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Article

Coupling Relationship of Urban Ecological Environment in Jiangsu, China

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Abstract: As the contradiction between urbanization and the ecological environment becomes more prominent, a coupling degree model based on coupling theory needs to be established to calculate their comprehensive levels. The coupling degree of the 13 cities in Jiangsu reveals the spatial pattern to propose countermeasures and suggestions. The results show that the comprehensive level of urbanization presents a stepped municipal spatial pattern of "the southern is higher than the central region and the central region is higher than the northern". The spatial pattern of the urban ecological environment is observed in two extreme cities, while the other cities are not significantly different. The degree of coupling and coordination between them has reached a high level of coupling, showing a spatial pattern of "stepped down to the north to the north". Finally, we propose targeted development strategies for different levels of regions.

Keywords: Urbanization, Ecological Environment, Coupling Model, Jiangsu

1. Introduction

By the end of 2021, the urbanization rate in China had reached 64.72%. The Northam curve shows that it is in the high-speed stage of 30–70% and continues to maintain proper growth [1]. However, problems occurred during the urbanization in China such as the tense urban-rural relationship, ecological environment deterioration, and so on [24]. Based on the topic, the new type of urbanization attracts interest in ecological livability, balanced urban and rural development, urban-rural integration, and other aspects [5,6]. The representative research methods include Environmental Kuznets Curve (EKC) [7,8], the PSR model for environmental quality assessment [9,10], and so on. Chinese scholars adopt the geometry method coupling EKC and urbanization curve to analyze the relationship between urbanization and the ecological environment [11]. Additionally, Qiao et al. took nine cities in central China as examples to study and analyze the coupling degree between urbanization and the ecological environment in the nine cities [12]. In the present study, Jiangsu was chosen as the research object to study the coupling relationship between urbanization and the ecological environment based on the municipal scale to provide the basis for further promoting the construction of new-type urbanization and ecological civilization.

2. Method and Materials

2.1. Coupling model of urbanization and ecological environment

According to the coupling degree values of urbanization and ecological environment, the coupling process is divided into four stages: low-level coupling, antagonism, running-in, and high-level coupling [13]. These four stages are important indexes to reflect the system coupling degree.

The concept of coupling originates from physics describes the process of interaction and mutual influence between electrical networks or electrical components [14]. In the present study, the degree of the correlation and interaction between the urbanization and ecological environment in Jiangsu is explored based on the concept of coupling. The detailed function model is shown as follows.

$$C = \left[U_1 * \frac{U_2}{\left(U_1 + \frac{U_2}{2}\right)^2} \right]^2 \quad (1)$$

In the model, U_1 and U_2 represent the urbanization development index and the ecological environment development index, respectively. The value range of coupling degree C of the urbanization-ecological environment is [0.1]. The closer the value is to 0, the lower the system coupling degree is, while the closer the value is to 1, the higher the coupling degree is. According to these values, the system coupling degree of the issue can be divided into four stages [15] as shown in Table 1. The calculation Equation of coupling coordination degree is presented as follows.

$$D = (C * T)^{\frac{1}{2}}, T = aU_1 + bU_2 \quad (2)$$

where D represents coupling coordination degree, C is coupling degree, and T is the comprehensive coordination index of urbanization and ecological environment, which reflects the coordination effect between them. Besides, a and b are undetermined coefficients, both of which are assigned 0.5.

2.2. Construction of index system and calculation of weight

The main socio-economic index data in the present study was obtained from the Statistical Yearbook of Jiangsu – 2017 and the 2017 statistical yearbook of thirteen prefecture-level cities in Jiangsu. Moreover, the part of the environmental index data was obtained from the China City Statistical Yearbook 2017 and the environmental bulletins published by the thirteen cities in Jiangsu.

