INTERACTION BETWEEN URBANIZATION AND ECO-ENVIRONMENT IN CENTRAL CHINA

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Abstract. This paper analyzed the spatial-temporal pattern of the degree of coordination between economic and environmental development in Central China region from 2008 to 2018 by means of the entropy method, exploratory spatial data analysis, and the Tapio decoupling index model and then explored the influencing factors with the Tobit model. The research found: (1) the urbanization level of the cities in Central China has been improved significantly, whereas their eco-environmental levels are fluctuating with the growth rate lower than that of urbanization. The coordination level between the two systems is on the rise, changing from primary dysfunction to intermediate coordination. (2) The coordination level is characterized by obvious spatial association dominated by Types H-H and L-L, as well as ever-increasing agglomeration. The decoupling between the two systems indicates that there is a negative effect between the two, and there is a problem regarding negative urbanization development. (3) Factors including energy consumption, investment in fixed assets, openness to the outside world, technological progress, and government management capabilities all have an impact on the coordination of the two with different levels of significance.
Keywords: *urbanization, eco-environmental, coupling and coordination, Tapio decoupling model, Tobit model*

Introduction

With the advancement of industrial revolution, the world has been plagued by environmental degradation hidden behind its surging economic progress. How to coordinate the development of economic growth and the eco-environmental system has become a major issue of common concern to all countries across the world (Zhang et al., 2020). Studies have shown that urbanization is an important factor driving multi-scale environmental changes, which has fundamentally transformed the regional landscape ecology (Xie et al., 2015). Urban expansion directly leads to changes in the landscape pattern, and the waste discharge in the process of urbanization also affects the global eco-environment (Fang et al., 2019). Carrying out researches on the interaction and coupling effects of urbanization and eco-environmental system will be the hotspot and frontier field of earth system science and sustainability scientific research in the next decade (Fang et al., 2016). China has undergone four decades of economic growth under the policy of Reform and Opening up, and has become the world's second largest economy. However, its surge in population, acceleration of the industrialization process, and leap of economic development have caused severe ecological and environmental problems. In turn, the deterioration of the eco-environmental system has hindered the development of

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urbanization. Urbanization is physically rooted in the ecological environment, and human demand for ecological services is the premise of sustainable development of urbanization. However, the extensive development mode of human beings has caused great disturbance and impact on the urban ecosystem, resulting in the problem of ecological disorder (Lu et al., 2007). The central regions are a relatively concentrated area of resource-based cities in China, and also an area characterized by relatively fast industrial transfer and urbanization in China (Wang and Liu, 2017). In recent years, with the ever-increasing level of urbanization, a series of severe environmental problems have emerged, and it is urgent to explore a green way for further development (Dong et al., 2019). In March 2021, the State Council issued the "guidance on promoting high quality development in Central China in the new era", emphasizing that the central region needs to change its development mode through industrial structure adjustment, transformation and upgrading, and the cultivation of emerging industries. In this context, it is very important to study the interaction between urbanization and ecological environment in Central China. At the same time, understanding the reasons for the development lag of ecological environment in some cities can provide policy basis for the coordinated development of the two.

The academic researches on the coupling coordination relationship between urbanization and the eco-environmental system have focused on two aspects: basic theory and change laws, and evaluation and simulation of the coupling coordination relationship. (1) As to researches on basic theories and change laws, in 1979, scholars David J. Rapport et al. proposed the theoretical framework of “Pressure-State-Response” (PSR) (Berger and Hodge, 1998). Turner et al. (2003) studied the interaction of human environment system and proposed the vulnerability framework. Scholars Grossman and Krueger (1995) studied the relationship between the two, and pointed out that there was an “inverted U-shaped” curve between them. Scholar Panayotou (1994) called this relationship curve the Environmental Kuznets Curve (EKC). Subsequently, in addition to the “inverted U-shaped” curve, many scholars found that the relationship between them also shows the “U-shaped” (Li, 2017), “N-shaped” (Wang et al., 2015), or “inverted-N-shaped” curves (Zhu et al., 2018). Scholars Yan and Tang (1984) conducted a series of discussions from the perspective of urban ecology and sustainable development. Scholars Liu et al. (2005) revealed the main factors of the interactive coupling between the two and explored the mutual restraint effect between them. Scholars Cui et al. (2019) conducted a comparative study on the advantages and disadvantages as well as the main applications of the dynamic simulation model coupling between them, proposed the concept of “Coupling Rubik’s Cube” (Liu et al., 2019), providing new theoretical support for the research of the coupling of the two. (2) As to the evaluation and simulation study on coupling coordination, Scholars Kline et al. (2001) described the impact of the US urbanization on landscape ecology through the gravity model. Scholars Kim et al. (2003) described the impact of urbanization on land ecology in Seoul by GIS and RS. Scholars Kok et al. (2000) analyzed the impact of urbanization on water resources in Indonesia based on fuzzy set theory. Scholars measured the coupling process and dynamic change of urbanization and eco-environmental in the urban agglomeration area (Wang et al., 2015; Chen et al., 2018; Liang et al., 2019). Scholar Lyu et al. (2019) studied the evolution characteristics of the coupling coordination degree between the two system in 285 prefecture-level cities in China. There are also studies involving the analysis of factors affecting the coordinated relationship between them (Deng et al., 2019; Zhao et al., 2020) and the prediction of future evolution trends (Han et al., 2014; Feng and Li, 2020).

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In general, scholars have conducted a lot of researches on the coupling coordination relationship between urbanization and eco-environment, and believed that there is a complex interaction between the two, which leads to different development results. However, related researches still have the following shortcomings: (1) the current researches mainly focus on the nation (Ma et al., 2012), urban agglomerations (Liu and Wang, 2015), provinces (Liu et al., 2018), prefectures and cities (Zhang et al., 2016) in terms of research scale, whereas there are relatively few studies on the Central China. (2) The existing studies have mostly measured and evaluated the coupling coordination level and spatial pattern of the two systems, however there are fewer studies on the interactive relationship and influential factors of the coupled development of the two. (3) The comparative analysis of the coupling pattern and characteristics of urbanization and ecological environment in different regions is relatively insufficient.

