E3S Web of Conferences **53**, 03070 (2018) https://doi.org/10.1051/e3sconf/20185303070
*ICAEER 2018*

# The spatial-temporal differences in coupling relationship between urbanization and eco-environment—a case study of the urban agglomeration in the middle reaches of the Yangtze River

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**Abstract.** Exploring the coupling coordinated relationship between urbanization and eco-environment of the urban agglomeration in the middle reaches of the Yangtze River (UAMRYR) from 2000 to 2015 can provide a theoretical basis for the overall planning and healthy development of the region. Therefore, in this article, we took 31 cities of the UAMRYR as the research area, and established an evaluation system to calculate the urbanization level and eco-environmental quality. Then, using entropy method and coupling measurement model, we analyzed the coupling coordination relationship between urbanization level and eco-environmental quality from spatial and temporal perspectives. Temporally, the coupling degree (CD) and coupling coordinated degree (CCD) continually rose during the 16 years. Spatially, the coordinated development level of urbanization level and eco-environmental quality had significant spatial differences. The CD presented the "northwest-southeast" spatial characteristics corresponding to high-low distribution. The CCD showed an inverted Y-shaped spatial pattern that gradually decreases outward from the provincial capital city. The coordinated development level of urbanization and eco-environment in the UAMRYR showed a central-periphery spatial pattern, and had an obvious spatial variation.

## 1 Introduction

The Development Plan for the Urban Agglomeration in the Middle Reaches of the Yangtze River (UAMRYR) clearly pointed out that we must vigorously develop the construction of ecological civilization. Therefore, the coordinated development of the urbanization and eco-environment of the UAMRYR has gradually become an important issue in the regional planning of the urban agglomeration. Many previous literatures had engaged in studying the relationship between urbanization and eco-environment. Grossman revealed that there existed an inverted U-shaped curve between urban economic growth and environmental pollution, namely the famous environmental Kuznets curve (EKC) [1]. Based on the coupling degree (CD) model and coupling coordinated degree (CCD) model, Liu found that the distribution of the CCD in each province had obvious regional differences, manifesting that the CCD of most provinces in the east is universal higher than in the centre and west [2]. Some scholars also used the system dynamics method to simulate and predict the coupled development pattern of urbanization and eco-environment [3]. In summary, most scholars studied the coupling relationship between urbanization and eco-environment at the provincial level and national level [4, 5]. A few scholars focused on the municipal level, but few scholars paid attention to the relationship from the perspective of urban agglomeration. As an important carrier of regional economic development and a main form of urbanization, the development quality of urban agglomeration is directly related to the development quality of regional economy and urbanization. Therefore, research on the coupling coordinated relationship between urbanization and eco-environment in urban agglomerations is of vital importance for the sustainable and healthy development of urban agglomerations and regional economies.

## 2 Study area

The UAMRYR is a large-scale urban agglomeration centred on the three provincial capitals of Wuhan, Changsha, and Nanchang. It covers a total of 31 cities in 3 provinces, including Wuhan Metropolitan Area, Ring of Chang-Zhu-Tan Urban Agglomeration, and Poyang Lake Eco-economic Zone (Figure 1), and it covers an area of 352,241 $km^2$, accounting for 3.30% of land in China, with the population of 128.00 million residents. As for the natural resources, it has a large number of waters (the Yangtze River, Dongting Lake, Poyang Lake, et al.) and high forest coverage rate (43.61%, much higher than 21.63% of the country).

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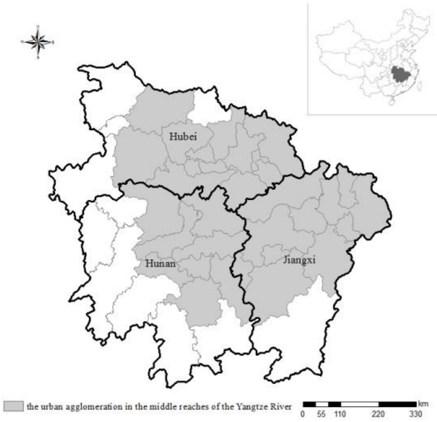


**Figure 1.** Location of study area.

## 3 methods

### 3.1 Data Pre-Processing

In this study, the spatial data are based on a scale of 1:4,000,000 and obtained from the National Geomatics Center of China. The economic and social development data of four years (2000, 2010, 2015 and 2015) were collected from the China City Statistical Yearbook, China City Construction Statistics Year book, China Regional Economic Statistical Yearbook. We applied Formula (1) and (2) to standardize all the statistical data and eliminate the influence of dimension, magnitude, and positive and negative orientation [6].

