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EVALUATION ON THE COUPLING COORDINATION OF ECONOMIC DEVELOPMENT AND ECOLOGICAL ENVIRONMENT CARRYING CAPACITY: CASE STUDY IN JIANGXI PROVINCE, CHINA

Evaluación de la coordinación del desarrollo económico y la capacidad de carga del ambiente ecológico: estudio de caso en la provincia de Jiangxi, China

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Key words: economic development, carrying capacity of ecological environment, coupling coordination model, spatio temporal evolution

ABSTRACT

Exploring the relationship between economic development and ecological environment is the inevitable requirement of regional sustainable development. We used an improved entropy method and a coupling coordinated model to assess the comprehensive evaluation index and the coupling coordination degree of economic development and ecological environmental carrying capacity of Jiangxi Province, from 2011 to 2019. Taking 2011 and 2019 as time nodes, this paper analyzed the spatial pattern evolution characteristics of 11 cities in Jiangxi Province. The results showed that: 1) Coordinated development degree presents a growth trend from 2011 to 2019, while the type of coordinated development is constantly shifting to a higher level; 2) the status of coordinated development in 11 prefecture-level cities has generally changed from low and primary to middle and high-level coordination; and 3) the spatial distribution characteristics showed that the coordinated development level in the northern and southern region were higher than the central region, and inter-regional differences gradually narrowed.

Palabras clave: Desarrollo económico, capacidad de carga del ambiente ecológico, modelo de coordinación de acoplamiento, evolución espacio temporal, provincia de Jiangxi

RESUMEN

El estudio de la relación entre el desarrollo económico y el ambiente ecológico es el requisito inevitable del desarrollo regional sostenible. Utilizamos un método de entropía mejorado y un modelo coordinado de acoplamiento para evaluar el índice de evaluación integral y el grado de coordinación de acoplamiento del desarrollo económico y la capacidad de carga ecológica de la provincia de Jiangxi, de 2011 a 2019. Tomando 2011 y 2019 como nodos temporales, este trabajo analizó las características de evolución de patrones espaciales de 11 ciudades en la provincia de Jiangxi. Los resultados mostraron que: 1) el grado de desarrollo coordinado presenta una tendencia de crecimiento de 2011 a 2019, mientras que el tipo de desarrollo coordinado está cambiando constantemente a un nivel más alto; 2) el estado del desarrollo coordinado en 11 prefecturas-ciudades ha cambiado generalmente de una coordinación de nivel bajo y primario a una coordinación de nivel medio y alto, y 3) las características de distribución espacial mostraron que el nivel de desarrollo coordinado en las regiones septentrional y meridional era superior al de la región central, y las diferencias interregionales se fueron reduciendo gradualmente.

INTRODUCTION

With the continuous development of regional economy, ecological environment restricting regional economic development become increasingly prominent (Wang et al. 2018, Kang et al. 2019). Only when the impact of human activities on geographical environment does not exceed the capacity of resource support and environmental absorption, can the sustainable development of the system be maintained (Tian and Sun 2018). How to coordinate the constraints between economy and environment is the issue that should be solved (Lv et al. 2018, Wang et al. 2018). Accordingly, carrying capacity of resources, environment or ecology became the theme words and core content of many studies (Martire et al. 2015, Chapman and Byron 2018).

At present, empirical studies have focused on carrying capacity evaluation in different fields, such as water resource (Pires et al. 2017, Ren et al. 2016), mining zone (Wang et al. 2016) and a comprehensive analysis of the urban environment (Irankhahi et al. 2017, Weng et al. 2020). Moreover, evaluating carrying capacities needs to establish functions and models, such as comprehensive evaluation method (Okey 2018, Guo et al. 2018); system dynamics model (Chapman and Darby 2016, Han et al. 2018), the ecological footprint method (Xun and Hu 2019, Su et al. 2018) and TOPSIS method (Wang et al. 2015, Yang et al. 2018). However, a single evaluation of resource and environmental carrying capacity cannot provide a comprehensive reference for coordinated development (Zhang et al. 2019).