Based on the above analysis, this study takes the central regions of China as the research object, we dynamically analyze the coordination degree and interactive connection between urbanization and eco-environmental by using the coupling coordination degree model and the Tapio model, and explain the factors affecting coordination degree through Tobit model, expecting to provide references for the development of the central regions, as well as cities in other regions.

The rest of this paper is organized as follows: Section 2 introduces the Study area, index selection and data sources. Section 3 introduces the research methods. Section 4 analyzes the interaction between urbanization and eco-environment, and explains the influencing factors of the coordination degree. Finally, the discussion and conclusion are carried out in Section 5 and 6.

Study area, index selection and data sources

Overview of the study area

The central part of China, including six neighboring provinces of Shanxi, Henan, Anhui, Hubei, Jiangxi, and Hunan, covers an area of about 1.028 million km^2 (*Figure 1*). By the end of 2017, the permanent resident population was about 368 million with a gross value of production of about 17.94 trillion yuan. Relying on about 10.7% of China's land, carrying about 26.51% of China's population, creating about 21.69% of China's GDP, the region serves as a densely populated area, transportation hub, economic hinterland and important market in China. On December 26, 2016, the "Promoting the rise of Central China in the 13^{th} Five-Year Plan" pointed out that constructing the central regions into "important national advanced manufacturing center, a focus of the new urbanization of China, the core area of modern agricultural development in China, the national ecological civilization demonstration zone and an important all-round opening support areas."

Index selection and data sources

Index selection

Based on the existing researches and the data available (Liang et al., 2019), the evaluation indicator system regarding the coordination degree between the two is established (*Table 1*).

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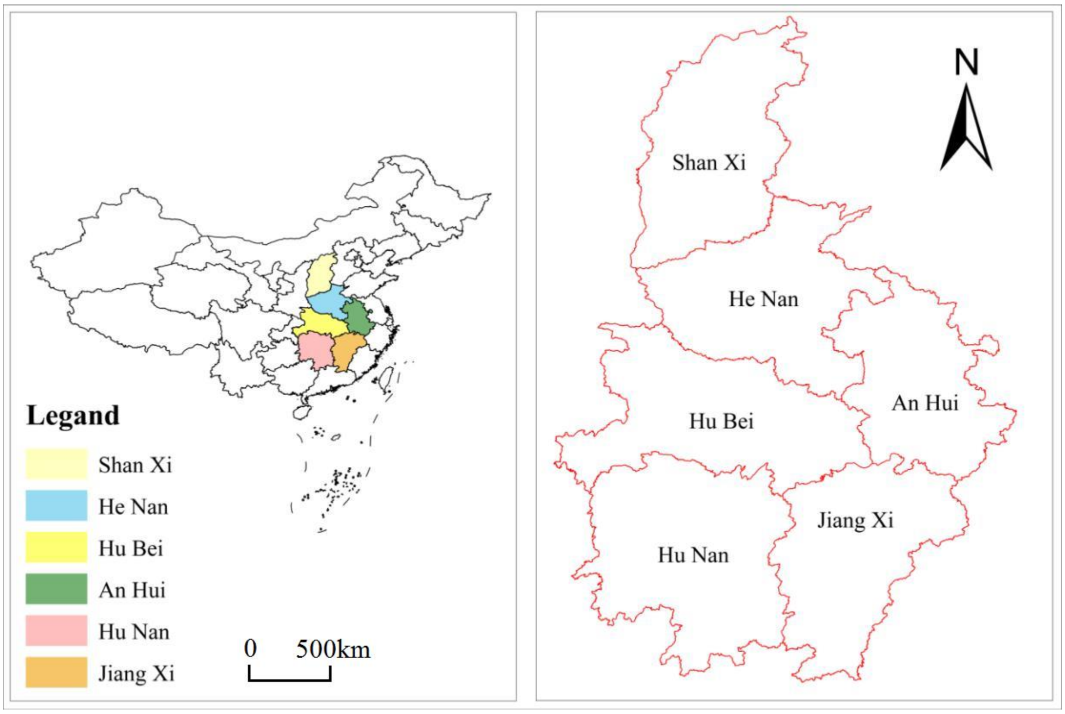

Figure 1. *Overview of the study area*

Table 1. *Evaluation index system*

System Layer	Criterion layer	Index layer	Index nature
Evaluation index system for urbaniza-tion level	Basic process	Urbanization rate of permanent population	+
		Proportion of secondary and tertiary industry employees in total employment	+
		Per capita GDP (CNY)	+
	Public service level	Number of beds in medical and health institutions per 1000 population	+
		Proportion of social security expenditure in fiscal expenditure	+
		Proportion of education expenditure in financial expenditure	+
		Urban-rural dual structure index	+
	Development vitality	GDP (CNY) growth rate	+
		Per capita retail sales of consumer goods	+
		Total export-import volume/GDP (CNY)	+
Evaluation index system for ecological environ-ment level	pressure	Industrial wastewater discharge	-
		Industrial sulfur dioxide discharge	-
		Industrial smoke (dust) discharge	-
	situation	Per capita water resource	+
		Good or moderate air quality achievement rate in urban area	+
		Green coverage rate in built-up areas	+
		Per capita park green land area	+
	response	Comprehensive utilization rate of industrial solid waste	+
		Centralized treatment rate of sewage treatment plant	+
		Decontamination rate of domestic garbage	+

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Research objects and data sources

The research objects are 83 cities in the six central provinces (limited by data availability, Tianmen, Xiantao, and Qianjiang cities are not included). Taking 2008-2018 as the research period, and the data comes from *China City Statistical Yearbook, China urban construction Statistical yearbook, the statistical yearbooks of Henan Province, Anhui Province, Shanxi Province, Hubei Province, Jiangxi Province and Hunan Province*.

Research methods

Entropy method

The entropy method is an objective weighting method, which can better overcome the subjectivity of index weighting with weights of higher credibility. Drawing on the existing research (Zhang et al., 2020), this study applies the entropy model to measure the urbanization and eco-environmental level of the researched area.