2.2.1 Construction of index system

Urbanization is a systematic process composed of four dimensions, including population, economy, society, and space. Ten indexes were selected to construct an urbanization system to evaluate the measurement of urbanization development level. At the same time, the ecological environment system was divided into three subsystems: the level, stress, and protection of the ecological environment. Moreover, eleven indexes were used to construct an ecological environment system to evaluate its development level (Table 2).

Table 1. Classification of the system coupling degree of urbanization-ecological environment.

Coupling degree value	Coupling degree	Stage performance
0—0.3	Low-level stage	Low-level urbanization and high ecological carrying capacity
0.3—0.5	Antagonism stage	The ecological carrying capacity decreases, and the rapid urbanization brings great stress to the ecological environment protection
0.5—0.8	Running-in stage	People's awareness of ecological environment protection is enhanced, and more funds are invested in ecological environment restoration
0.8—1	High-level stage	Urbanization and ecological environment achieve harmonious interaction

2.2.2 Method for the calculation of weight

The entropy method can reflect the utility value of index information entropy and possesses high reliability in calculating index weight. The detailed calculation steps of the entropy method are shown as follows [16–18].

(1) Standardized processing of indexes

$$\text{Positive index:} x'_{ij} = \frac{x_{ij} - min(x_1, x_2, \cdots x_n)}{max(x_1, x_2, \cdots x_n) - min(x_1, x_2, \cdots x_n)} \quad (3)$$

$$\text{Negative index:} x'_{ij} = \frac{max(x_1, x_2, \cdots x_n) - x_{ij}}{max(x_1, x_2 \cdots) - min(x_1, x_2, \cdots x_n)} \quad (4)$$

In the above Equation, x_{ij} represents the j^{th} index of the i^{th} region.

(2) Calculation of the proportion (P_{ij}) of the i^{th} region under the j^{th} index in the i^{th} area

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, (i = 1,2 \cdots n, j = 1,2,, \cdots m) \quad (5)$$

(3) Calculation of the entropy of the j^{th} index

$$e_j = -k \sum_{i=1}^{n} p_{ij}\, ln(p_{ij}) \quad (6)$$

where $k > 0$, $k = 1/ln(n)$ and $e_j >= 0$.

(4) Calculation of weight

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} (1 \le j \le m) \quad (7)$$

In the above Equation,

$$g_i = \frac{1 - e_j}{m - E_e}, E_e = \sum_{j=1}^{m} e_j, o \le g_t \le 1, \sum_{j=1}^{m} g_j = 1$$

Calculation of the comprehensive score of each region is

$$s_i = \sum_{j=1}^{m} w_j * p_{ij}, (i = 1,2 \cdots n\ ) \quad (8)$$

The weight values calculated by the above methods in Table 2 show that the contribution rate of the current per capita residential building area (0.1163), the proportion of the increased value of secondary and tertiary industries in GDP (0.1057), and per capita GDP (0.1017) to urbanization are more prominent in the urbanization system. Additionally, they have a significant impact on economic urbanization and spatial urbanization. Furthermore, in the ecological environment system, per capita industrial waste gas emissions (0.1395), the comprehensive utilization rate of industrial solid waste (0.1070), and the discharge standard-meeting rate of industrial wastewater (0.0961) has a significant influence on the ecological environment. For example, the high per capita discharge amount of industrial wastewater can lead to eco-environmental stress (Table 2).

Table 2. Evaluation index system of the coupling system of urbanization and ecological environment.

