Analysis on the Coupling Relationship between Urbanization and Regional Ecological Security and Empirical Analysis

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Abstract: With the acceleration of urbanization, regional ecological security issues have become increasingly prominent. There is a complex relationship between urbanization and urban ecological security. This paper uses the method of system analysis to qualitatively describe the coupling relationship between urbanization system and urban regional ecological security system, and quantitatively evaluate the coupling and coordination relationship between these two systems. The results show that the spatial urbanization subsystem is the most driven to the urbanization system, and the ecological security response system is an important factor to maintain and enhance the urban ecological security. Therefore, the spatial urbanization subsystem and the ecological security response subsystem have the greatest influence on the coupled system between urbanization and urban ecological security. Taking Shaanxi Province as an example, it is analyzed that the coordination degree between Shaanxi's urbanization system and regional ecological security system is increasing from 2005 to 2016, and has experienced four stages : uncoordinated recession, low coordination, moderate coordination and high coordination. The coordination degree between urbanization development and urban ecological security has been continuously improved, indicating that urbanization development has a positive role in promoting urban ecological security.

1 Introduction

As the objective requirement of the development of modern market economy, urbanization promotes the development of society, the improvement of productivity and the growth of economic efficiency[1]. With the acceleration of urbanization, under the interference of nature and human activities, the ecological environment in the region poses a threat to human survival and sustainable development[2], and regional ecological security issues are increasingly prominent. At the same time, some studies have shown that the higher the level of urbanization, the greater the negative impact on ecological security in a certain areas[3]. However, in the face of developed European countries, the average level of urbanization has reached 70%, and their ecological security status has not deteriorated significantly, but has improved.

From what has been discussed above, it is not sufficient to think that the development of urbanization will affect the ecological security of urban areas. The main reasons are: 1. Urbanization is a dynamic and multi-dimensional complex system, which includes many aspects such as population urbanization, economic urbanization, social urbanization, landscape urbanization, etc., and there are complex interactions between them. 2. Regional ecological security is also a complex and comprehensive state, which includes three aspects: natural ecological security, economic ecological security and social ecological security[4]. Therefore, there is no simple relationship between urbanization and regional ecological security. Therefore, a scientific understanding of the relationship between urbanization development and urban regional ecological security is of great significance for a country and a region to formulate urbanization strategies that are conducive to urban regional ecological security in the future.

2 Identification of the relationship between urbanization and regional ecological security

2.1 The positive impact of urbanization on regional ecological security

Firstly, the reduction of rural population has alleviated the pressure of agricultural resources and rural ecology, which has produced good environmental benefits. Due to the increase of urban population and the increase of social investment in cities, urban areas have been better developed. In this way, more rural population will come to the city, their education level will be improved correspondingly, and the population quality of the whole society will be improved. All these factors have an important positive impact on urban ecological security[5-6]. Secondly, as the city's economic development level improves, the urban economic structure is optimized, and the relationship between population, resources and environment is gradually coordinated, which have positively improved the ecological security of urban areas[7-8]. In the end, the development of urban social undertakings will promote the scientific management of urban management, and at the same time promote the widespread spread of ecological civilization concept among urban residents, which will deeply influence people's lifestyle. In the long run, it has far-reaching significance for improving the urban ecological environment and promoting regional ecological security.

2.2 The negative impact of urbanization on regional ecological security

Firstly, the development of industry also brings about serious air pollution, and the modern city high-rise buildings are piled up, making the pollutant not easy to dilute and spread, which has a serious negative impact on people's health. Secondly, as the city expands outward, the structure of land use changes accordingly. When the urban system is not yet perfect, the impact of urban space expansion on the ecological environment is mainly reflected in the increase of the construction land area and the continuous reduction of land area such as arable land, woodland, grassland and wetland, the loss of ecosystem service value and the enhancement of urban "heat island effect". Industrialization has indeed improved people's living standards, but it has brought about serious ecological pollution and environmental damage.

3 Construction of Coupling Measure Model of Urbanization and Regional Ecological Security

3.1 Index system construction

Urbanization is a comprehensive manifestation of many aspects. Therefore, it has multidimensional characteristics: in terms of population, it refers to the proportion of urban population; in terms of space, it refers to the continuous expansion of urban area; in terms of industry, more non-agricultural economy has replaced agricultural economy; In terms of social culture, it means that urban-related lifestyles and life concepts are spread and popularized[9].

According to the characteristics of urbanization and following the principle of selection of indicators, this paper combines the actual situation of social development and the availability of data, and refers to related research[10-11]. Finally, four comprehensive indicators of the first-level indicators and 13 secondary indicators are formed, as shown in Table 1.