Measurement of coupling coordination

Based on relevant literature, the coupling coordination degree model of urbanization and ecological environment is established to measure the coupling coordination level between the two.

$$C = \alpha F(x) + \beta G(y) \quad \text{(Eq.1)}$$

$$T = \alpha F(x) + \beta G(y) \quad \text{(Eq.2)}$$

$$D = \sqrt{C \times T} \quad \text{(Eq.3)}$$

where *C* is the coupling level; *F(x)* is the urbanization level; *G(y)* is the eco-environmental level; *T* is the development index; *D* is the coordination level, and α and β is the contribution share of each system respectively. Based on the existing research (Zhang et al., 2020), α and β are both set as 0.5, and the coordination degree is divided into 10 grades (*Table 2*).

Table 2. *Evaluation of coordination level*

No.	Coordination degree	Coordination level	No.	Coordination degree	Coordination level
1	0.00~0.09	Extremely out of coordination	6	0.50~0.59	Marginal coordination
2	0.10~0.19	Seriously out of coordination	7	0.60~0.69	Primary coordination
3	0.20~0.29	Medium dysfunction	8	0.70~0.79	Moderate coordination
4	0.30~0.39	Mild dysfunction	9	0.80~0.89	Good coordination
5	0.40~0.49	Close to dysfunction	10	0.90~1.00	High~quality coordination

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Exploratory spatial data analysis

The core of ESDA lies in measuring the spatial correlation of geographic elements, which can usually be divided into global spatial autocorrelations (Global Moran' *I*, measured by *Formula 4*) and local spatial autocorrelations (Local Moran' *I*, measured by *Formula 5*). The Formula is as follows (He and Shao, 2018):

$$I = \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - u)(x_j - u) \Big/ \frac{1}{n}\sum_{j=1}^{n}(x_i - u)^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij} \quad \text{(Eq.4)}$$

$$I_i = Z_i \sum_{j=1}^{n} Z_j \quad \text{(Eq.5)}$$

where x_i and x_j are the coordination degrees of cities *i* and *j*, respectively; *u* is the average of the coordination degrees; w_{ij} is the spatial weight matrix constructed based on neighboring standards; *n* is the number of cities; z_i and z_j are the standardized values of the variance of the coordination degrees for cities *i* and *j*.

Decoupling model construction

In order to reflect the dynamic relationship between the two systems, Tapio decoupling index model is introduced (Feng and Li, 2020). This study has established a decoupling index in line with the ratio of the changing rate of the eco-environmental level (ΔE) to the changing rate of the urbanization level (ΔU), to describe how the eco-environmental system is changing in the process of urbanization:

$$DI_t = \left[(E_t - E_{t-1})/E_{t-1}\right] / \left[(U_t - U_{t-1})/U_{t-1}\right] \quad \text{(Eq.6)}$$

where DI_t is the decoupling index; E_t and E_{t-1} are the eco-environmental level indexes in years *t* and *t-1*; U_t and U_{t-1} are indexes related to urbanization in years *t* and *t-1*.

Tapio’s classification standard for decoupling index coefficients is widely used in the study of the relationship of economic growth with resources and environment. It has become an important criterion in the empirical study of decoupling (Guo et al., 2018). Among all kinds of decoupling, the expansion negative decoupling is the most ideal status, whereas the strong decoupling status is the least. In view of the fact that cities in the central regions have maintained stable economic growth from 2008 to 2018, the study only considers the situation when the ΔU value is greater than zero. The decoupling classification standard proposed by Tapio has been refined in the study, that is, the coefficients of the decoupling index are divided and assigned with an interval of 0.2 to reflect the gap in the decoupling state among cities in detail. The higher the decoupling score, the better the decoupling status is (Lu et al., 2020). (refer to *Table 3* for the assignment standard).

Analysis of influencing factors

Following the analysis of relevant literature (Zhang et al., 2020; Zhao et al., 2020), this study selects indicators from five aspects to perform regression analysis on the influencing factors of coordination, that is, the national electricity consumption to represent energy consumption (x_1), and the proportion of fixed asset investment to represent investment intensity in fixed assets (x_2), the proportion of foreign investment in

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GDP to characterize openness to the outside world (x_3), the proportion of science and technology expenditure in fiscal expenditure to characterize technological progress (x_4), the proportion of regional fiscal expenditure in GDP to represent government management capability (x_5). Since the value range of coordination degree is between 0 and 1, indicating truncations, the panel Tobit model for measurement is introduced to analyze the influencing factors of coordination degree. The model formula is:

$$D = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_4 x_4 + \alpha_5 x_5 + \varepsilon \quad \text{(Eq.7)}$$

where D is the coordination degree; α_0 is a constant term; α_i is a regression coefficient; ε is a random error term.

Table 3. *Evaluation of decoupling level between urbanization and eco-environmental*

Decoupling status	Decoupling connotation	Judgment condition	Decoupling index	Score
Expansion negative decoupling	The growth rate of eco-environmental level is significantly higher than that of urbanization.	ΔE>0, ΔU>0, D∈(1.2, +∞)	[1.6, +∞) (1.4, 1.6) (1.2, 1.4)	12 11 10
Expansion connection	The growth rate of eco-environmental principally remains the same as that of urbanization.	ΔE>0, ΔU>0, D∈[0.8, 1.2]	[1, 1.2] [0.8, 1)	9 8
Relative decoupling with expansion	The growth rate of eco-environmental lags behind that of urbanization	ΔE>0, ΔU>0, D∈[0, 0.8)	[0.6, 0.8) [0.4, 0.6) [0.2, 0.4) [0, 0.2)	7 6 5 4
Strong decoupling	The level of eco-environmental has regressed with the increasing urbanization.	ΔE<0, ΔU>0, D∈(-∞, 0)	[-0.2, 0) [-0.4, -0.2) (-∞, -0.4)	3 2 1

Results

Analysis of urbanization and eco-environmental development

Temporal and spatial evolution features

The urbanization and eco-environmental assessment indexes of the central regions in 2008, 2013 and 2018 are selected for spatial visualization analysis (*Figure 2*). In order to reflect the standardization and comparability at different times, the natural breaking point method is used to group the evaluation indexes into 5 categories (*Table 4*), and ArcGIS 10.3 software was used to visualize the data in maps (*Figure 2*).

