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Evaluating Sustainable Development of Land Resources in the Yangtze River Economic Belt of China

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ABSTRACT

The Yangtze River Economic Belt (YREB) is one of the most economically active regions in China, where an imbalance between the demand for land and the non-renewable is increasingly prominent. The authors present the patterns of land use in the YREB, then construct an evaluation index based on the pressure-state-response model. The TOPSIS model is used to evaluate sustainable land development in the YREB, and the spatial deductive characteristics of sustainable development levels are analyzed using three aspects: global spatial correlation, local spatial correlation, and regional difference. The results about the YREB show that (1) the comprehensive sustainable land development score is average, indicating moderate sustainability with a fluctuating upward trend and good prospects. (2) The sustainable development levels of land have strong positive spatial correlation and agglomeration; the agglomeration characteristics follow a pattern similar to that of the status of economic development. (3) Sustainable development levels of land in the provinces and cities show great spatial differences.

KEYWORDS

Evaluation Index, Land Use, PSR-TOPSIS Model, Spatiotemporal Deduction Characteristics

INTRODUCTION

Land resources are the most basic and important natural resource; they include both natural and social elements, and provide materials needed for production (Kretschmann, 2013). Specifically, the natural elements of land resources are the inherent attributes formed by long-term interactions and various restrictive elements such as lithology, slope, altitude, soil texture, etc. These characteristics directly affect the suitability and quality of land resources. The social elements of land resources are the specific attributes that promote production through development and utilization of land resources. Although development and utilization of land can create economic and social benefits, they can also lead to several problems, such as soil erosion, desertification, and a decline in the regional ecological energy value. Therefore, land use is related to sustainable development.

The YREB straddles three major regions in China, covering 11 provinces and cities, and occupying 2.05 million square kilometers, which is 21.4% of China's territory. The YREB accounts for more than 40% of China's population and GDP, making it a major strategic development region with national and global influence. Due to rapid economic development and the increasing population density in

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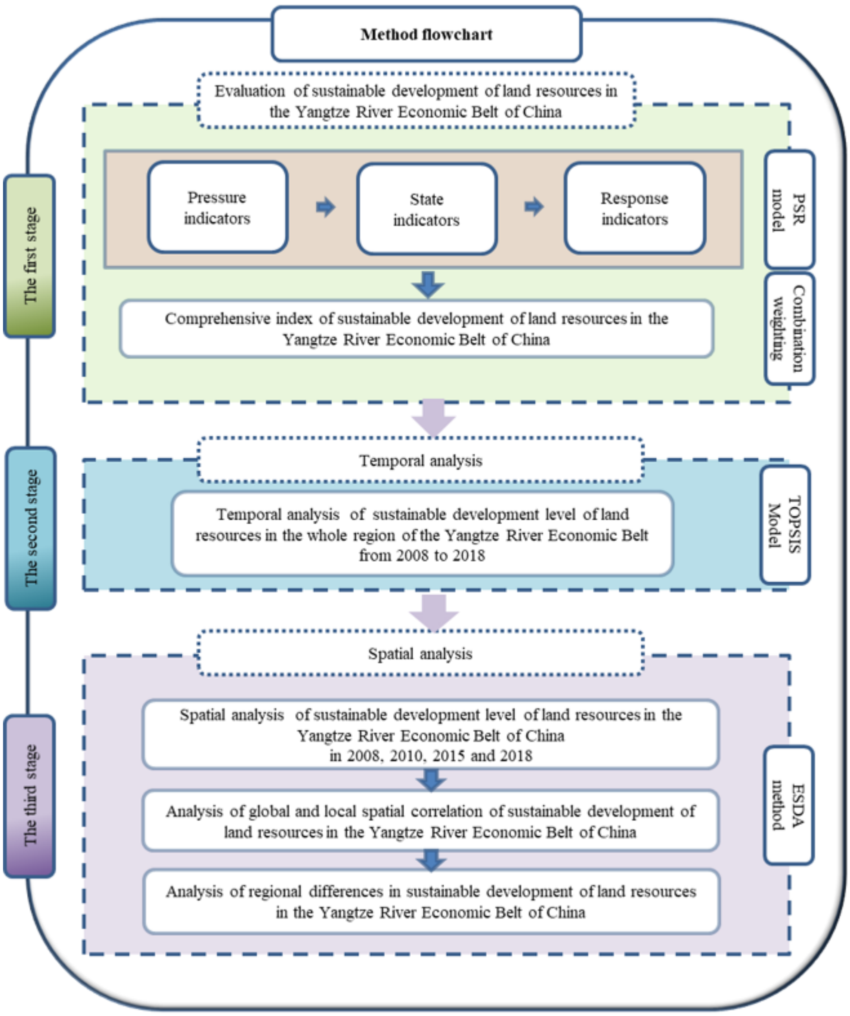
Figure 1. Method flow chart



the YREB, the demands of land are increasingly diversified, and the connections and competition among ecological, economic, and social elements are complex. Additionally, the limited amount of land in the YREB is a significant threat to land use sustainability. Therefore, it is of great practical significance to evaluate the sustainable development level of land resources, understand the current situation of land development and utilization, and clarify the existing problems in land use. In this study, we used various models and methods to analyze the sustainable development level of land resources in the YREB (Figure 1).

LITERATURE REVIEW

Land resources refer to the land that can be used by human beings in the foreseeable future based on current capacity conditions (Fürst et al., 2013; Guang & Qing, 2006; Hurni, 2000). The Framework for the Evaluation of Sustainable Land Management promulgated by the Food and Agriculture Organization of the United Nations (FAO) in 1993 sets out the basic principles, procedures, and five criteria for the sustainable use of land resources (Food and Agriculture Organization, 1993). Weiland asserted that sustainable use of land resources is the key to healthy economic and social development (Weiland et al., 2016). Ecological, economic, social, and cultural aspects should be integrated into long-term planning of land resource utilization, and the relationship between people and land, and between people, resources, and the environment should be coordinated (Weiland et al., 2016). Since then, studies on evaluating and modelling environmentally friendly land resource utilization have been gradually increasing. Scholars began to analyze the impact of natural, social, and economic factors on the sustainable use of land resources (Cocklin et al., 2004; Reidsma et al., 2011; Song et al., 2015; Song et al., 2019), and sustainable utilization has become a research focus.