Positive indicator: $X_{ij} = (x_{ij} - \min\{x_j\})/(\max\{x_j\} - \min\{x_j\})$ (1)

Negative indicator: $X_{ij} = (\max\{x_j\} - x_{ij})/(\max\{x_j\} - \min\{x_j\})$ (2)

where $x_{ij}$ denotes the value of indicator $j$ in year $i$ and $\max\{x_j\}$ and $\min\{x_j\}$ represent the maximum and minimum value of indicator $j$ for all years, respectively.

### 3.2 Index system

Based on previous researches [7], we constructed the index system of urbanization from four aspects (demographic urbanization, spatial urbanization, economic urbanization and social urbanization), and the index system of eco-environment was also established from four aspects (eco-environment level, eco-environment endowment, eco-environment pressure and eco-environment response). Then we used principal component analysis and multicollinearity analysis to select indicators and determine the main influencing factors. Table 1 showed the comprehensive index system, in which 18 indicators were used to calculate the urbanization level and 13 indicators were used to calculate the eco-environmental quality.

**Table 1.** Index system of the urbanization level and eco-environmental quality. (* represent negative indicator)

| Sub-system | First Grade Index | Basic Grade Indicators |
|---|---|---|
| The integration value of urbanization | Demographic urbanization | Proportion of urban population (%) |
| | | Proportion of employment in the secondary and tertiary industries (%) |
| | Spatial urbanization | Percentage of built-up area in the total land area (%) |
| | | Area of built-up per capita (sq.m.) |
| | | Pavement area per capita (sq.m.) |
| | Economic urbanization | GDP per capita (Yuan) |
| | | Gross industrial output value per capita (Yuan) |
| | | Proportion of the secondary and tertiary industries in GDP (%) |
| | | Local finance income per capita (Yuan) |
| | | Total investment in fixed asset (10000 Yuan) |
| | Social urbanization | Total retail sales of consumer goods per capita (Yuan) |
| | | Disposable income of urban residents per capita (Yuan) |
| | | Students enrollment of regular institutions of higher education per 10,000 people |
| | | Number of internet users per $10^4$ people |
| | | Number of beds of hospitals per $10^3$ people |
| | | Number of doctors per $10^3$ people |
| | | Number of telephones users per $10^4$ people |
| | | Number of public transportation vehicles per $10^4$ people |
| The integration value of eco-environmental quality | Eco-environment level | Total water resources per capita ($m^3$/capital) |
| | | Cultivated area per capita (sq.m./capital) |
| | | Gross sown area of grain crops per capita ($hm^2$) |
| | | Yield of grain crops per capita (tons/capital) |
| | Eco-environment endowment | Green coverage rate of built-up area (%) |
| | | Green area per capita (sq.m.) |
| | | Forest coverage (%) |
| | Eco-environment pressure | Emission of industrial waste water per capita * (tons/capita) |
| | | Discharged volume of industrial $SO_2$ per capita * (tons/capital) |
| | | Emission of industrial dust per capita * (tons/capital) |
| | Eco-environment response | Comprehensive utilization rate of industrial solid waste (%) |
| | | Hazard-free treatment rate of domestic garbage (%) |
| | | Urban sewage treatment rate (%) |

 https://doi.org/10.1051/e3sconf/20185303070

### 3.3 Comprehensive evaluation

In this article, the entropy method was used to determine the weight of each indicator listed in Table 1. After obtaining the weight of each indicator, we calculated the comprehensive scores of urbanization level and eco-environmental quality from 2000 and 2015 by weighted summation. The calculation method is as follows:

$$P_{ij} = X_{ij} \Big/ \sum_{i=1}^{m} X_{ij}, \left(i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\right) \quad (3)$$

$$w_j = \left(1 + (\ln m)^{-1} \sum_{i=1}^{m} \left(P_{ij} \times \ln P_{ij}\right)\right) \Big/ \sum_{j=1}^{n} \left(1 + (\ln m)^{-1} \sum_{i=1}^{m} \left(P_{ij} \times \ln P_{ij}\right)\right) \quad (4)$$

$$Y_i = \sum_{j=1}^{n} w_j X_{ij} \quad (5)$$

where $P_{ij}$ is the proportion of indicator *j* in year *i*; *n* is the number of indicators, and *m* represents years; $w_j$ denotes weight of the indicator *j*; $Y_i$ denotes composite score in year *i*.