Coupling originated from physics, mainly refers to the phenomenon that systems affect each other through various interactions (Li et al. 2012). Many researchers (Tang 2015, Li and Yi 2020) used the coupling model to evaluate relationships between the elements of multi-system. Previous studies showed coupling model could reflect the stage characteristics of the coordination relationship. Given the lack of current research aimed at the coupling coordination degree of regional economy and environment, this study was innovative in making analysis of coordinated relationship between economic development and ecological environmental carrying capacity.

METHODS AND MATERIALS

The indicator system

Based on the relevant research literature (Fu et al. 2020, Liu et al. 2011),we constructed the evaluation indexes of economic development system and ecological environmental carrying capacity system based on the principles of scientific, systematic and feasibility. The indexes were aim to combine with the study of regional economic and ecological characteristics. As shown in **Table I**, the evaluation index system of coupling coordinated development has fifteen indexes. Indicator selection basis and meaning are as follows.

(1) Economic development subsystem. We selected two indicators of development level and development efficiency to reflect the socio-economic development. On the one hand, development level means the scale, speed and level of economic development, which was analyzed from the index of GDP growth rate, per capita GDP, growths rate of industrial added value above scale and per capita disposable income. On the other hand, development efficiency reflected whether the development process was of high quality. Fixed asset investment effect coefficient, labor productivity and rate of energy output denoted efficiency of capital development, labor production and energy use, respectively.

A total of seven indexes include the current situation of economic development.

(2) Ecological environmental carrying capacity subsystem. Since resource utilization and environmental rehabilitation have important implications for regional development, the ecological resources factor and environmental governance must be considered. Therefore, the ecological resources mainly include three aspects, that is, water, construction land and afforestation. The three indexes involve water resources per capita, construction land area per capita and green coverage ratio of built-up areas. Meanwhile, environment as a supporting factor for economic development should be considered as governance capability and level. The five indexes concerning "five wastes" (industrial wastewater, industrial waste gas, industrial solid waste, domestic sewage, and domestic garbage) include capacity of environmental pollution control.

Determination of index weight

In order to overcome the problem of insufficient deviation in the measurement results of the entropy method, we used the improved entropy weight method which is an objective weighting method. When calculating the entropy value, the standardized method is used to weight the index weight, which reduces the influence of extreme value on the comprehensive evaluation (Li et al. 2012). The steps were as follows (formulas (1)-(5)), the weight of each index in the system is shown in **Table I**.

Standardized processing of raw data:

Positive indicator :

$$x'_{ij} = (x_{ij} - x_{\min j})/(x_{\max j} - x_{\min j}) \tag{1}$$

Negative indicator :

$$x'_{ij} = (x_{\max j} - x_{ij})/(x_{\max j} - x_{\min j}) \tag{2}$$

The proportion of the indicator:

$$R_{ij} = x'_{ij} / \sum_{i=1}^{n} x'_{ij} \tag{3}$$

Entropy of the indicator:

$$e_j = -(\ln n)^{-1} / \sum_{i=1}^{n} R_{ij} \ln R_{ij} \tag{4}$$

Weight of the indicator:

$$W_{ij} = (1 - e_j) / \sum_{i=1}^{n} (1 - e_j) \tag{5}$$

where x_{ij} is original data; x'_{ij} is standardized data; $x_{\max j}$, $x_{\min j}$ denote respectively, the maximum and minimum values of the original data; W_{ij} represents the weight of indicator.

Coupling coordination degree model

This paper constructed the coupling coordination degree model to reveal the synchronization and order between economic development and ecological environment systems, and also reflects the dynamic and balanced development state between systems (Yang 2003, Wang et al. 2017). In order to better judge the overall harmony degree of interaction, the comprehensive evaluation index was calculated based on

TABLE I. EVALUATION INDEX SYSTEM OF COUPLING COORDINATED DEVELOPMENT.