The Sustainable Land Use Management and Information Systems International Academic Conference was held in the Netherlands in August 1997 and established an evaluation index for sustainable land resource development. Scholars generally believe that the evaluation index should be established based on natural, economic, and social aspects. These factors have subsequently been included in quantitative evaluations of the sustainable development level of land resources (Dumanski & Pieri, 2000; Van Paassen et al., 2007). However, the initial model could only explain the mutual influence among variables and could not interact with decision-makers and executors (Loevinsohn et al., 2002). As a result, the development of evaluation models became more "flexible," gradually integrating information from end participants (researchers, land planners, decision makers) in the simulation, and fully accounting for the needs, knowledge structure, and wishes of decision makers (Braimoh, 2009; Gonzalez-Redin et al., 2019; Kerr et al., 2016; Wang et al., 2017). With the continual development of technology, the application of big data, artificial intelligence, and other technologies in the field of sustainable development have improved the accuracy of the evaluation index (Law et al., 2021; Sarkar et al., 2014; Zhu et al., 2019). GIS, remote sensing, and other technologies have been increasingly used in the construction of an evaluation index for the sustainable development of land resources (Abera et al., 2019; Dewan & Yamaguchi, 2009; Li et al., 2016; Osman et al., 2016).

Commonly used methods for the quantitative evaluation of sustainable development levels of land resources include mathematical modeling (AbdelRahman et al., 2018), the ecological footprint method (H.-S. Chen, 2017), the entropy weight method (Reidsma et al., 2011), the analytic hierarchy process (Kazemi et al., 2016; Soares-Filho et al., 2014), and the TOPSIS model (Zhang et al., 2020). Among them, the entropy weight and TOPSIS models are most commonly used because they can evaluate the sustainable development level of land resources from the data, and the evaluation results are relatively objective. In recent years, descriptive statistical methods such as the Moran's I and spatial convergence models (Chen et al., 2020; Liu et al., 2019; Xie & Wang, 2015) have also been increasingly applied in relevant studies for the analysis of spatial distribution characteristics of the level of sustainable development of land resources.

It remains necessary to construct an evaluation index for the sustainable development levels of land resources in line with China's national conditions. At present, most of the related studies present changes in the sustainable development level of land resources in a certain region for a certain period, or analyze the difference in sustainable development levels of land resources within a certain region. No comprehensive studies across spatial and temporal dimensions have been carried out. Based on the PSR-TOPSIS model, this study comprehensively evaluates the sustainable development levels of land resources in the YREB, both spatially and temporally. Based on the results, countermeasures and suggestions to promote sustainable development levels of land resources in the YREB are suggested.

THE GENERAL SITUATION OF THE YANGTZE RIVER ECONOMIC BELT AND THE CURRENT PATTERNS OF LAND USE

Overview of the Yangtze River Economic Belt

The YREB plays an important strategic role in spatial geography, ecological resources, and industrial structure. In terms of spatial geography, the YREB is located on the east–west axis of the territorial space development zone, integrating coastal, riverside, border, and inland openings. It has the unique advantages of an east–west two-way opening. It has formed an opening along the river with the Shanghai Pudong New Area as the leader, the Yangtze River Delta as the guide, and riverside open cities as the fulcrum; it has an important position in transportation and economic development. In terms of ecological resources, the YREB has a high ecological status. With water as a link, it connects upstream and downstream, left and right banks, and main tributaries, and has abundant freshwater resources, accounting for about 35% of the total water resources in the country. Mountains, rivers, forests, fields, lakes and grass are to be incorporated into one, with effective conservation, biological breeding, oxygen release, carbon fixation, and environmental purification. Large reserves of mineral resources create great potential for development. In terms of industrial structure, the YREB is one of the principal industrial corridors in China. It combines a large number of modern industries such as steel, automobile, electronics, and petrochemicals, and houses a large number of high-energy, high volume tech industries and super-large enterprises.

Current Land Use Patterns in the Yangtze River Economic Belt

By the end of 2018, the area of the YREB was approximately 1.867 billion hectares, with a per capita land area of approximately 3.14 ha (based on the permanent resident population). There were 1,096 nature reserves, covering 17.782 million hectares, accounting for about 9% of the total land area of the YREB. A total of 184 geoparks have been built, with an investment of 37.44 billion yuan, accounting for more than 50% of the whole country. A total of 50.597 million hectares of soil erosion have been brought under control, and 1.862 million hectares are expanded, accounting for 40.2 percent and 31.6 percent of the whole country respectively, respectively. Restoration of mining land had been conducted in an area of 18,000 hectares, accounting for 23.4 percent of the country’s total area. The types of land resources in the YREB can be subdivided into agricultural and construction land. Agricultural land can be divided into cultivated land, woodland, garden land, and grassland, while construction land can be divided into urban, village, industrial, and mining land; transportation land; and water and land for water facilities. The changes in the land resource use structure in the YREB in 2010, 2014, and 2018 are shown in Table 1.

Considering Table 1, along with the acceleration of construction, urbanization, and industrialization in the YREB, the area of cultivated land gradually reduced while construction land increased. Under the influence of policies directing the return of farmland to forest and limiting logging, the area of woodland increased steadily.

Land use patterns differed among the provinces. The proportion of cultivated land in Jiangsu and Anhui, traditional agricultural provinces, was relatively high. Zhejiang, Hunan, and Jiangxi had the highest proportion of forest land. Grassland resources in Sichuan and Yunnan were abundant due to their geographical location and other natural factors. Shanghai and Jiangsu had a relatively large proportion of construction land, which was consistent with the relatively developed economies of these provinces.

CONSTRUCTION OF AN EVALUATION INDEX FOR THE SUSTAINABLE DEVELOPMENT OF LAND USE RESOURCES IN THE YANGTZE RIVER ECONOMIC BELT

PSR Model

The PSR model is commonly used by the Organization for Economic Cooperation and Development (OECD) in the assessment of ecological environment quality and consists of three levels: pressure, state, and response. Pressure refers to the negative effects and impacts on natural resources when production and living activities are carried out. State refers to the state of natural resources under pressure, and response refers to a series of measures taken to relieve the pressure and improve the state of natural resources to tackle the negative effects of production and living activities. The index

Table 1. Changes in land resource use structure in the Yangtze River Economic Belt in 2010, 2014, and 2018

Land Type	2010		2014		2018	
	Area (100 Million Hectares)	Specific Gravity (%)	Area (100 Million Hectares)	Specific Gravity (%)	Area (100 Million Hectares)	Specific Gravity (%)
Agricultural land	1.59	92.37	1.61	91.74	1.62	91.25
Arable land	0.46	25.51	0.45	25.72	0.44	25.89
Woodland	0.95	55.66	0.99	56.43	1.01	57.03
Garden plot	0.05	2.88	0.06	3.17	0.06	3.40
Grassland	0.14	8.32	0.11	6.42	0.09	4.94
Building land	0.13	7.63	0.14	8.26	0.16	8.75
Urban, village, industrial, and mining land	0.10	6.13	0.12	6.70	0.13	7.15
Transportation land	0.01	0.63	0.01	0.73	0.01	0.81
Water and land for water facilities	0.02	0.88	0.01	0.83	0.01	0.80
Total	1.73	100.00	1.75	100.00	1.76	100.00

Note: Data were derived from the China Statistical Yearbooks, which were last updated in 2018.

chain formed by pressure, state, and response indexes has comprehensive characteristics and can reveal specific problems and changes in the sustainable utilization of natural resources.