### 3.4 Coupling degree model

Coupling refers to a phenomenon in which two or more systems influence each other through diverse interactions [8]. The coupling degree indicates the degree of interaction between systems or elements. The coupling degree of the two systems generally adopts the following model:

$$C = 2\sqrt{U \cdot E}/(U + E) \quad (6)$$

where *U* denotes urbanization level and *E* denotes eco-environmental quality. Obviously, C∈[0,1], the closer C is to 1, the stronger the coupling degree between the systems is. When C=1, the coupling degree reaches the maximum, indicating that the correlation between the systems is extremely strong. When C=0, the coupling degree is the smallest, indicating that the systems are not related to each other and do not affect each other.

### 3.5 Coupling coordinated degree model

Coupling degree can only explain the degree of interaction and mutual influence between systems, but cannot truly reflect the coordinated development level of urbanization and eco-environment [9]. To further reflect the coupling coordination development level of urbanization and eco-environment, the following coupling coordination model was established:

$$D = (C \cdot T)^{1/2}, \; T = aU + bE \quad (7)$$

where D is coupling coordination degree; *T* is a comprehensive coordination index reflecting urbanization level and eco-environmental quality; *a* and *b* are undetermined coefficients, which represent the degree of contribution of urbanization level and eco-environmental quality to urban development. Taking into account the same contribution of them, *a*=*b*=0.5 is taken here. In practical applications, we generally make *T*∈ (0,1) to ensure D∈ (0,1).

## 4 Results

### 4.1 Evaluation results of urbanization level and eco-environmental quality

We used the indicators in Table 1 and the entropy method to calculate the comprehensive scores of urbanization level and eco-environmental quality in 31 cities in 4 years (see Figure 2). In the study area, the level of urbanization in each city was significantly different. The values of urbanization level in the three central cities (Wuhan, Changsha, and Nanchang) were obviously higher than other cities, and the urbanization level of each city kept increasing year by year during the study period. The eco-environmental quality also had significant spatial-temporal differences. The eco-environmental quality of most cities increased obviously from 2000 to 2010, and remained stable since 2010. Overall, the eco-environmental quality in Ji'an, Yichun, Fuzhou and Changde were better than other cities from 2000-2015.

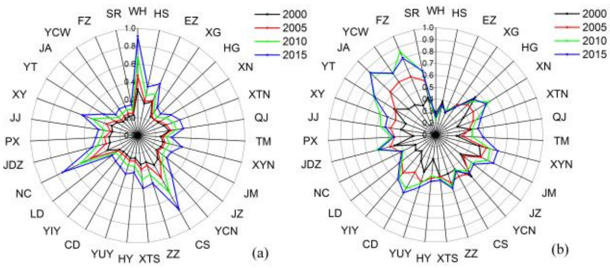


**Figure 2.** Comprehensive levels for 31 cities in different years: (a) urbanization level; (b) eco-environmental quality.

### 4.2. Evaluation results of coupling degree and coupling coordinated degree

According to equation (6) and (7), we calculated the CD and CCD of urbanization level and eco-environmental quality (see Figures 3). These values were further divided into five categories (Table 2).

**Table 2.** Classification of the coupling development of urbanization level and eco-environmental quality.

| | interval | degree |
|---|---|---|
| C | 0.4≤C<0.58 | Weak coupling |
| | 0.58≤C<0.69 | Low coupling |
| | 0.69≤C<0.77 | Medium coupling |
| | 0.77≤C<0.84 | High coupling |
| | 0.84≤C<1 | Strong coupling |
| D | 0.3≤D<0.4 | Severe disorder |
| | 0.4≤D<0.5 | Moderate disorder |
| | 0.5≤D<0.6 | Mild disorder |
| | 0.6≤D<0.7 | Moderate coordination |
| | 0.7≤D<0.8 | High coordination |

It can be seen from the figure that the CD of the UAMRYR was raising from 2000 to 2010. The average CD increased from the medium coupling in 2000 to the strong coupling in 2015. The cities with relatively high coupling mainly concentrated in the northwest of the urban agglomeration, showing a gradual decreasing trend from the northwest to the southeast in the spatial distribute, and the coupling degree is the lowest in the southeast.