Sub-system	Criterion	Index	Unit	Weight
Economic development (x)	Development level (x_1)	Annual growth rate of GDP (x_{11})	%	0.130
		Per capita GDP x_{12})	10 000Yuan	0.120
		Growth rate of industrial added value above scale (x_{13})	%	0.203
		Per capita disposable income of urban residents (x_{14})	Yuan	0.113
	Development efficiency (x_2)	Fixed asset investment effect coefficient (x_{21})	%	0.128
		Labor productivity (x_{22})	10 000Yuan /capita	0.137
		Rate of energy output (x_{23})	10 000 Yuan/ton of standard coal	0.169
Ecological environmental carrying capacity (y)	Ecological resources (y_1)	Per capita water resources (y_{11})	10 000m^3/capita	0.121
		Per capita construction land area (y_{12})	square kilometers	0.213
		Greening coverage rate of built-up area (y_{13})	%	0.139
	Environmental support(y_2)	Capacity of industrial waste water treatment facilities (y_{21})	10 000 tons / day	0.146
		Capacity of industrial waste gas treatment facilities (y_{22})	10 000 m^3/hour	0.143
		Rate of general industrial solid waste utilization (y_{23})	%	0.126
		Rate of municipal sewage treatment (y_{24})	%	0.105
		Rate of domestic waste harmless disposal (y_{25})	%	0.112

the weight of system index, according to weighted sum calculation shown in equation (6) and (7); the coupling coordination degree evaluation model is shown in equation (8), (9) and (10):

$$f(x) = \sum W_{ij} x'_{ij} \tag{6}$$

$$g(y) = \sum W_{ij} y'_{ij} \tag{7}$$

$$C = \left\{ \frac{f(x) \cdot g(y)}{\left[\frac{1}{2} f(x) + \frac{1}{2} g(x)\right]^2} \right\}^k \tag{8}$$

$$T = \alpha f(x) + \beta g(y) \tag{9}$$

$$D = \sqrt{C \cdot T} \tag{10}$$

where $f(x)$ refers to the comprehensive evaluation index of economic development ; $g(y)$ refers to the comprehensive evaluation index of ecological environment carrying capacity; C is system coupling degree; T is the index of comprehensive development; D is the degree of system coupling coordination; α and β denote undetermined coefficients to define the importance of two subsystems ($\alpha = \beta = 0.5$); K represents adjustment coefficient (K=2).

As shown in **table II**, the degree of coupling coordination was divided into five types and three stages according to the existing research literature (Chelan et al. 2018). Coupling coordination range is from 0 to 1. The larger the value shows that the more coordinated the economic development and ecological environmental carrying capacity system.

The Theil index

The Theil index is a method for measuring regional disparity. The greater value of the Taylor index indicates the greater regional difference. It can decompose the overall differences into intra-group and inter-group, which are denoted as T_b and T_w respectively (Malakar et al. 2017). Assuming that the sample size is n, all samples can be further divided into k regions. Then the number of samples contained in each region is denoted as n_k. If y_i and y_k are used to represent the coordination values of the i sample and the k region, respectively, the Theil index formula can be expressed as:

$$T = T_b + T_w \tag{11}$$

$$T_b = \sum_{k=1}^{k} y_k \log \frac{y_k}{n_k/n} \tag{12}$$

$$T_w = \sum_{k=1}^{k} y_k \left(\frac{y_i}{y_k} \log \frac{y_i / y_k}{y_{n_k}} \right) \tag{13}$$

Study area and data source

Study area

Jiangxi Province is located in the central part of southeast China, with an area of 166 900 square kilometers. It has 11 prefecture-level cities and 100 counties (cities and districts). There are more than 2400 rivers in the whole area. The terrain of Jiangxi Province is mainly hilly and mountainous, and the climate is warm, abundant rainfall, subtropical humid climate. Based on the strategy of rising central China, Jiangxi is experiencing rapid development. In 2019, it had a GDP of 24757.5 billion Yuan. However, the development of industry and urbanization will have an impact on resource demand and environmental change. According to the statistical yearbook, the environmental protection measures have been continuously strengthened in recent years, and the ecological environment is superior. For example, the total water resources reached 2051.6 billion cubic meters, and per capita water and arable land yield per acre are higher than the national average. At the same time, the forest coverage rate is as high as 63%. In addition, mineral resources have obvious advantages in the country. There are 139 kinds of mineral resources in nine categories that have been identified.