System level	First-level	Secondary-class index level	Weight	Index
Urbanization system	Demographic urbanization	Proportion of urban population (%)	0.0953	Positive
		Proportion of the employee in the secondary and tertiary industries (%)	0.1008	Positive
	Economic urbanization	Per capita GDP (ten-thousand yuan)	0.1017	Positive
		Proportion of the increased value of secondary and tertiary industries in GDP (%)	0.1057	Positive
	Social urbanization	Per capita disposable income for urban residents (ten-thousand yuan)	0.1005	Positive
		Number of college students per 10,000 people (person)	0.0800	Positive
		Number of health technicians per 10,000 people (person)	0.1131	Positive
	Spatial urbanization	Current per capita residential building area (m^2)	0.1163	Positive
		Urban per capita road area (m^2)	0.0933	Positive
		Per capita built-up area (km^2)	0.0936	Positive
Ecological environment system	Ecological environment level	Green coverage rate of built-up area (%)	0.0928	Positive
		Per capita area of public green space (m^2)	0.0871	Positive
		Per capita area of cultivated land (m^2)	0.0840	Positive
		Per capita total water resources (m^3)	0.0879	Positive
	Eco-environmental stress	Per capita discharge amount of industrial wastewater (m^3)	0.0686	Negative
		Per capita discharge amount of industrial waste gas (ten-thousand m^3)	0.1395	Negative
		Per capita produced volume of industrial solid waste (t)	0.0818	Negative
	Ecological environment protection	Discharge standard-meeting rate of industrial wastewater (%)	0.0961	Positive
		Per capita removal volume of industrial fumes (t)	0.0823	Positive
		Comprehensive utilization rate of industrial solid waste (%)	0.1070	Positive
		Energy use per unit of GDP（ton/ ten-thousand yuan）	0.0840	Negative

3. Results and Discussion

3.1 Comprehensive development level of urbanization in Jiangsu

By using the SPSS cluster analysis method, the urbanization development level was divided into three categories: lower, medium, and higher levels. The classification criteria are shown in Table 3. The five cities in the north of Jiangsu show a relatively low level of urbanization development. The three cities in the mid-part of Jiangsu are at the middle level and the five cities in the south of Jiangsu are at the relatively high level. The comprehensive level of urbanization in Jiangsu presents a municipal spatial pattern of "the southern region is higher than the central region which again is higher than the northern region", and the urbanization gap between the southern region and the northern region is significant (Fig. 1).

Table 3. Urbanization level type in Jiangsu.

Urbanization level	Type	City
0-0.30	Lower	Xuzhou, Lianyungang, Suqian, Huaian, Yancheng

0.30-0.60	Medium	Yangzhou, Taizhou and Nantong
0.60-1	Higher	Nanjing, Zhenjiang, Suzhou, Wuxi and Changzhou

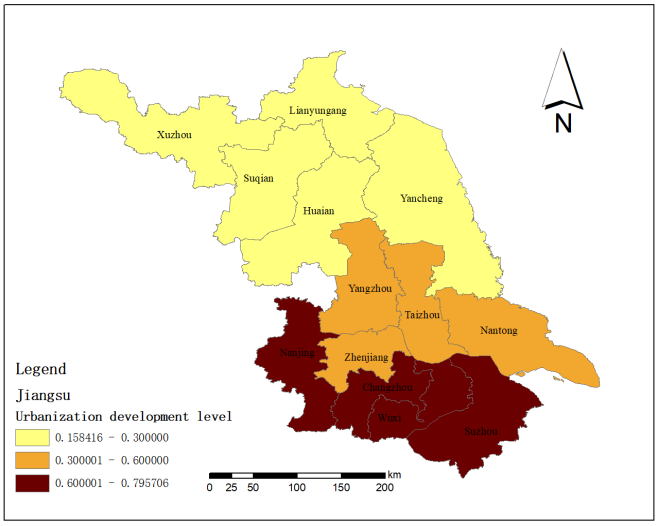

Figure 1. Inter-city pattern of the comprehensive level of urbanization in Jiangsu in 2016.

3.2. Comprehensive level of ecological environment in Jiangsu

The ecological environment level was also divided into three categories as lower, medium, and higher levels. The classification criteria are shown in Table 4. From the perspective of inter-city spatial pattern, the ecological environment level of Lianyungang is relatively low while the eleven cities, such as Nanjing, Zhenjiang, and Wuxi are in the middle level, and the difference is not significant. Additionally, Nantong is in a higher level (Fig. 2).