Table 4. *Classification criteria for the evaluation indexes*

Level classification	Low	Sub-medium	Medium	Sub-high	High
Urbanization	<0.176	0.176~0.238	0.239~0.306	0.307~0.410	0.411<
eco-environmental	<0.401	0.401~0.481	0.482~0.534	0.535~0.597	0.598<

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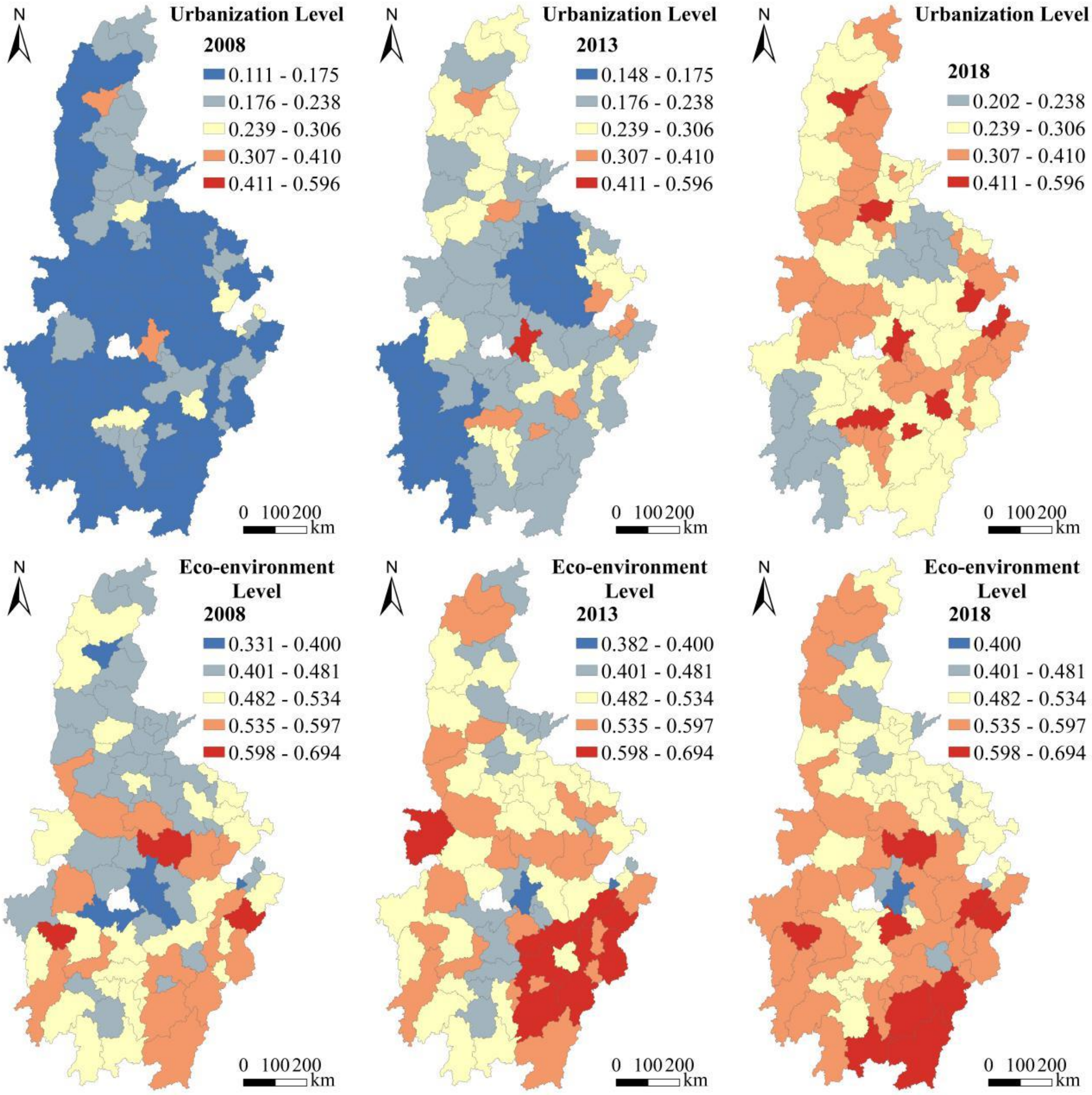

Figure 2. *Spatial-temporal evolution of urbanization and eco-environmental on 2008 to 2018*

The urbanization level of each city and town has significantly increased during the research period, exhibiting a spatial pattern of "sparse distribution of high-value areas, clustered distribution of low-value areas" and a relatively stable hierarchical structure as shown in *Figure 2*. The average value of urbanization in years 2008, 2013 and 2018 is 0.173, 0.237, and 0.319, respectively, with no area of negative growth in urbanization. (1) The high-level cities are mostly the capital cities of the provinces, indicating that the provincial capital cities have had high-quality resources within displaying a strong siphon effect. (2) The sub-high and medium-level cities are mainly located around the provincial capital cities with a tendency of ever-strengthening agglomeration effect, indicating that the radiation range of provincial capital cities is increasing, and the related areas are at a higher urbanization level relying on the trickle-down effect of provincial capital cities and their own development. (3) Sub-medium and low-level cities are mainly distributed in the fringe areas of the provinces, characterized by strong concentration and gradually-decreasing number. This shows that the uneven development of urbanization is still

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prominent, the radiation of provincial capital cities is insufficient, and the degree of integrative urbanization is lower.

The development of eco-environmental level is fluctuating even with some cities showing a trend of negative growth. The average value of the eco-environmental development in years 2008, 2013 and 2018 is 0.488, 0.518, and 0.535, respectively, and the growth rate is lower than that of urbanization. Different from the spatial distribution of urbanization levels, cities with higher levels of urbanization generally have lower levels of eco-environmental development. (1) Sub-medium and low-level cities are basically the provincial capital cities or the cities around, the number of which is small and declining. This shows that although these cities have relatively higher levels of urbanization, they face higher pressure in eco-environmental development, and local governments need to put more efforts into strengthening ecology environment construction. (2) Medium-level cities are mainly distributed around provincial capital cities with the agglomeration area gradually shifting to the south, indicating that geographical factors are important in affecting the level of urban eco-environmental development. The northern area is mainly plains and has less rainfall. Although these geographical factors are conducive to urban development, their eco-environmental system is more likely to be destroyed. The southern region is dominated by mountains with abundant rainfall and a better eco-environmental system, but the level of urbanization therein is low. (3) High and sub-high level cities are mainly distributed in the marginal areas of the provinces, concentrated in areas of southern Henan Province, southern Anhui Province, Hunan Province and Jiangxi Province, and the number is increasing.