TABLE II. CLASSIFICATION OF COUPLING COORDINATED DEVELOPMENT.

Coordinated development stage	Coupling coordination interval	Types of coordinated development
Disorder development stage	(0.0 ~ 0.5]	Low-level
Grinding-in development stage	(0.5 ~ 0.6] (0.6 ~ 0.7]	Primary Middle-level
Coordinated development stage	(0.7 ~ 0.8] (0.8 ~ 1.0]	High-level Superior quality

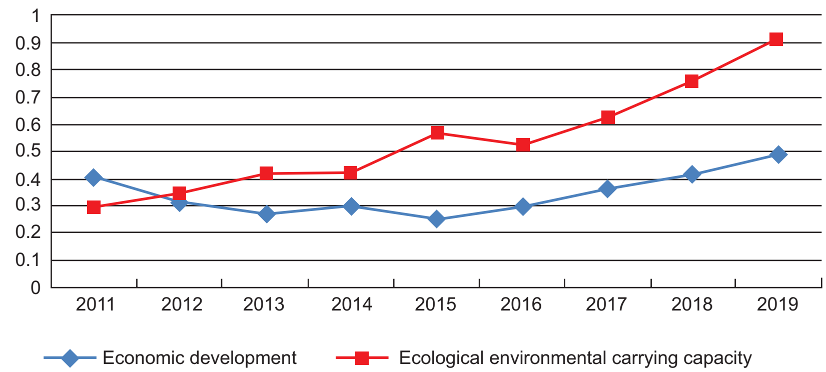


Fig. 1. The comprehensive evaluation indexes from 2011 to 2019.

Data source

Since the time range of the research object is from 2011 to 2019, the research data were obtained from the Jiangxi Statistical Yearbook (2011-2019), the Statistical Bulletin of National Economic and Social Development of Jiangxi Province (2011-2019), China Urban Statistical Yearbook (2011-2019), and spatial data are derived from the standard map of the standard map service system of the Ministry of Natural Resources.

RESULTS AND DISCUSSION

Analysis of the coupling coordination

The original data describing 15 indicators in Jiangxi Province (2011-2019) were calculated using steps (1)-(8) above (**Fig. 1** and **Table III**). As demonstrated in **Figure1**, two comprehensive evaluation indexes showed a fluctuating upward trend of the in Jiangxi Province. The value of ecological environmental carrying capacity increased from 0.301 to 0.913, with an average annual growth of 22.59 % from 2011 to 2019.The level of economic development sub-system fluctuated around 0.3 during first five years and then obviously increased from 2016 to 2019. Comparing the two comprehensive evaluation indexes, the level of economic development was slightly higher than the level of the ecological environmental carrying capacity in 2011, while trends in the following eight years were opposite to that**.** Overall, composite index level of two subsystems in Jiangxi Province showed a synchronous growth trend and has a certain degree of positive correlation.

As shown in **table III**, there is a slackening in growth of the coupling coordination degree from 2011 to 2019 in Jiangxi. According to **table II**, the type of coupling coordination development was moving from primary coordination to middle and high coordination, which showed that more attention was paid to improving the comprehensive utilization of resources and environmental protection level. Economic development could get the strong support of environmental conditions, while the economy development also strengthened the carrying capacity of ecological environment.