With the development of the social economy and the progress of science and technology, people's ability to develop and utilize land resources is increasing constantly, evidencing the gradual strengthening of the ability to exchange material, energy, and information with land resources, and the increasing pressure on land resources; this is due to the influence of various factors. Therefore, pressure indicators should be selected from many aspects, such as population, economy, and society, to measure the negative effects of land resource development and utilization of natural resources. Due to a combination of influencing factors, the pressure on land resources leads to changes in their quality and quantity. State indicators are selected from the perspectives of natural, economic, and social attributes to reflect the main characteristics of land resources under pressure. To reduce the pressure on and improve the state of land resources, policies, legislation, and systems encourage reasonable allocation and effective, sustainable use of land resources. Governance and control indicators can be used as response indicators to explore the strength of the overall planning of land resources.

Construction of an Evaluation Index of Sustainable Development Level of Land Resources in the Yangtze River Economic Belt Based on the PSR Model

The evaluation of the sustainable development level of land resources needs to consider land resources as a complex system of nature and social economy, and to examine and evaluate the state, process, and development trend characteristics of the whole system as a human–land relationship. Therefore, it is necessary to select sensitive indices that accurately reflect various characteristics. At the same time, the following principles should be followed when constructing an evaluation index for the sustainable development of land resources:

1. **Principle of stratification and quantification**: The index should include multiple levels, such as target, criterion, and index. It is necessary to carry out a quantitative evaluation at each level and produce a comprehensive evaluation index.

2. **Dynamic principle**: Sustainable development levels are not only restricted by the conditions of land resources, but also by social and economic factors. The sustainable development levels of land resources can change over time, and the evaluation index should be able to take these changes into account.
3. **Scientific principle**: China has a vast territory, and different regions have separate land endowments. Therefore, it is necessary to design a systematic evaluation index based on the characteristics of land resources in the YREB.

According to these principles, the evaluation index of sustainable development level of land resources in the YREB based on the PSR model was composed of the following:

1. **Pressure indicators**: Population growth and economic and social progress are the main factors threatening the security of land resources. The natural population growth rate and population density were chosen to reflect the pressure of population growth on sustainable land resource utilization. The annual growth rate of per capita GDP and the proportion of GDP of secondary industries were selected to reflect the pressure of economic development. The amount of industrial land as a proportion of urban construction land area and the use of agricultural resources per unit of arable land area reflect the pressure of social development on the sustainable use of land resources.
2. **State indicators**: These were selected using three dimensions: ecological, economic, and social attributes. Natural attributes reflect intrinsic and essential characteristics of land resources, while understanding the nature of land resources. The effective irrigated area, grain yield, green coverage rate, and forest coverage rate of built-up areas were selected to represent inherent attributes. Economic attributes are the embodiment of the value of land resources, which is manifested through development and utilization of land resources. Economic density and land equal fixed asset investments were selected to represent economic attributes. When land resources are utilized for material production, these constitute material elements of social productivity. Land resources affect the national economy and people's livelihoods, and are the basic elements for people's survival. The per capita cultivated land area, urbanization rate, and rural per capita disposable income were selected to represent social attributes.
3. **Response indicators**: To compensate for the negative effects of production activities on natural resources and ensure sustainable use of land resources, society and individuals take a series of measures to carry out long-term or periodic management and governance transformation of land resources, to reduce the pressure on and improve the state of land resources. Therefore, representative indicators were selected as response indicators from two aspects of governance and control, and the proportion of environmental protection investment in GDP, soil erosion control area, and afforestation area were selected as response indicators. The comprehensive utilization rate of industrial solid waste, environmental regulation, and the urban domestic sewage treatment rate were selected as control response indicators.

RESEARCH METHODS AND DATA SOURCES

Research Methods

Standardization of Data

To eliminate dimensional effects, the data were standardized. The formula for positive and negative indicators are shown in equations (1) and (2) respectively:

$$X_{ij}^{'} = \frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}} \tag{1}$$

$$X_{ij}^{'} = \frac{X_{\max} - X_{ij}}{X_{\max} - X_{\min}} \tag{2}$$

In equations (1) and (2), i =1, 2, 3..., m, denotes year; j = 1, 2, 3..., n, denotes index; X_{ij} is the original value of the j index in the i year; $X_{ij}^{'}$ is the standardized index value of X_{ij}; $X_{\min}$ is the minimum value in X_{ij}; and $X_{\max}$ is the maximum value in X_{ij}.

Determination of index weight

The entropy weight method measures the degree of influence of each index by calculating the entropy value of each index. The greater the entropy value, the higher the weight and this has strict mathematical significance and strong objectivity. The entropy weight method was used to calculate the weight of each index. The calculation process was as follows:

1. First, all indexes were quantified to the same degree to calculate the proportion P_{ij} of the index value in year i of the j evaluation index and the entropy value e_j of the j evaluation index, using the following equations:

$$P_{ij} = X_{ij}^{'} \Big/ \sum_{i=1}^{m} X_{ij}^{'} \quad \text{and} \tag{3}$$

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} P_{ij} \ln P_{ij} \tag{4}$$

where $0 \le e_j \le 1$, $P_{ij} = 0$, and $P_{ij} \ln P_{ij} = 0$.

2. The utility value of index j (coefficient of difference) was calculated. For the j index, if e_j is smaller, the utility value d_j, weight of the index, will be larger. Otherwise, the utility value d_j of the index will be smaller, and the degree, value, and weight of the index will be smaller. The utility value (coefficient of difference) was calculated using the following equation:

$$d_j = 1 - e_j \tag{5}$$

3. The weight of index j was calculated using the following equation:

$$w_j = d_j \Big/ \sum_{j=1}^{n} d_j \tag{6}$$

where $0 \le w_j \le 1$, $\sum_{j=1}^{n} w_j = 1$.

In conclusion, the weight of the evaluation index of the sustainable development level of land resources in the YREB from 2008 to 2018 was obtained using the entropy weight method. Then, the average value of each index in each year was taken as the final weight of the index. The explicit calculation results are listed in Table 2.

TOPSIS Model

The central idea of the TOPSIS model is to weigh the normalized decision matrix, determine the positive ideal solution and negative ideal value, calculate the Euclidean distance from the evaluation object to the positive ideal value scheme and the negative ideal value scheme, and calculate the relative closeness of the two Euclidean distances. Finally, relative closeness is used as the evaluation index to measure sustainable development levels of land resource value. The positive and negative ideal value schemes are defined as follows: a positive ideal value scheme is generally the best scheme and contains the most ideal information value; the negative ideal value scheme assumes the worst and contains the least ideal value of information.