Table 1 Urbanization evaluation index system and its weight

System layer	Subsystem layer	Indicator layer (unit)
Urbanization level comprehensive measurement system	Urbanization of population	Urban population （%）
		Urban population size(10,000）
		Second and third industry employment population （10,000）
		Urban population density (persons per square kilometer)
	Urbanization of economic	Per capita GDP (yuan)
		Per capita industrial output value (yuan) （yuan）
		The proportion of output value of the second and third industries（%）
	Urbanization of spatial	Built-up area (square kilometers)
		Per capita park green area (m^2)
		Per capita urban road area (m^2)
	Urbanization of social	Number of students in the school (person)
		Number of doctors (per 10,000 people)
		Number of hospital beds (per 10,000 people)

Regarding ecological safety assessment, there are many types of models used in domestic and foreign literature, such as PSR model, DSR model, DPSER model, etc[12-14]. Currently widely used is the Pressure-State-Response Model (PSR), which was jointly proposed by the Economic Development Organization (OECD) and the United Nations Environment Programme (UNEP). This paper uses the PSR model to construct an ecological safety assessment model.

The stress-state-response model, in which "stress" refers to the cause of ecological safety problems, this paper selects the pressure factors of land, resources and environment; "state" is used to measure the state of human caused natural environment. Based on data availability and comparability, this paper selects two indicators of resources and environment; "response" refers to the ability of human beings to cope with ecological security crisis. This paper selects three elements of pollution control, economic input and humanities and society to reflect. Finally, referring to the relevant literature, according to the relevant principles, the urban ecological security evaluation index system constructed is shown in Table 2.

Table 2 Ecological security evaluation index system and its weight

Target layer	Project layer	Indicator layer
Ecological security comprehensive index	Ecosystem pressure	Energy consumption per unit of GDP (tons of standard coal / 10,000 yuan)

		Per capita urban road area (m^2)
		Per capita public green area (m^2)
		Total industrial SO_2 emissions (tons)
		Chemical oxygen demand emissions (tons)
		Total industrial wastewater discharge (10,000 tons)
		Per capita GDP(yuan)
		Urban population density (persons per square kilometer)
		Population Machinery Growth Rate (%)
	Ecosystem status	Green coverage rate in built-up areas (%)
		Urban construction land area (square kilometers)
		Average air quality rate (%)
		Regional ambient noise average (db)
	Ecosystem response	Industrial solid waste treatment rate (%)
		Comprehensive utilization rate of industrial solid waste (%)
		Centralized treatment rate of urban domestic sewage (%)
		Harmless treatment rate of municipal solid waste (%)
		Cumulative soil erosion control area (thousand hectares)
		The tertiary industry accounts for the proportion of GDP (%)
		Environmental pollution control investment as a percentage of GDP (%)
		R&D investment as a percentage of GDP (%)
		Engel coefficient (%)
		Collection of books (per 10,000 people)
		Number of hospital beds (per 10,000 people)
		Number of students in the school (person)

3.2 Termination of the weight of evaluation indicators

In this study, the entropy weight coefficient method is used to assign weights to two system indicators. The calculation steps are as follows:

① Data standardization processing: since the dimensions and magnitude of each indicator and the positive and negative orientations of the indicators are different, the initial data needs to be standardized. For the positive and negative categories of indicators, the standardization method is as follows:

Positive effect indicator：

$$X_{ij}' = (X_{ij} - \min X_j) / (\max X_j - \min X_j)$$

Negative effect indicator：

$$X_{ij}' = (\max X_{ij} - X_j) / (\max X_j - \min X_j)$$

②Calculate the proportion of the j indicator value in the i year：

$$Y_{ij} = X_{ij} / \sum_{i=1}^{m} X_{ij}'$$

③ Calculation of index information entropy ： $e_j = -k \sum_{i=1}^{m} (Y_{ij} \times \ln Y_{ij})$

Suppose $k = \frac{1}{\ln m}$ ， then $0 \le e_j \le 1$ ， and when $Y_{ij} = 0$， suppose $Y_{ij} \times \ln Y_{ij} = 0$；

④Calculation of information entropy redundancy： $d_j = 1 - e_j$；

⑤ Determination of indicator weight ： $w_i = d_j / \sum_{j=1}^{n} d_j$ 。

In this formula： X_{ij}' and X_{ij} are the standardized and original values of the j item in the i year. The $\max X_j$ and the $\min X_j$, they are the maximum and minimum values of the j-th single indicator for all years. Where m is the number of years of evaluation and n is the number of indicators.

3.3 Thesis of Urbanization and Regional Ecological Security Evaluation Indicators

For the urbanization level index, the 27 indicators data of population, economy, society and space are first standardized, then the weight calculation is performed by the entropy weight method, and the urbanization level index of 4 aspects is obtained by weighted summation. These four aspects of the urbanization level index are multiplied by the corresponding weights, and after accumulating, the comprehensive urbanization level index is obtained[15].