National trend features

Based on the urbanization and eco-environmental assessment indexes in years 2008, 2013, and 2018, the Geostatistical Analyst tool in ArcGIS is applied to visualize the spatial representation, and the spatial change trend map of the development levels of the two is obtained thereby (*Figure 3*). It can be seen from *Figure 3*: (1) the overall pattern of the spatial urbanization evolution keeps stable, characterized by a higher-level in eastern part compared with that in the western part, and a higher level in northern part compared with that in the southern part. As time goes by, the trend line in the east-west direction shows an “inverted U-shaped” distribution of small variation. The trend line in the north-south direction changes from a “straight line” to an “inverted U” distribution with ever-expanding spatial differences, and the downward trend in the southern regions grows more pronounced. (2) The spatial evolution of the eco-environmental system shows prominently staged features. In the east-west direction, the trend lines of the three years all show a “U-shaped” distribution, with a gradual transition from a higher-level east compared with the west to a higher-level west compared with the east. In the north-south direction, the trend line varies from a “straight line” to a “U-shaped” distribution, with the northern region more advanced and rising faster than the southern part.

Variation of the coordination degree

Spatiotemporal differentiation of coordination

The coordination degree is calculated by *formulas (1), (2), (3),* and ArcGIS 10.3 software was used to visualize the data in maps (*Figure 4*). In 2008, 12 cities were at the level of marginal coordination, 42 cities on the verge of dysfunction, and 29 cities at

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slightly dysfunction. In 2013, 10 cities were at the level of primary coordination, 41 cities marginal coordination, and 32 cities on the verge of dysfunction. In 2018, 2 cities area at the level of intermediate coordination, 37 cities at primary coordination, 42 cities at marginal coordination, and only 2 cities on the verge of dysfunction. On the whole, their levels of coordination are on the rise along with obvious spatial differences, showing a spatial evolution trend of higher in the east and north while lower in the west and south. The spatial distribution of cities of diverse coordination degrees remains stable and the rating-circle structure is marked. Cities with a higher level of coordination are mainly located in provincial capitals such as Taiyuan, Zhengzhou, Wuhan, Hefei, Changsha, and Nanchang, with a trend of gradually expanding to surrounding areas. Cities with a lower level of coordination are mainly concentrated in the border areas of Henan and Anhui Provinces, western Hunan Province, and southern Jiangxi Province. These cities are far away from the provincial capitals and are lacking of central forces to drive their entire development, so the urbanization process therein is slow. During the researched, the coefficient of variation of the urban coordination level is 0.156 (2008), 0.128 (2013), and 0.090 (2018) respectively. The declining variation coefficients indicate that the differences in the coordination level of cities have been decreasing and the spatial distribution tends to be more balanced.

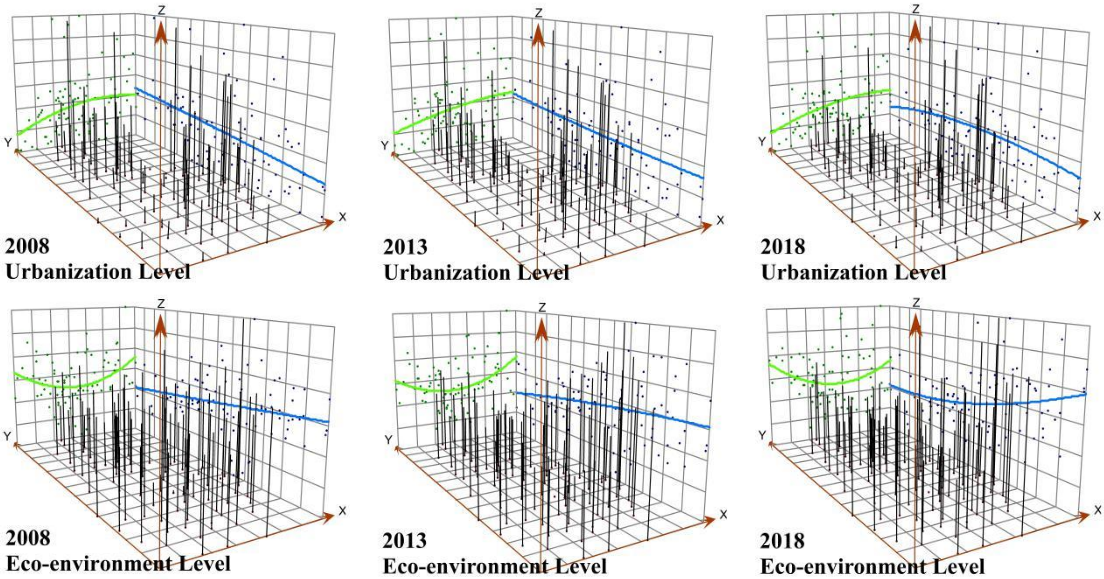

Figure 3. *Spatial change trend of urbanization and eco-environmental on 2008 to 2018*

Spatial correlation characteristics of coordination degree

The continuous shrinking of the gap in coordination degree between the two systems can only reflect its spatial heterogeneity instead of the traits of spatial interaction. Therefore, this study aims to reveal the spatial correlation characteristics of their coordination by ESDA (*Equations 4 and 5*). During the studied period, the Moran's I values of the coordination degree are positive (*Table 5*). The Moran's I values rise from 0.296 to 0.337, indicating that the coordination degree is obviously correlated with spatial distribution and the agglomeration is increasing.