Table 4. Ecological environment level type in Jiangsu.

Ecological environment level	Type	City
0-0.45	Lower	Lianyungang
0.45-0.70	Medium	Nanjing, Zhenjiang, Wuxi, Suzhou, Huaian, Taizhou, Yancheng, Suqian, Suzhou and Changzhou
0.70-1	Higher	Nantong

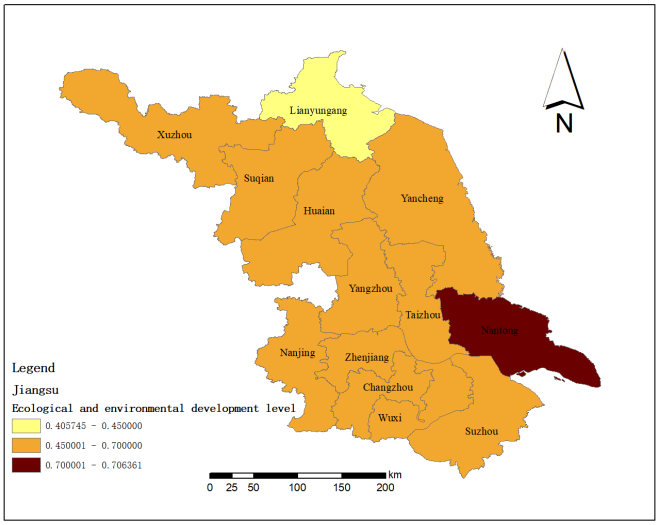

Figure 2. Inter-city pattern of the comprehensive level of ecological environment in Jiangsu.

3.3. Coupling degree of urbanization-ecological environment comprehensive level in Jiangsu

According to Eq. (1), the coupling values of urbanization and the ecological environment of 13 cities in Jiangsu were obtained. In addition, as shown in Table 1, all the coupling values are between 0.8 and 1. All thirteen cities in Jiangsu have reached the high-level coupling stage. These results indicate that urbanization and the ecological environment have harmonious interaction. The coupling level of the ecological environment was divided into three categories to further analyze the inter-city pattern. The classification criteria are shown in Table 5 and Fig. 3. From the spatial perspective, the coupling level presents a municipal spatial pattern of "high level in the south, low level in the north and lower level in the coastal area", indicating that the northern cities are still insufficient in the coordinated development of them.

Table 5. Coupling degree type of urbanization and ecological environment in Jiangsu.

Coupling degree	Type	City
0.80-0.90	Lower	Suqian, Yancheng
0.90-0.95	Medium	Xuzhou, Lianyungang, Huaian
0.95-1.00	Higher	Nanjing, Wuxi, Suzhou, Changzhou, Zhenjiang, Taizhou, Yangzhou and Nantong

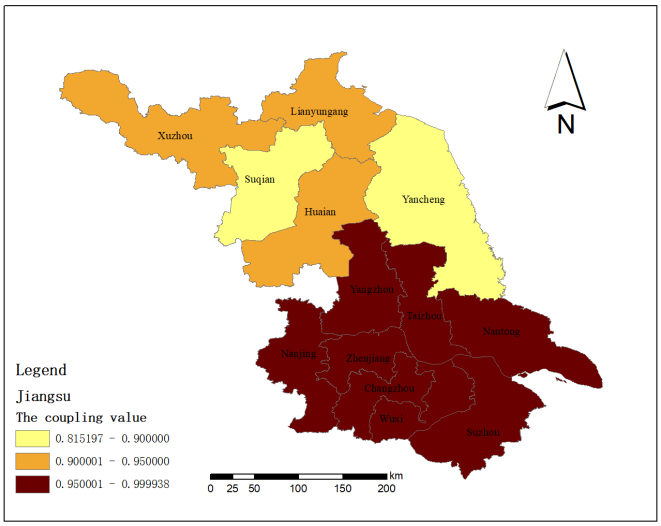

Figure 3. Inter-city pattern of the coupling degree of urbanization and ecological environment.