We developed a TOPSIS model using the following steps:

1. Evaluation indexes (*p*) for evaluation objects (*n*) were selected for comprehensive evaluation. The initial judgment matrix (original data matrix) is shown in equation (7):

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix} \tag{7}$$

2. Because the dimensions of each index may be different, the decision matrix was normalized and the original data were standardized to obtain matrix G, as shown in Equation (8). Standardization was done using the maximum standardization method.

$$G = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1p} \\ g_{21} & g_{22} & \cdots & g_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ g_{n1} & g_{n2} & \cdots & g_{np} \end{bmatrix} \tag{8}$$

3. Then, we made a weighted judgment decision matrix, Z, as shown in Equation (9), where i =1, 2... n; j = 1, 2... P, and is the weight of the JTH index. The entropy weight method was used for weight calculation, as described above.

Table 2. Evaluation indexes and weight of sustainable development level of land resources in the Yangtze River Economic Belt based on the PSR model

Rule Layer	Element Layer	Index Layer	Unit	Attribute	Weight
Pressure 0.3444	Population growth 0.1023	Natural population growth rate	‰	inverse	0.0429
		Urban population density	People per square kilometer	inverse	0.0594
	economic development 0.1112	Per capita GDP growth rate	%	inverse	0.0529
		Ratio of secondary industry in GDP	%	inverse	0.0583
	Social development 0.1309	Proportion of industrial land in urban construction land area	%	inverse	0.0697
		Use of agricultural means of production per unit arable land area	Tons/ Half an acre	inverse	0.0611
State 0.3526	Nature attribute 0.0833	Ratio of effective irrigated area to arable land	%	positive	0.0251
		Per unit area yield of grain	Kg/ha	positive	0.0197
		Green coverage rate in built-up areas	%	positive	0.0173
		Forest coverage	%	positive	0.0212
	Economic attribute 0.1583	Economic density	Yuan/square kilometer	positive	0.1000
		Social fixed asset investment per unit of land	100 million yuan/ square kilometer	positive	0.0853
	Social attribute 0.0840	Arable land per capita	Half an acre	positive	0.0266
		Urbanization rate	%	positive	0.0277
		Rural per capita disposable income	yuan	positive	0.0297
Response 0.3031	Governance 0.1720	Proportion of investment in environmental pollution control in GDP	%	positive	0.0541
		The proportion of soil erosion control area	%	positive	0.0556
		The total area of afforestation accounts for the land area	%	positive	0.0623
	Control 0.1310	Comprehensive utilization rate of industrial solid waste	%	positive	0.0792
		Urban domestic sewage treatment rate	%	positive	0.0518

Note: the pressure index is a reverse indicator, the state index and response indicators are forward indicators.

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1p} \\ z_{21} & z_{22} & \cdots & z_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ z_{n1} & z_{n2} & \cdots & z_{np} \end{bmatrix} \tag{9}$$

4. The positive ideal value vectors Z^{+} and negative ideal value vectors Z^{-} were determined using equation (10).

$$Z^{+} = (Z_{1}^{+}, Z_{2}^{+}, ...Z_{p}^{+})\,;\, Z^{-} = (Z_{1}^{-}, Z_{2}^{-}, ...Z_{p}^{-}) \tag{10}$$

In equation (10), $Z_{j}^{+} = (z_{1j}, z_{2j}, ...z_{nj})$, j = 1, 2, ...p, and $Z_{j}^{-} = (z_{1j}, z_{2j}, ...z_{nj})$.

5. The Euclidean distance between the evaluated object and the positive ideal value scheme was calculated using Equation (11).

$$D_{i}^{+} = \sqrt{\sum_{j=1}^{p} (z_{ij} - z_{j}^{+})^{2}} \tag{11}$$

The Euclidean distance between the evaluated object and the negative ideal value scheme was calculated using equation (12).

$$D_{i}^{-} = \sqrt{\sum_{j=1}^{p} (z_{ij} - z_{j}^{-})^{2}} \tag{12}$$

6. After the distances between the positive ideal value scheme and the negative ideal value scheme were determined, the relative proximity was calculated, that is, the evaluation index value of the sustainability of land resources, using Equation (13).

$$C_{i} = \frac{D_{i}^{-}}{D_{i}^{+} + D_{i}^{-}},\ i = 1, 2, 3, ..., n \tag{13}$$

7. The targets were sorted according to the size of C_{i} to form the basis for decision making. The larger C_{i} is, the more ideal it is, indicating that the sustainable development level of land resources in year *i* is higher, with $0 \le C_{i} \le 1$.
8. According to the existing research results, four grading standards for evaluating the sustainability of land resources in the YREB were determined, as shown in Table 3.

Global Moran's I Index

Global Moran's I index reflects spatial adjacency or similar property values between adjacent area units. It was used to analyze whether spatially adjacent regional units had the same attributes. It was calculated using the following equation:

$$\mathrm{I} = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(E_{i} - \bar{E}\right)\left(E_{j} - \bar{E}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}\left(E_{i} - \bar{E}\right)^{2}} \tag{14}$$

Table 3. Standard for evaluating the level of sustainable development of land resources in the Yangtze River Economic Belt

Grade	Evaluation Score	Meaning	Stage	Ecological Health Status
I	(0.8.1.0]	Very high sustainability	Sustainable utilization stage	Good natural condition, little external pressure, stable structure, normal function
II	(0.6,0.8]	High sustainability	Basic sustainable utilization stage	Better natural conditions, less external pressure, generally stable structure, normal function
III	(0.4,0.6]	Moderate sustainability	Initial stage of sustainable use	Natural conditions change, high external pressure, structural change, slight degradation of function
IV	[0,0.4]	Low sustainability	Unsustainable utilization stage	Destruction of nature, external pressure, structure destruction and function degradation

In equation (14), I is the global Moran's I index, n is the number of samples, E_i and E_j are the attribute values of regions i and j, $\overline{E}$ is the average value of all region attribute values, and w_{ij} is the spatial weight of regions i and *j*. In this study, a spatial weight matrix was constructed based on the first-order Rook adjacency relation.

The significance of the global Moran's I index can be tested by its standardized statistic Z-value, which is calculated using the following equation:

$$\mathrm{Z}(\mathrm{I}) = \frac{I - E(I)}{\sqrt{var(I)}}, \tag{15}$$

In equation (15), $E(I)$ is the mathematical expectation and $var(I)$ is the variance.