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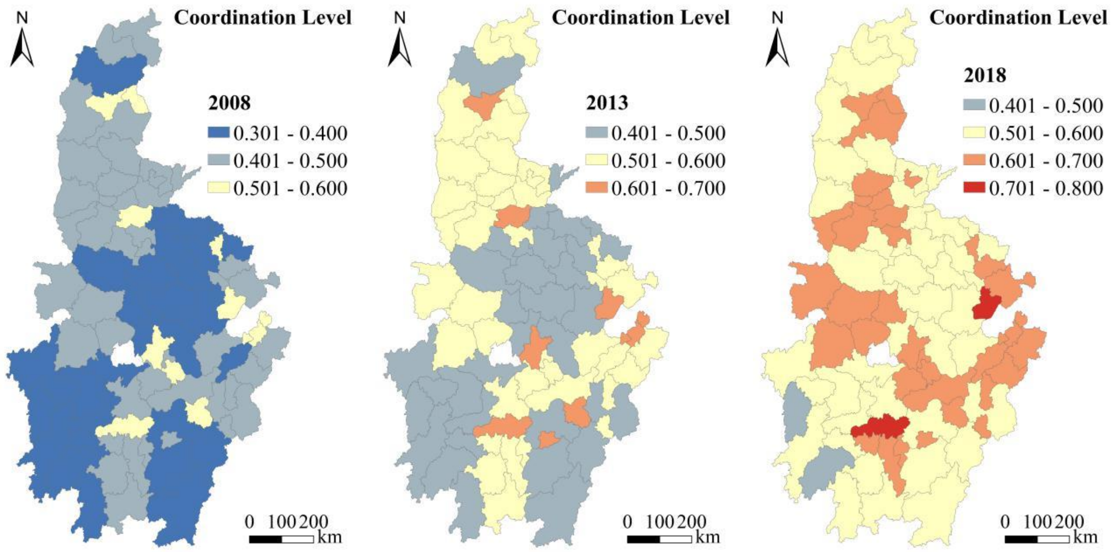

Figure 4. *Spatial-temporal evolution of the coordination level on 2008 to 2018*

Table 5. *The Moran's I values of coordination degrees*

Year	Moran's I	Z-score	P
2008	0.296	3.490	0.000
2013	0.346	4.103	0.000
2018	0.337	4.331	0.000

The local spatial autocorrelation identifies the spatial correlation types of the coordination degree and ArcGIS 10.3 software was used to visualize the data in maps (*Figure 5*). There are four different types of local spatial autocorrelation, namely H-H, H-L, L-H and L-L. Among them, H-H and L-L indicate that adjacent cities have positive spatial correlation, that is, cities with high or low coupling coordination have spatial agglomeration effect; H-L and L-H indicate that adjacent cities have negative spatial correlation, that is, cities with high (low) coupling coordination degrees are surrounded by cities with low (high) coupling coordination degrees. As shown in *Figure 5*: (1) The H-H district is mainly concentrated around provincial capital cities. These cities together with their surrounding areas have a relatively higher level of coordinated development and a lower degree of differentiation. As time goes by, the H-H district with Taiyuan and Zhengzhou as the poles tend to gradually disappear. The cities of higher-level development tend to increase in number at first and then decrease, and gradually shift to the eastern region; (2) The L-L district is relatively stable in term of spatial distribution, concentrated in the western part of Hunan Province, the junction area of Henan and Anhui Provinces, and the number of cities therein is likely to increase slightly. These cities are lacking of location advantages, and are relying on traditional resource-based industries in terms of development, therefore their urbanization level is relatively low and showing low-value associations; (3) The L-H district, a subsidence area (or the area under radiation), is mainly distributed around the H-H district. There is tendency that the L-H district will be converted into the H-H district. For instance, Xinzhou City and Xianning City in the L-H district have changed into insignificant districts, and Xuancheng City,

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Chizhou City and Huangshan City in the L-H district have changed into the H-H district, indicating the great radiation effect of cities in the H-H district; (4) The H-L district is a significant polarization zone, mainly distributed around the L-L district. There is only one city, Huaibei City, in the H-L district, demonstrating the extremely unbalanced development in Anhui Province: the weaker radiation capacity of Hefei, the provincial capital city, and the lower urbanization level of the northwestern region as a whole. Huaibei City is supposed to strengthen cooperation with Bengbu City and Chuzhou City to improve its level of development and promote the development of its surrounding cities.

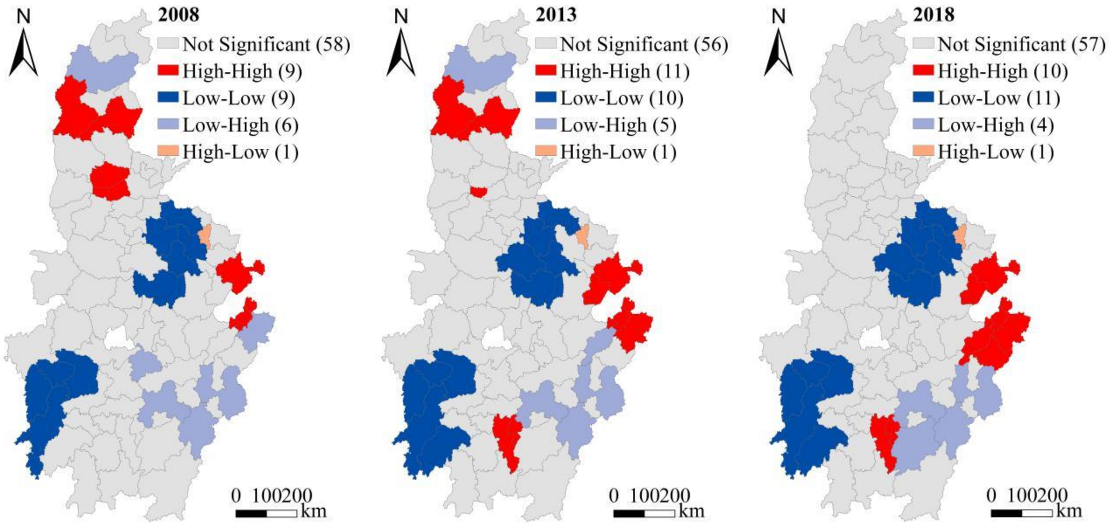

***Figure 5.** LISA agglomeration map of the coordination level on 2008 to 2018*

In general, the level of coordination degree has obvious spatial autocorrelation, dominated by the spatial positive correlation of Types H-H and L-L. However, the number of cities in the L-L agglomeration zone is increasing, and the support for the zone is supposed to be strengthened to improve the level of the urban agglomeration.