According to Eq. (2), the highest coordination degree of the issue of the thirteen prefecture-level cities in Jiangsu reaches 0.84, the lowest is approximately 0.53 and the average coordination degree is 0.68. The overall coordination degree has reached the middle or higher level. The coordination degree of 13 cities was divided into three categories by using the cluster analysis method in SPSS21 software. As shown in Fig. 4, the coordination of this issue in Jiangsu generally presents a stair-stepping pattern of "progressive decrease from the south to the north".

Table 6. Coordination degree type of urbanization and ecological environment in Jiangsu.

Coordination degree	Type	City
0.530844–0.673370	Lower	Xuzhou, Lianyungang, Suqian, Huaian and Yancheng
0.673370–0.756431	Medium	Yangzhou, Zhenjiang, Nantong, and Taizhou
0.756431–0.804850	Higher	Nanjing, Wuxi, Suzhou, and Changzhou

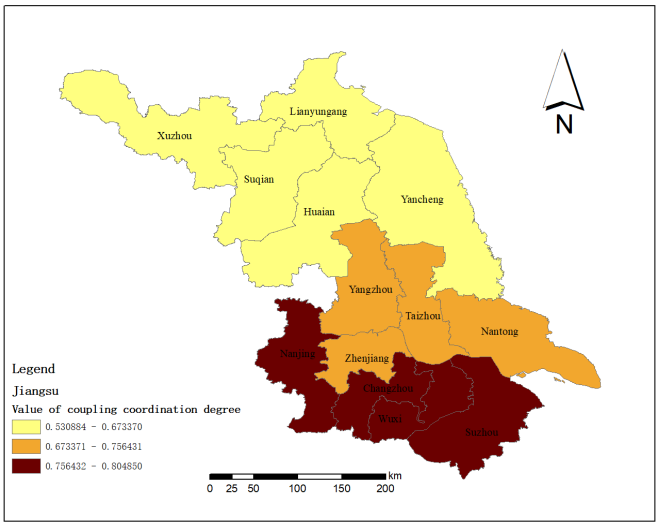

Figure 4. Inter-city pattern of the coordination degree of urbanization and ecological environment.

4. Conclusion

The municipal governments need to promote the construction of new-type urbanization and ecological civilization, drive the healthy development of urbanization, and ensure the quality of urbanization development. Furthermore, the criteria for measuring the level of urbanization development should pay more attention to the destruction and protection of resources and the environment. At the same time, a more perfect evaluation index system should be established, and the relevant policies and regulations should be improved.

The development strategy of adjusting measures to local conditions needs to be adopted. For the cities with a relatively high coupling degree, the quality of urbanization development needs to be optimized and improved to the ecological environment level based on maintaining the original urbanization level. Meanwhile, attention should be paid to development optimization. Besides, for the cities with relatively low coupling degrees, the relevant strategies should be adopted, such as steadily improving the urbanization development level, reducing resource consumption, and advocating green GDP construction.

The southern cities need to pay more attention to improving the quality of urbanization, elevating social security, and the quality of urban residents' life. Secondly, they need to promote the quality of the ecological environment, optimize the exploitation of resources and utilize superior geographical conditions and technological advantages to develop the modern economy.

The proposed strategies of "Jianghuai Ecological Economic Zone" and "Yangtze River Delta City Cluster" are a guidance and planning for the future development of the central cities. The central cities should take advantage of ecological resources to develop an ecological economy.

In the northern cities of Jiangsu, urbanization has caused serious damage to the ecological environment. Ecological restoration is important to recover the ecological environment and protect the ecological resources. Therefore, reducing resource consumption and advocating green GDP development are necessary while improving the level of urbanization.

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