Local Spatial Autocorrelation

Local indicators of spatial association (LISAs) were used to measure the spatial difference between a regional unit and its adjacent units and to test whether there were similar or different observed values clustered together in local areas. The local Moran's I index, a commonly used method for local spatial autocorrelation analysis, was calculated using the following equation:

$$I_i = \frac{\left(E_i - \overline{E}\right)}{\sum_{i=1}^{N}\left(E_i - \overline{E}\right)^2} \sum_{j=1}^{N} w_{ij}\left(E_j - \overline{E}\right) \tag{16}$$

In Equation (16), E_i and E_j are the attribute values of regions i and j, respectively; $\overline{E}$ is the average value of all regional attribute values; and w_{ij} is the adjacent space weight of regions i and *j*. When $I_i > 0$, this indicates that regions with similar eigenvalues were agglomerated. When $I_i < 0$.

Theil Index

The Theil index, which measures the overall differences among regions, can be decomposed into intra-group and inter-group differences. It was used to determine trends and ranges of change, as well as their contribution rate to the overall differences. The higher the Theil index value, which ranges from 0 to 1, the greater the regional difference, and vice versa.

Assuming that a sample containing n individuals is divided into K groups, each group is $g_k\left(k=1,\ldots,K\right)$. The number of individuals in group k, denoted as g_k, is n_k, and thus, $\sum_{k=1}^{K}n_k=n$. y_i and y_k represent the level of a certain body i and the total level of g_k, respectively. The inter-group difference is denoted by T_b, and the intra-group difference is denoted by T_w. The Theil exponential decomposition formula is as follows:

$$\mathrm{T}=T_b+T_w=\sum_{k=1}^{K}y_k\ln\left(\frac{y_k}{\frac{n_k}{n}}\right)+\sum_{k=1}^{K}y_k\left(\sum_{i\in g_k}\frac{y_i}{y_k}\ln\left(\frac{\frac{y_i}{y_k}}{\frac{1}{n_k}}\right)\right), \tag{17}$$

$$T_b=\sum_{k=1}^{K}y_k\ln\left(\frac{y_k}{\frac{n_k}{n}}\right) \tag{18}$$

$$T_w=\sum_{k=1}^{K}y_k\left(\sum_{i\in g_k}\frac{y_i}{y_k}\ln\left(\frac{\frac{y_i}{y_k}}{\frac{1}{n_k}}\right)\right), \tag{19}$$

Data Sources

The natural population growth rate, per capita GDP growth, national economy gross domestic product, secondary industry share of GDP, industrial solid waste comprehensive utilization, rural per capita disposable income, and the growth rate of investment in fixed assets were derived from the statistical yearbooks of 11 provinces and cities (Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, human, Chongqing, Sichuan, Guizhou, and Yunnan) of the YREB. The urban population density, ratio of industrial land area to urban construction land area, green coverage rate of the built-up area, and rate of urban domestic sewage treatment were derived from the Statistical Yearbook of Urban Construction of China. Effective irrigation area, cultivated land area, plastic film and pesticide usage amount, per capita cultivated land area water and soil loss control area were derived from the China Rural Statistical Yearbook. The forest coverage rate, grain yield per unit area, urbanization rate, and total afforestation area were derived from the website of the National Bureau of Statistics. The proportion of GDP invested in environmental pollution control was derived from the China Environmental Statistics Yearbook. The time span was from 2008 to 2018, and some missing data were calculated using the interpolation method.

MEASUREMENT RESULTS AND ANALYSIS OF SUSTAINABLE DEVELOPMENT LEVEL OF LAND RESOURCES IN THE YANGTZE RIVER ECONOMIC BELT

Temporal Characteristics of Sustainable Development Level of Land Resources in the Yangtze Economic Belt

Table 4 shows the sustainable development level of all land resources in the YREB from 2008 to 2018 based on the index developed. The index values were between 0.5000 and 0.7500, which indicates moderate sustainability. Based on the index values, the sustainable development level of land resources showed a fluctuating upward trend from 2008 to 2018. With the acceleration of urbanization, the populations of provinces and cities in the YREB continued to grow and people increasingly developed land resources, generating large demand for land. This is the main reason for the unstable levels of sustainable development from 2008 to 2018.

From 2008 to 2012, there was less planning for land resources in the YREB. Policies pursued a “high starting point and high standard” and focused on image projects and political achievement projects, resulting in unreasonable use of land resources. Therefore, sustainable development fluctuated at low levels during this period. From 2013, the provinces and municipalities of the YREB carried out large-scale reform of the land resource use system, and governmental focus on rational use of land resources. Therefore, from 2013 to 2015, sustainable development levels rose rapidly, and the contradiction between people and land were alleviated. However, due to the pressure of frequent floods in South China and defects in the land system, land resources in the YREB were overwhelmed. Therefore, sustainable development levels showed a downward trend in 2016. This indicates that the sustainable land use system of the YREB could not effectively deal with natural disasters and lacked the ability to self-regulate. From 2017 to 2018, a series of governance projects, such as contaminated soil remediation and land subsidence prevention and control, were implemented, which improved the overall environment of the YREB, greatly reduced the pressure on the land resource utilization system. Therefore, sustainable development levels gradually increased.

The TOPSIS evaluation results for the sustainable development level of land resources in the YREB. From 2008 to 2012, the pressure of regional population growth and economic and social progress on the development and utilization of land resources increased. After 2012, the population growth rate gradually decreased. With the expansion of urban construction areas, the urban population density appeared to be stable, and the pressure from population growth also weakened. With the transformation of the economic development model and the optimization of industrial structures, the pressure of economic and social development also gradually weakened. To deal with the global economic crisis, China introduced many economic stimulus policies in 2008, which led to exponential economic growth and caused excessive consumption of land resources, leaving land resources in a fragile state. After 2011, the amount of fixed asset investment per land area and urban economic density increased simultaneously, which improved the usage efficiency of land resources. In addition, the rural per capita disposable income began to increase rapidly, the urbanization process slowed down slightly, and the state of land resources improved. Guided by policies focusing on national economic development and ecological environment construction, local governments increased investment in environmental protection and strengthened environmental control, such as soil erosion and afforestation. Progressions in science and technology led to a higher utilization rate of industrial solid waste and increased the treatment rate of urban domestic sewage. Therefore, the sustainable development level of land resources in the YREB began to rise.