Analysis of interaction relationship

The decoupling index and decoupling score of the urbanization and eco-environmental level from 2008 to 2013 and from 2013 to 2018 are calculated by *Formula (6)*. The ArcGIS 10.3 software is applied to carry out the visualization analysis of the decoupling scores obtained in the two periods, and display the spatial differences of the decoupling state in the central regions (*Figure 6*). As shown in *Figure 6*: there are only two types of decoupling states for the two systems: strong decoupling (a decoupling score of 2-3) and relative decoupling with expansion (a decoupling score of 4-7). From 2008 to 2013, the decoupling index of each city varies from -0.36 to 0.78, with an average value of 0.18, and there are 17 cities in a state of strong decoupling, accounting for 20.48% of the total; from 2013 to 2018, the decoupling index of each city ranges from -0.40 to 0.61, with an average value of 0.10, and 27 cities are in a state of strong decoupling, accounting for 32.53% of the total. According to the difference between the decoupling scores of each city during the two periods (T2-T1), these cities can be divided into 3 groups, which are, (1) Active urbanization: T2>T1, dominated by a higher urbanization index growth rate

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compared with that of the eco-environmental index, and the eco-environmental system herein is gradually improving. There are 21 cities of this type, accounting for 25.30% of the total; (2) Neutral urbanization: T2=T1, dominated by a positive growth of both urbanization and eco-environmental indexes. There are 19 cities of this type, accounting for 22.89% of the total; (3) Passive urbanization: T2<T1, dominated by a positive growth of urbanization index and negative growth of eco-environmental index. There are 43 cities of this type, accounting for 51.81% of the total. In general, the number of cities with strong decoupling is increasing, and the number of cities with higher scores is declining. It shows that the urbanization process has put a certain amount of pressure on the eco-environmental system. Although the coordination of the two systems has been on the rise, the decoupling index shows that the two systems are in negative interaction which presents a fluctuating trend with time.

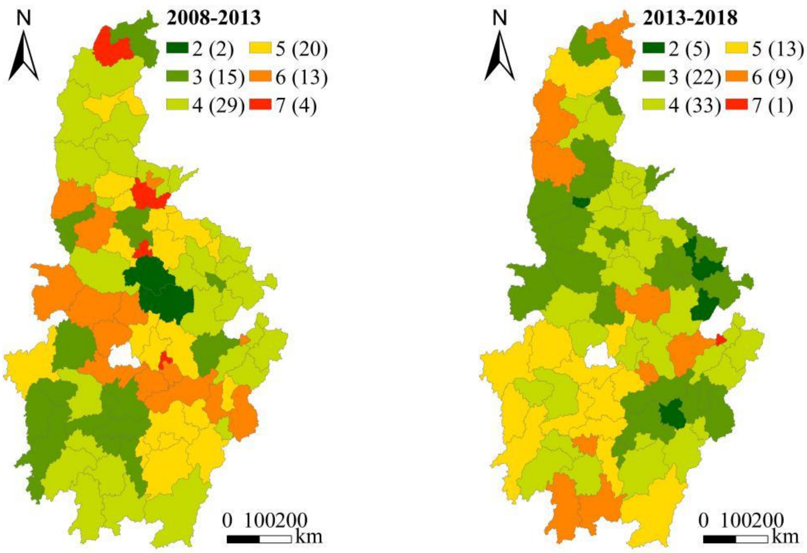

Figure 6. *Spatial pattern of urbanization and eco-environmental's decoupling status in 2008~2013 and 2013~2018*

Factors affecting the coordination degree

According to *Formula (7)*, the panel Tobit model for measurement is applied to analyze the impact of various factors on the coordination degree between the two systems. It can be seen from *Table 6* that all the five factors have an effect of diverse differences on the coordination degree. Among them, energy consumption, intensity of investment in fixed assets and opening to the outside world have a negative impact, while technological progress and government management ability have a positive impact.

Table 6. *Regression results*

Explanatory variable	x1	x2	x3	x4	x5	C	Log likelihood	Wald chi2(5)	Prob > chi2
	-0.112 ** (0.028)	-0.087 *** (0.018)	-0.094 ** (0.014)	0.119 *** (0.029)	0.063 ** (0.011)	0.505 *** (0.021)	391.96	275.83	0

Note: *** and ** indicate the significance at 1% and 5% respectively; The values in parentheses are standard deviations.

In detail, (1) The regression coefficient of energy consumption is -0.112. The central regions are the base of China’s traditional industries, the industrial pattern dominated by steel, petrochemical and equipment manufacturing industries has a large demand for energy. Their extensive economic growth relies on high-energy-consuming industries and leads to serious environmental pollution (Chang and Guan, 2020). (2) The regression coefficient of intensity of investment in fixed assets is -0.087. The secondary industry, the focus of fixed asset investment in urban China, a large amount of energy consumption and large-scale investment in the secondary industry has caused great environmental pollution (Wang et al., 2018). (3) The regression coefficient of openness to the outside world is -0.094. A view prevailing in the researches is the “Pollution Shelters Hypothesis” (List and Catherine, 2000). The expansion of the economic scale induced by the increased foreign investment has also led to environmental pollution (Zhang and Guo, 2009). The central regions of China have actively pushed forward the industrial transfer of both domestic and foreign industries. Although the economic development has been improved significantly, various problems including the low-level industrial structure and high dependence on foreign investment, have adversely affected the environment. (4) The regression coefficient of technological progress is 0.094. In recent years, the high-tech industrialization and environmental index growth out of scientific and technological progress in the central regions have made rapid progress. The four provinces of Hunan, Henan, Hubei and Anhui have achieved even faster improvement and exceeded the national average value. It's concluded that the advancement of science and technology has promoted the efficiency of energy use and the ability of environmental pollution control. (5) The regression coefficient of government management ability is 0.098. It shows that, the central regions are supposed to rely on the role of the market and the government in resource allocation, avoiding the waste of resources caused by blind competition and repeated construction, and promoting the coordinated development in Central China.