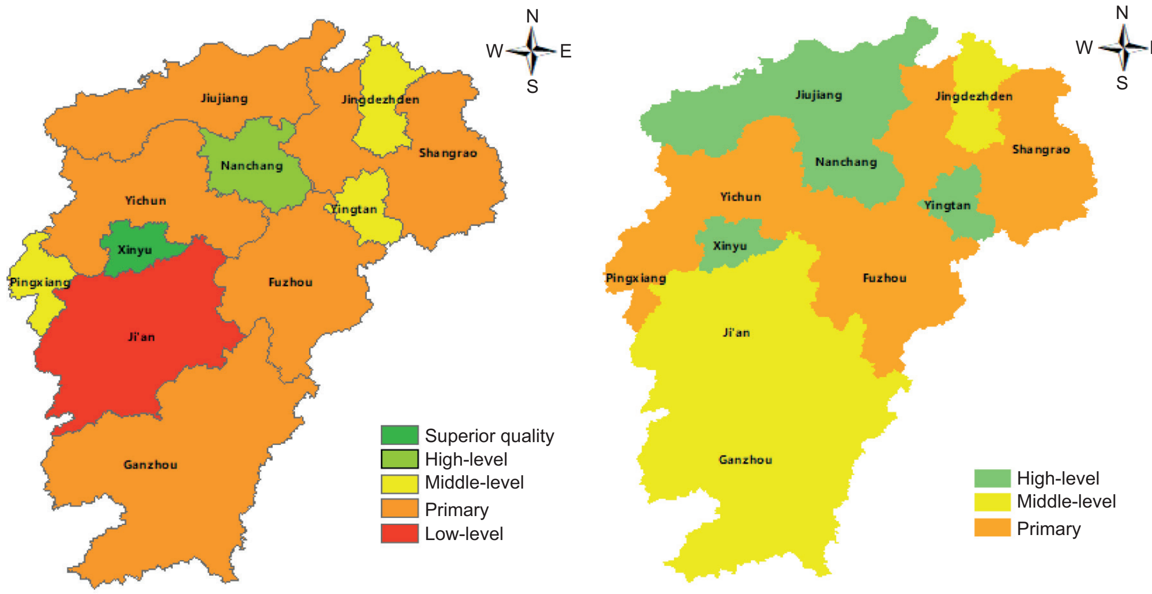
TABLE III. TYPES OF COUPLING COORDINATION DEVELOPMENT FROM 2011 TO 2019.

Year	*T*	*D*	Type
2011	0.353	0.581	Primary
2012	0.330	0.572	Primary
2013	0.348	0.563	Primary
2014	0.359	0.582	Primary
2015	0.406	0.545	Primary
2016	0.411	0.593	Primary
2017	0.498	0.655	Middle-level
2018	0.589	0.704	High-level
2019	0.699	0.759	High-level

Analysis of spatial pattern evolution

In order to more intuitively reflect the spatial evolution characteristics of regional coordinated development, we selected the data of 11 prefecture-level cities in Jiangxi and calculated the coupling coordination degree in 2011and 2019. ArcGIS10.2 software is used to visualize the spatial pattern evolution (**Fig. 2**, a and b).

Figure 2 shows significant changes of coupling coordination degree in these 11 cities. Comparison the results of two years illustrated that the proportion of high-level coordination increased from 9% to 36%, while the proportion of primary coordination decreased from 45% to 36%. In 2019, low-level



(a) 2011 (b) 2019

Fig. 2. Spatial differentiation characteristics of coupling coordination degree in Jiangxi Province.

cities no longer existed. These findings indicated that primary and middle-lever coordination gradually shifts to high-lever coordination. The cities with the greatest improvement in coordination are Ji'an and Jiujiang. As a provincial capital city, Nanchang has maintained a high degree of coordinated development. Xinyu and Pingxiang belong to resource declining cities. Therefore, the coordinated development types decreased.

From the coordinated development of cities, in the coordinated development stage zones, there are 3 central, 2 northern in 2011. However, there are seven cities in the coordinated development stage in 2019, which are concentrated in the northern and southern regions of Jiangxi. Therefore, the characteristics of spatial variation showed that the coordinated development level of the northern regions is higher, followed by the southern region, and the level of the central regions is relatively low.

Analysis of regional differences

To further investigate the sources of regional differences, considering geographic feature, the 11 cities were divided into three regions: the northern regions (Nanchang, Jingdezhen, Jiujiang, Shangrao), central regions (Yichun, Xinyu, Pingxiang, Yingtan, Fuzhou) and southern regions (Ji'an, Ganzhou). According to Equations (11) – (13), the Theil index from 2011 to 2019 is calculated shown in **table IV**.