Table 4. TOPSIS evaluation results of the overall sustainable development level of land resources in the Yangtze River Economic Belt from 2008 to 2018

Year	Pressure C Value	State C Value	Response C Value	Total Index C Value	Estimation Scale
2008	0.5343	0.3236	0.5232	0.5305	III
2009	0.4250	0.3598	0.5652	0.5000	III
2010	0.3565	0.3705	0.6236	0.5226	III
2011	0.3467	0.4557	0.6056	0.5126	III
2012	0.4688	0.5485	0.6003	0.5527	III
2013	0.4930	0.6312	0.6463	0.5807	III
2014	0.5751	0.7251	0.6196	0.6038	II
2015	0.6563	0.7924	0.7286	0.7050	II
2016	0.6472	0.7641	0.7078	0.6540	II
2017	0.6734	0.8202	0.7099	0.7297	II
2018	0.7085	0.8698	0.6787	0.7402	II

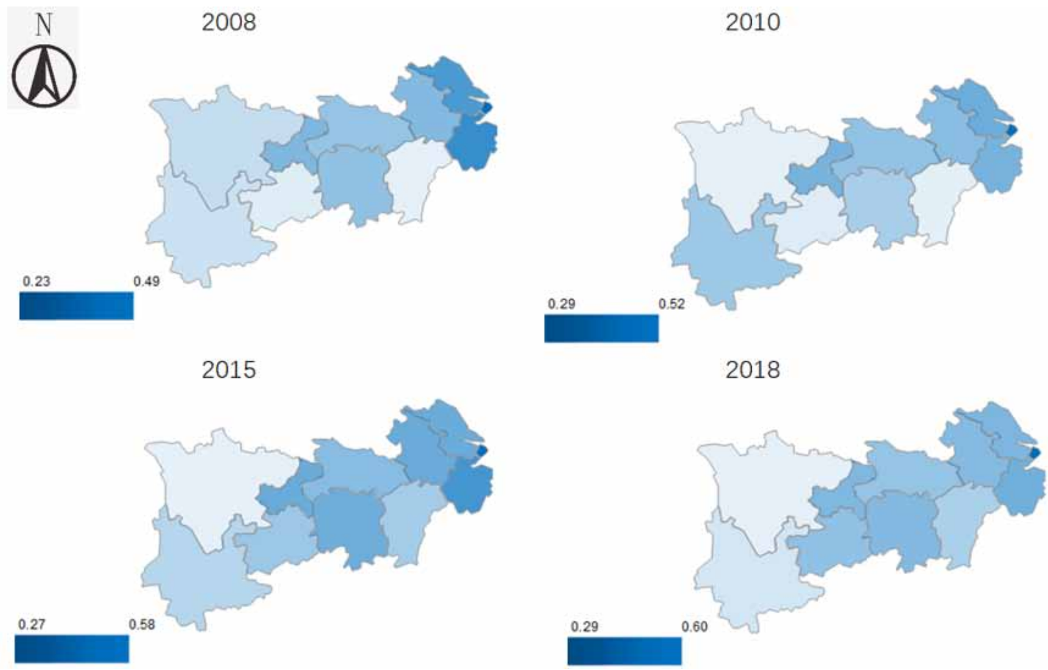
Spatial Characteristics of Sustainable Development Level of Land Resources in the Yangtze River Economic Belt

Spatial Distribution

To determine whether the sustainable development levels of land resources in the provinces and cities of the YREB had spatial correlation, we selected the first year of data collection, the last year of the 11th and 12th five-year plans, and the last year of data collection, namely, 2008, 2010, 2015, and 2018, to analyze the spatial distribution of the sustainable development levels (Figure 2). The sustainable development levels of the provinces and cities of the YREB had obvious regional characteristics. The sustainable development level was higher in the eastern coastal area and lower in the central and western regions. This shows that the levels of sustainable development of land resources among provinces and cities in the Yangtze River Economic Belt had a spatial correlation.

Descriptive statistical results of the sustainable development levels of land resources in the provinces and cities of the YREB are given in Table 4. We divided the YREB into three regions: upper, middle, and lower reaches. The upper reaches include Sichuan, Chongqing, Yunnan, and Guizhou; the middle reaches include Anhui, Hunan, Hubei, and Jiangxi; and the lower reaches include Shanghai, Jiangsu, and Zhejiang. In general, the spatial pattern of sustainable development levels reflected economic progress. The sustainable development level of land resources in the lower reaches was the highest, followed by the middle reaches, then the upper reaches. With geographical advantages, the lower reaches of the YREB had superior scientific, technological, and educational resources and higher investment in environmental pollution control than other regions. In addition, several financial and high-tech industries were gathered in the lower reaches of the YREB, and the sustainable development level of local resources was greater than that of the other two regions. Among them, Shanghai's economy developed rapidly and had a high overall level. Its economic development was strong in terms of resilience, vitality, and incisiveness, showing a trend of high-quality development. The sustainable development level was significantly higher than that of other regions. Jiangsu and Zhejiang are located on the golden coast of the YREB, with a high-quality ecological foundation. These provinces had intensive land use and improved their sustainable utilization efficiency of land resources. Therefore, the sustainable development level in these provinces was high. In Anhui, the balanced development of urbanization and agricultural modernization were promoted, and the sustainable development level

Figure 2. Spatial distribution of sustainable development level of land resources in the Yangtze River Economic Belt in 2008, 2010, 2015 and 2018



was only lower than that in Jiangsu, Zhejiang, Shanghai, and Chongqing. The middle reaches of the Yangtze River Economic Belt, which contain many rivers and lakes, such as the famous Poyang Lake and Dong Ting Lake, are rich in grain, cotton, and aquatic products. High-quality and sustainable urban construction was carried out in this region, along with progress in municipal and rural areas, and the overall development trend was good. The upper reaches of the YREB were rich in resources and had many energy-consuming industries but lacked high-tech industries; therefore, the sustainable development level was low. However, Chongqing had a reasonable level of sustainable development because of its low population density and large investment in environmental governance and protection.

Global Spatial Correlation

In this study, the global Moran's I index was used to test the global spatial correlation of the sustainable development levels of land resources in all provinces and cities of the YREB from 2008 to 2018. The test results are presented in Table 6.

From 2008 to 2018, the global Moran's I index of the sustainable development levels of land resources in all provinces and cities of the YREB was greater than or equal to 0.2, and passed the significance test of 5% in all years. This shows that there were significant positive correlations between sustainable development levels of land resources among the provinces and cities of the YREB during the research period. In terms of spatial distribution, for provinces and cities with higher levels of sustainable development of land resources, the levels of surrounding provinces and cities were also high; whereas, for provinces and cities with lower levels of sustainable development of land resources, the levels of surrounding provinces and cities were also low. In addition, the overall Moran's I index in the provinces and cities of the YREB showed a downward trend during the study period, and the spatial correlation gradually weakened.