Discussion

Compared with other regions, the coordination level of urbanization and ecological environment in the central region not only shows a general trend, but also has its own characteristics: (1) The urbanization level of the central region continues to rise, and the eco-environment level fluctuates, which is similar to the development trend of the Yellow River Basin (Zhao et al., 2020). Overall, the urbanization level of the central region lags behind the ecological environment level, which is similar to the development trend of the Yangtze River economic belt (Ren et al., 2019; Wang and Yu, 2020), but it is quite different from the pattern of cities with lagging ecological environment, such as the northeast region and the southwest region (Sun et al., 2014; Zhang et al., 2016). (2) Similar to the Yangtze River Delta Urban Agglomeration and the Qinghai Tibet Plateau, the coordination degree of urbanization and eco-environment in the central region is gradually rising, but the improvement speed of urbanization level is significantly faster than that of ecological environment level (Sun et al., 2017; Feng and Li, 2020). The coupling and coordination relationship between the two has strong spatial correlation, and the spatial correlation is further strengthened, which is similar to the Yangtze River economic belt (Ren et al., 2019). (3) The interaction between the two shows that urbanization has a negative effect on eco-environment, and there are negative urbanization problems, which is similar to the development trend of Qinghai Tibet

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Plateau (Feng and Li, 2020). The growth rate of ecological environment in Tibet is obviously faster than that of urbanization. It shows that the stress effect of urbanization on ecological environment is dynamic and unsustainable, and the protection of ecological environment will also restrict the development of urbanization (Shang and Jiang, 2019). (4) In terms of influencing factors of coupling coordination between the two, energy consumption, fixed asset investment and technological progress are more significant, which is consistent with Beijing Tianjin Hebei Urban Agglomeration and Yangtze River Delta urban agglomeration (Sun et al., 2017; Yang et al., 2020). The government management ability and opening up have significant impact on the Pearl River Delta and Yangtze River Delta urban agglomerations, but the impact of energy consumption is not significant (Sun et al., 2017; Zhang et al., 2020). It shows that there is a big gap between the economic development level and market openness degree of the central region, the Yangtze River Delta Urban Agglomeration and the Pearl River Delta urban agglomeration.

Through the analysis of the commonness and individuality of the coordination degree of urbanization and ecological environment in the central region and other regions, it shows that the coordination degree of urbanization and ecological environment has some similarities in the temporal evolution and spatial pattern, but there are differences in the balance of regional development, development types and influencing factors. In the future, the central region should further advance science and technology to reduce the interference and damage of regional development on resources and environment; We should enhance the environmental access threshold of fixed assets investment, adjust the investment structure, and promote the balanced development of regional economy and environment; In the process of introducing foreign capital, we need to be careful about the environmental pollution of the introduced industries, and also pay attention to the cultivation of local industries, so as to reduce the dependence on foreign capital. In addition, we should strengthen the monitoring of energy consumption, introduce advanced production technology, and give full play to the spillover effect of cleaner production technology.

The main values of this study are as follows: (1) Further enrich the empirical research on the coupling and coordination relationship between urbanization and ecological environment in Central China, and make a comparative analysis on other regions, so as to provide guidance for promoting the coupling and coordination development of urbanization and ecological environment in Central China. (2) Using Tapio decoupling index model to analyze the dynamic relationship between urbanization and ecological environment can further reveal the relative development of the two, and clarify the stage and degree of the impact of urbanization on ecological environment. (3) This paper attempts to point out the specific reasons for promoting or hindering the coordinated development of urbanization and ecological environment, so as to provide the basis for promoting the coordinated and sustainable development in Central China.

The deficiencies and prospects of this paper: (1) In the aspect of index selection, this paper mainly relies on statistical data, and lacks the quantification of the scale, quantity and quality of ecological space, resulting in incomplete evaluation results. In the future, we can improve the research system and conduct more in-depth research. (2) In terms of research scale, there is a lack of research on urban internal space. In the future, we can use big data and remote sensing technology to study the relationship between human activities and ecological environment at the micro scale of internal urban areas. (3) The interaction mechanism between urbanization and ecological environment is very complex.

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We can discuss the interaction between urbanization and ecological resilience from the perspective of ecological resilience in the future. (4) With the improvement of basic data and technical methods, we can further explore the influencing factors.

Conclusion

Taking the central region as the research object, this paper constructs the evaluation system of urbanization and ecological environment, calculates the coordination degree of urbanization and ecological environment by using entropy method and coupling coordination degree model, analyzes the spatial-temporal evolution characteristics and interaction relationship of coordination degree by using spatial autocorrelation analysis and Tapio decoupling model, and uses Tobit model to further explain its influencing factors. The conclusions are as follows:

(1) The urbanization level of cities in Central China has been constantly improved in 2008-2018, the ecological environment level fluctuates, the coordination level between them is constantly improving and the differences between cities gradually decrease. The evolution of coordination degree has a certain level of path-dependent. The higher the coordination level, the more stable it is towards the same level.

(2) The coordination degree of urbanization and ecological environment exhibits a significant spatial correlation trait. The spatial correlation is dominated by Types H-H and L-L spatial positive correlation. There are only two types of decoupling between the two systems: strong decoupling and relative decoupling with expansion, and the number of cities in the strong decoupling status is on the rise, indicating that there is a negative interaction between the two systems, which is an issue related to negative urbanization.

(3) Influencing factors such as energy consumption, investment in fixed assets, and openness to the outside world all have a negative impact, whereas technological progress and government management capabilities have a positive impact.

Overall, the coordination degree of urbanization and ecological environment of cities in Central China is still at the stage of continuous adjustment, and it is in an important period from primary coordination to intermediate coordination. Under the requirements of new urbanization, we can improve the coupling coordination degree between the two from two aspects. One is to continuously play the leading role of core cities, improve the level of urbanization of peripheral cities and promote regional coordinated development. Secondly, the ecological environment of the central city is enhanced through legal constraints and planning, including strengthening the control of construction land, implementing low-carbon life and clean production, and reasonably distributing urban green space system.

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