As shown in **table IV**, the Theil index from 2011 to 2019 was significantly positive and decreased year by year, which indicated that the regional differences in the coupling and coordinated development of economic development and ecological environment exist objectively and decrease over time. The Theil index remained above 0.08 from 2011 to 2016, however, it decreased to 0.0066 in 2019.Thus, the regional gap was more obvious in the early stage, and the gap narrowed later. From the perspective of

TABLE IV. THE THEIL INDEX DECOMPOSITION VALUE OF THE COORDINATED DEVELOPMENT DEGREE.

Year	T_b	D_b	T_w	D_w	T
2011	0.0048	0.3002	0.0111	0.6997	0.0159
2012	0.0029	0.3203	0.0082	0.6796	0.0121
2013	0.0015	0.1249	0.0107	0.8751	0.0123
2014	0.0013	0.1504	0.0076	0.8457	0.0089
2015	0.0011	0.1294	0.0076	0.8706	0.0088
2016	0.0005	0.0600	0.0078	0.9399	0.0083
2017	0.0011	0.1017	0.0099	0.8983	0.0111
2018	0.0005	0.0692	0.0068	0.9308	0.0073
2019	0.0001	0.015	0.0065	0.9850	0.0066

T_b: Interregional differences; T_w: Intraregional differences; D_b: Interregional contribution; D_w: Intraregional contribution; T: The Theil index the relationship between interregional and intraregional disparities, interregional disparities showed a decreasing trend. The contribution of interregional disparities decreased from 30 % to 1.5 % from 2011 to 2019, while at the same time, the contribution of intra-regional disparities increased year by year, and interregional disparities became more obvious. Intraregional disparities have become the main source of regional disparities in the coupling and coordinated development, which reflects that more attention should be paid to coordinated development within the region at this stage.

The formation and expansion of regional differences are the result of comprehensive factors such as natural geographical environment, economic policy, traffic conditions, openness to the outside world and industrial structure. Jiujiang in the northern region is a famous port city. Nanchang is the intersection hub of two vertical and horizontal arteries, the Beijing Kowloon Railway and the Shanghai Kunming railway. The southern region belongs to the Economic Zone on the West Bank of the Taiwan Strait. It is an important area connecting the Yangtze River Delta and the Pearl River Delta, as well as South China and the Taiwan Strait. The superior location conditions in the north and south of Jiangxi have created good external environmental conditions for the development of non-state-owned economy, with a high degree of openness, which has advantageously promoted the improvement of its marketization level, achieved rapid development and opened the gap between regions. From the scientific outlook on development to the current supply side reform, the central region lacks large-scale industrial development. Relying solely on resources to build a city can indeed bring immediate results, but it lacks sustainability. In terms of industrial structure adjustment and environmental governance, it also lags behind the northern and southern regions.

CONCLUSIONS

This paper studied the coupling coordination degree of economic development and ecological environmental carrying capacity of Jiangxi Province from 2011 to 2019. In addition, analysis of spatial pattern evolution and regional difference was carried out for the support index of 11 cities. As above obtained findings showed, Jiangxi Province has been continuously improved in economic development, effective utilization of resources and environmental protection. The degree of coordinated coupling showed an upward trend from 2011 to 2019. Moreover, type of coordinated development has changed from primary coordination development to middle-lever coordinated development and then high-lever coordination development.

There are obvious geographical features for the coordinated development in 11 cities, and the overall level of coordinated development was improved, from low and middle-level coordination to middle and high-level coordination. Furthermore, the coordinated development level of the northern regions is higher, followed by the southern region, and the coordinated development level of the central regions is relatively low. However, according to the Theil index, interregional disparities showed a decreasing trend, while intraregional disparities have become the main source of regional disparities in the coupling and coordinated development. These results demonstrated that it is necessary to strengthen the improvement of urban ecological environment, and promote economy development and ecological environment synchronous coordination. The related government agencies should take active measures to further change the mode of economic growth, and promote the development of efficient ecological economy development relying on regional resource advantages.

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