down of green development and large regional differences in development in Hunan Province. The reasons for this may be related to policy development, industrial restructuring, and pollutant treatment levels in each county. This phenomenon verifies the hypothesis in the introduction. Due to the rapid development of agriculture and industry in the past two decades, Hunan Province has neglected the protection of environmental resources and ecology, so the green development index has shown a downward trend, especially in the northeastern region dominated by agriculture, which is greatly affected by human interference, and has the lowest green development index.

The contradiction between economic development and environmental protection has existed for a long time. Therefore, while promoting economic development and social progress, it is also necessary to always pay attention to resource conservation and environmental protection. It is very important to seek a balance between economic growth and the harmonious development of the environment. The green development mode is a deep exploration of the harmonious coexistence model between human beings and nature when dealing with today's global resource and environmental problems [45–51]. In addition, green development is not a stylized model but needs to be comprehensively judged according to the social, economic, and environmental conditions of different regions and explored from multiple perspectives and in-depth levels to discover the inhibitory factors that affect the harmonious development of cities [54–56]. It is not difficult to find that the improvement in the level of green development requires coordination and improvement in various factors. The government should play an active role in macro-control, such as increasing R&D investment in energy conservation, emission reduction, and resource utilization; reasonably formulating relevant laws and regulations; further strengthening the control of pollutant discharge and resource waste; encouraging the development of emerging green industries; advocating for the optimization and improvement of industrial structure and provide corresponding subsidies and technical support for farmers; and reducing damage to cultivated land, forest land, and rivers. In addition, enterprises should introduce relevant environmental protection technologies to improve production efficiency and reduce the waste of resources in the production process. Finally, residents need to raise awareness of environmental protection and promote the concept of green development. Only through multi-party coordination can the level of green development be comprehensively improved.

On the whole, it is necessary to correctly understand regional differences and apply local advantageous conditions to formulate relevant green development methods. In addition, there are also significant differences in the level of green development in different regions of China. Therefore, it is necessary to strengthen exchanges and cooperation between provinces and cities and introduce advanced management experience and technical means.

It is also necessary to speed up the transformation of old industries in the northwest region and increase production capacity, to reduce pollution emissions and speed up economic development. At the same time, it is also necessary to strengthen the urban infrastructure construction, maintain the balance between economic development and environmental protection, and improve the overall level of green development.

5. Conclusions

The results show that the counties in Hunan Province have achieved good results in the early stage of green development, and show a trend of steady improvement. However, in recent years, the level of green development has declined significantly. Although it has eased in 2020, the proportion of highly competitive green development regions is still insignificant, indicating that counties in Hunan Province urgently need to change their green development models. From 2005 to 2020, the county green development index showed an agglomeration distribution (HH and LL). The overall ranking of the green development index was in the order of eastern counties > central counties > northeast counties > southwest counties, and the difference between western counties and northwest counties is not obvious. In addition, from 2005 to 2020, the green development level of each county has obvious spatial differentiation characteristics. It is worth mentioning that the D and P systems have a significant role in promoting the green development of the county, while the S and I systems have a certain role in promoting the green development of the county. Based on the evolution mechanism of green development in Hunan Province, this paper studied the new green development evaluation system and put forward three suggestions for green development in Hunan Province as follows:

(1) According to the comprehensive judgment of the social, economic and environmental conditions in Hunan Province, investigate in-depth from multiple angles and levels to discover the restrictive factors of green development and implement ecological compensation or industrial transformation measures to reduce the restrictive effect.
(2) The government could increase investment in energy conservation, emission reduction, and resource utilization; strengthen the control of pollutant discharge and resource waste; and encourage the development of emerging green industries.
(3) Strengthen exchanges and cooperation between provinces and cities and introduce advanced management experience and technical means. Strengthen urban infrastructure construction, increase industrial production capacity, reduce pollution emissions, and ensure a balance between economic development and environmental protection.

This study couples the SD and DPSIR models, and establishes a green development index model from the five aspects of driving force, pressure, state, impact, and response, combining resources, the ecological environment, and socioeconomic indicators. However, the selection of evaluation indicators is subject to a certain degree of subjectivity, and this study fails to accurately predict the future green development of Hunan Province. Future research should adopt scenario simulation to predict green development as the research direction.

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