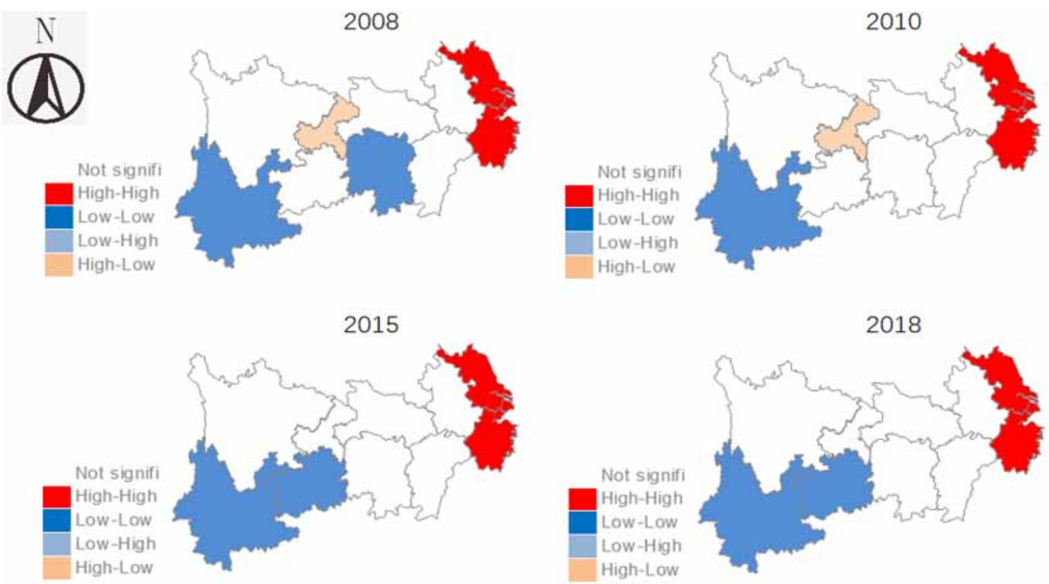
Table 5. Descriptive statistics of sustainable development level of land resources in provinces and cities of the Yangtze River Economic Belt

Year	Area	Average	Sd	Max	Min	Ranking
2008-2010	Yangtze River Economic Belt	0.3492	0.0732	0.5236	0.2268	-
	Shanghai	0.5048	0.0158	0.5236	0.485	1
	Zhejiang	0.4065	0.0129	0.4243	0.3942	2
	Jiangsu	0.4045	0.0055	0.4118	0.3986	3
	Chongqing	0.371	0.0238	0.4	0.3418	4
	Anhui	0.3567	0.0187	0.3819	0.337	5
	Hubei	0.3451	0.0231	0.3727	0.3163	6
	Human	0.3352	0.0115	0.3501	0.3223	7
	Yunnan	0.3222	0.0465	0.361	0.2569	8
	Sichuan	0.2738	0.0094	0.2868	0.265	9
	Guizhou	0.2627	0.0254	0.2959	0.2341	10
	Jiangxi	0.259	0.0254	0.2888	0.2268	11
2011-2015	Yangtze River Economic Belt	0.3931	0.0708	0.5751	0.2667	-
	Shanghai	0.5514	0.0195	0.5751	0.5253	1
	Zhejiang	0.4462	0.0253	0.4831	0.4058	2
	Chongqing	0.4215	0.0081	0.433	0.41	3
	Jiangsu	0.4193	0.011	0.4317	0.403	4
	Anhui	0.4119	0.0199	0.433	0.388	5
	Hubei	0.3975	0.0071	0.4086	0.3907	6
	Human	0.3808	0.024	0.4264	0.357	7
	Yunnan	0.3441	0.0116	0.3637	0.332	8
	Guizhou	0.3441	0.0122	0.3659	0.3322	9
	Jiangxi	0.3326	0.0125	0.3541	0.3155	10
	Sichuan	0.2744	0.0045	0.2798	0.2667	11
2016-2018	Yangtze River Economic Belt	0.4119	0.0775	0.6048	0.2854	-
	Shanghai	0.6014	0.0025	0.6048	0.5988	1
	Zhejiang	0.4629	0.0084	0.4719	0.4518	2
	Chongqing	0.4301	0.002	0.4326	0.4277	3
	Jiangsu	0.4297	0.006	0.4356	0.4215	4
	Anhui	0.4241	0.007	0.4333	0.4163	5
	Human	0.4232	0.0101	0.4336	0.4096	6
	Hubei	0.3989	0.0025	0.4012	0.3954	7
	Guizhou	0.3833	0.0267	0.4083	0.3463	8
	Jiangxi	0.358	0.0109	0.3734	0.3493	9
	Yunnan	0.3283	0.0067	0.3362	0.3197	10
	Sichuan	0.291	0.004	0.2942	0.2854	11

Table 6. The global spatial correlation test results of sustainable development level of land resources in the Yangtze River Economic Belt from 2008 to 2018

Year	Moran's I index	Z-statistic	P-value
2008	0.4756	2.8865	0.009
2009	0.2931	2.0959	0.038
2010	0.2509	1.9737	0.035
2011	0.218	1.9292	0.035
2012	0.2954	2.3345	0.016
2013	0.3217	2.3455	0.019
2014	0.363	2.5354	0.009
2015	0.358	2.4919	0.02
2016	0.3262	2.5348	0.009
2017	0.2828	2.2396	0.021
2018	0.275	2.2564	0.015

Figure 3. LISA agglomeration map of sustainable development level of land resources in provinces and cities of the Yangtze River Economic Belt in 2008, 2010, 2015, and 2018



Local Spatial Correlation

The local spatial correlation of the sustainable development levels of land resources in the provinces and cities was further analyzed through a LISA agglomeration map (Figure 3).

The sustainable development level of land resources in the provinces and cities of the YREB had strong spatial agglomeration. The downstream region had a high–high agglomeration pattern overall. Shanghai, due to its advantages in science and technology and environmental pollution control, promoted the sustainable development of land resources in Jiangsu, Zhejiang, and Anhui provinces. Overall, the upper reaches of China had a low–low agglomeration pattern, and the sustainable development levels of land resources was quite low. In areas with low–low agglomeration patterns, except for Yunnan, the characteristics of agglomeration changed over time. In 2008, Yunnan and Hunan had low–low agglomeration patterns. However, Hunan was not in a low–low agglomeration in 2010. Moreover, with the rapid economic development of southwest China, Guizhou was included in a low–low agglomeration in 2015.

Analysis Of Regional Differences Based On The Theil Index

The YREB stretches across three major areas of China's eastern and western regions. There are significant differences among provinces and cities in terms of resources, ecological environment, and cultural background. Therefore, the spatial differences in the sustainable development levels of land resources among provinces and cities in the YREB were an objective phenomenon. Table 7 displays the Theil index and its structural decomposition results for the sustainable development levels in the provinces and cities of the YREB from 2008 to 2018.