At the same time, it can be seen that the CCD of urbanization level and eco-environmental quality in the UAMRYR showed a rising trend from 2000 to 2015. In 2000, the CCD had three types — severe disorder, moderate disorder and mild disorder. By 2015, the types of the CCD changed to mild disorder, moderate coordination and high coordination. From the perspective of spatial attribute, the CCD of urbanization level and eco-environmental quality in the UAMRYR was headed by Wuhan, Changsha, and Nanchang. It showed an inverted Y-shaped spatial pattern which basically conforms to the “distance attenuation rule”, that is, the farther away from the provincial capital city is, the lower the CCD is.

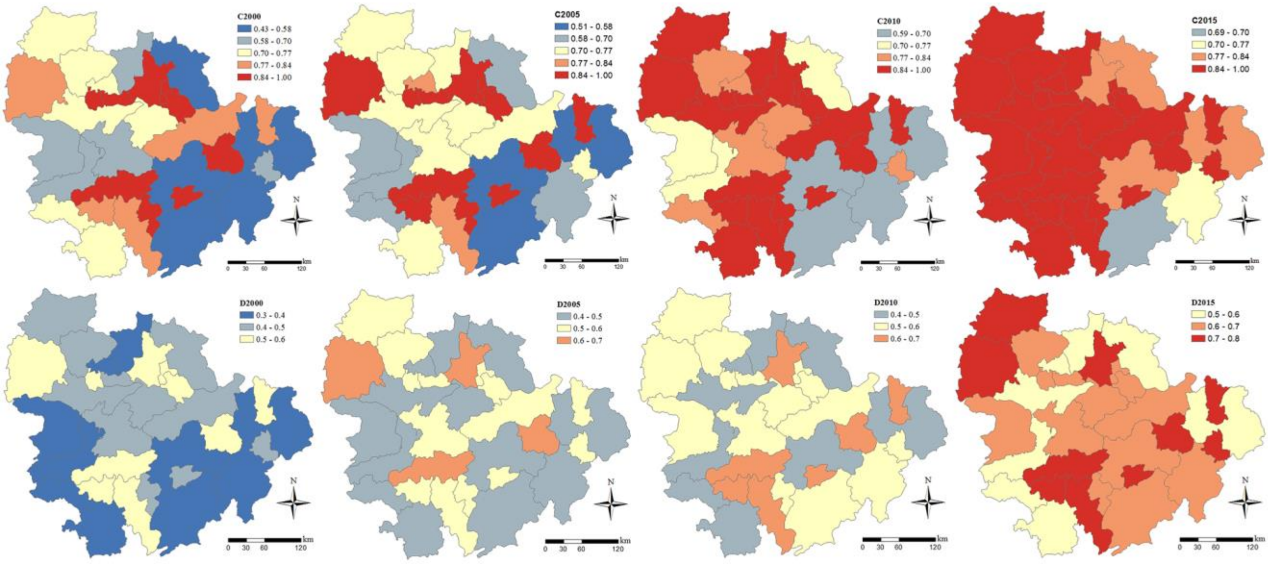


**Figure 3.**The coupling degree (C) and coupling coordination degree (D) of the UMRYR in four years**.**

## 5 Conclusions

From the perspective of temporal attribute, the CD and CCD of urbanization level and eco-environmental quality in the UAMRYR gradually rose since 2000. The average CD increased from the medium coupling in 2000 to the strong coupling in 2015. The average CCD increased from the mild disorder in 2000 to the moderate coordination in 2015. It demonstrated that the coordinated development level of urbanization and eco-environment was continuously improving. From the perspective of spatial attribute, there existed a spatial imbalance and spatial heterogeneity in the coordinated development of urbanization and eco-environment in the UAMRYR from 2000 to 2015. The CD presented a “staircase pattern” in these years, namely, the southeast region < the central region < the northwest region. The CCD showed an inverted Y-shaped spatial pattern that gradually decreases outward from the provincial capital city. In order to gradually reduce or even eliminate the gap between the southeast-northwest and centre-periphery of the UAMRYR, it is necessary to enhance the radiative driving capacity of its three major urban agglomerations and promote the coordinated development of the regions, so that the urbanization and eco-environment of the UAMRYR can maintain sustainable and healthy development.

## Acknowledgments

This work was supported by the National Natural Science Foundation of China (41471339, 41571514) and the Fundamental Research Funds for the Central Universities of China (185208017).

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