During the study period, the sustainable development levels of land resources in the YREB varied greatly among provinces, showed a downward trend. Among them, the contribution rate of the Theil index in each province and city showed a downward trend among regions, while the contribution rate of the Theil index within regions showed an upward trend. After the decomposition of the Theil index in each of the three regions, it was found that the difference in sustainable development levels of land resources in the upstream reaches was the largest, followed by the downstream reaches, then the middle reaches. This is because the provinces and cities in the lower reaches had a large gap in terms of area and population, leading to a substantial difference in the level of sustainable development. In the upstream reaches, the sustainable development of land resources in Chongqing was highest, but sustainable development was low in other provinces and cities. Therefore, the level of sustainable development of land resources varied significantly.

CONCLUSION

Based on land resource utilization in the YREB from 2008 to 2018, we constructed an evaluation index for the sustainable development levels of land resources based on the PSR model, and used the TOPSIS model to quantify the sustainable development levels of land resources in the YREB. The global and local Moran's I indices and the Theil index were used to analyze the spatial correlations and differences in sustainable development levels of land resources in provinces and cities of the YREB. The main findings were as follows:

1. The sustainable development levels of land resources in the YREB were between 0.5000 and 0.7500, which indicates moderate sustainability. The sustainable development levels showed an upward trend from 2008 to 2018, indicating that sustainability was generally good, with some instability. There were significant regional characteristics: the sustainable development levels of land resources in the eastern coastal area were the highest, followed by the middle and western regions. The levels of sustainable development of land resources in the provinces and cities of the YREB were spatially correlated, with the spatial pattern reflecting economic development.
2. During the study period, there were significant positive correlations between the levels of sustainable development of land resources among the provinces and cities of the YREB. For provinces and cities with a high level of sustainable development of land resources, the sustainable development levels of land resources in the surrounding provinces and cities were

Table 7. Theil indexes and its structural decomposition results of sustainable development level of land resources in the Yangtze River Economic Belt from 2008 to 2018

Year	Overall Difference	Intra-Regional Differences	Inter-Regional Difference	Downstream Area	Middle Area	Upstream Area
2008	0.4743	0.0099 (35.39%)	0.018 (64.61%)	0.0084 (13.7%)	0.0119 (10.26%)	0.0105 (11.43%)
2009	0.4255	0.0097 (50.78%)	0.0094 (49.22%)	0.0092 (20.56%)	0.0073 (9.26%)	0.0124 (20.96%)
2010	0.4647	0.0079 (52.57%)	0.0072 (47.43%)	0.008 (22.28%)	0.0056 (9.27%)	0.0096 (21.01%)
2011	0.5373	0.0073 (57.45%)	0.0054 (42.55%)	0.0075 (24.7%)	0.004 (7.98%)	0.0094 (24.77%)
2012	0.5431	0.0075 (53.53%)	0.0065 (46.47%)	0.0085 (25.47%)	0.002 (3.78%)	0.0105 (24.28%)
2013	0.5329	0.0072 (46.27%)	0.0083 (53.73%)	0.0055 (15.12%)	0.0035 (5.77%)	0.0123 (25.39%)
2014	0.5077	0.008 (45.69%)	0.0096 (54.31%)	0.0082 (19.96%)	0.0038 (5.48%)	0.0113 (20.25%)
2015	0.4868	0.0084 (46.71%)	0.0096 (53.29%)	0.0072 (16.97%)	0.0029 (4.14%)	0.0149 (25.6%)
2016	0.4434	0.009 (49.23%)	0.0093 (50.77%)	0.0114 (26.74%)	0.0023 (3.21%)	0.0112 (19.28%)
2017	0.137	0.0085 (51.32%)	0.0081 (48.68%)	0.0099 (25.16%)	0.0037 (5.76%)	0.0107 (20.4%)
2018	0.2056	0.0091 (55.66%)	0.0073 (44.34%)	0.0112 (28.75%)	0.0015 (2.35%)	0.0126 (24.56%)

Note: Percentage contribution is in parentheses.

also high, whereas for provinces and cities with low levels of sustainable development, the levels of sustainable development of land resources in the surrounding provinces and cities were also low.

3. There were significant regional differences in the sustainable development levels of land resources among provinces and cities in the YREB. The sustainable development levels of land resources among provinces and cities in the upper reaches of the YREB had the largest differences, followed by the lower and middle reaches. Therefore, while improving the overall sustainable development level of land resources in the YREB, it is necessary to maintain coordinated development among provinces and cities and narrow the gap in the sustainable development levels of land resources among regions.

Policy Suggestions

The results demonstrate that in the YREB there are low levels of sustainable development and large regional differences in sustainable development. To solve these problems, we suggest the following:

1. Strengthen ecological construction and protect land resources. Regional populations should be reasonably controlled to maintain positive interactions among the population, economic society, and ecological environment. Economic resources should continue to be developed, social resources should be distributed, and natural resources should be utilized ecologically. Development and utilization of land resources should not be at the expense of land resources and the environment.

In the process of sustainable utilization of land resources, a certain quantity and quality of key resources (such as arable land, forest, grassland, and water resources) must be maintained to ensure that future demand for land resources can be met. Provincial and municipal governments should elevate the sustainable use of land resources to the level of green development in the YREB. While developing and utilizing land resources, it is important to consider land resource constraints, decline of land resource quality, and serious pollution of land resources, and ecological construction should be placed in a prominent position.

2. Ensure economic performance and revitalize land resources. Provincial and municipal governments should introduce industrial projects according to the specific conditions of land resources in each region, activate land resources, fully realize their value, improve the industrial chain, and achieve provincial economic development. Specifically, coastal areas should make use of their geographical advantages to attract foreign investment, promote the upgrading of industrial structure and industrial opening, and enhance the position of industry in the global value chain. Based on the advantages of land resources, the central region should clearly define industrial orientation and strategic need, formulate long-term industrial development plans in a targeted and step-by-step manner, and gain competitive advantages in domestic economic construction. The western region is limited to management and technology and has a single industry structure. Therefore, priority should be given to improving infrastructure construction, gradually establishing advantageous industries in line with the characteristics of its own land resources, and accelerating development of the tertiary industry.
3. Bridge the gap between regions and achieve coordinated development. The country should increase investment in infrastructure in the interior areas of the YREB, narrow the gap between these and the developed areas, and support the development of areas with poor land resource sustainability. Land use in urban and rural areas should be coordinated; land use in urban areas should be highly intensive, guiding the orderly expansion of land for construction purposes. The provinces of the YREB should strengthen cooperation to ensure the orderly development of land resources in each region, optimize the allocation of land resources, reduce the repeated construction of land

resources, and reduce the unbridled competition of land resource development and utilization among regions.

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