The calculation formula: $M = \sum_{i=1}^{n=4} f_i w_i$. In this formula： M is the comprehensive urbanization level index; f_i is the urbanization level index of population, economy, society and space, and w_i is the corresponding weight.

Similarly, a weighting function is used to derive the development index of the urbanization and ecological security system and its various subsystems. Its calculation formula is:

$$u(X) = \sum_{i=1}^{3}\sum_{j=1}^{n}(X_{ij}^{'} \cdot \omega_j)$$

$$f(Y) = \sum_{i=1}^{4}\sum_{j=1}^{n}(Y_{ij}^{'} \cdot \omega_j)$$

In this formula: $X_{ij}^{'}$ and $Y_{ij}^{'}$ are standardized values for individual indicators of urbanization and ecological security systems, $\sum^{n}(X_{ij}^{'} \bullet \omega_j)$ and $\sum^{n}(Y_{ij}^{'} \bullet \omega_j)$ are the evaluation values of the development indexes of various subsystems of urbanization and ecological security. $u(X)$ and $f(Y)$ are the combined values of the urbanization system and the urban regional ecological security system development index. Their numerical values are positively correlated with the corresponding urbanization level and ecological security status.

3.4 Construction of Coupling Relationship Model between Urbanization and Regional Ecological Security

Extending the coupling degree model of multiple systems by means of the coupling concept in physics,

$$C_n = \left\{\left(u_1, u_2, ..., u_n\right) / \left[\prod(u_i + u_j)\right]\right\}^{1/n}$$

The coupling evaluation model of urbanization and ecological security can be obtained as follows:

$$C_n = \left\{\left(u(X) \cdot f(Y)\right) / \left[\frac{u(X) + f(Y)}{2}\right]^2\right\}^k$$

$$D = \sqrt{C \cdot T}\ , \qquad T = pu(X) + qf(Y)$$

In this formula: C is the coupling degree between urbanization system and ecological security system ($0 \le C \le 1$), it reflects the degree of interaction between the two systems; T is the comprehensive evaluation index of the development level of urbanization system and ecological security system; p and q is the weight coefficient , reflecting the degree of influence of the two systems on the urbanization-ecological safety coupling system; D is the degree of coordinated development ($0 \le D \le 1$) ,it measures the degree to which the two systems are in harmony with each other during development. Here, the difference between the degree of coupling and the degree of coordinated development is that the degree of coupling mainly reflects the degree of interaction between systems, it does not indicate right or wrong; and the degree of coordinated development indicates the degree of benign coupling in the interaction, reflecting the degree of coordination.

According to existing research, the coupling relationship between urbanization and urban ecological security can be divided into four categories according to the size of coordinated development degree D; These four categories can be divided into 12 different coupling coordination types according to the size relationship between $u(X)$ and $f(Y)$ (as shown in Table 3), and the coordination and development of the two systems are judged accordingly.

4 Empirical analysis

4.1 Research objects and data sources

This paper takes China's Shaanxi Province as the research object, and empirically analyzes the coupling relationship between urbanization and urban regional ecological security. The relevant indicators in the urbanization evaluation index system mainly come from the Shaanxi Statistical Yearbook (2006-2017) and the website of the National Bureau of Statistics. The relevant indicators in the ecological security evaluation model are mainly from the China Urban Statistical Yearbook (2006-2017) and Shaanxi Environmental Statistics Bulletin (2005-2016).

Table 3 Coordination type and evaluation criteria of urbanization and ecological security coupling

D	Coupling phase	Relationship between $U(X)$ and $f(Y)$	Coordination type
$0 < D \le 0.3$	Uncoordinated A_1	$U(X) > f(Y)$	The two systems do not coordinate the development of recession, and the development of ecological security lags behind A_{11}
		$U(X) = f(Y)$	Uncoordinated recession development, simultaneous development of the two systems A_{12}
		$U(X) < f(Y)$	Uncoordinated recession development, urbanization development lag A_{13}
$0.3 < D \le 0.5$	Low coordination A_2	$U(X) > f(Y)$	Low degree of coordinated development, ecological safety development lag A_{21}
		$U(X) = f(Y)$	Low degree of coordinated development, simultaneous development of the two systems A_{22}

		$U(X) < f(Y)$	Low degree of coordinated development, urbanization development lags behind A_{23}
$0.5 < D \le 0.8$	Moderate coordination A_3	$U(X) > f(Y)$	Moderate coordinated development, ecological safety development lags behind A_{31}
		$U(X) = f(Y)$	Moderate coordinated development, simultaneous development of the two systems A_{32}
		$U(X) < f(Y)$	Moderate coordinated development, urbanization development lags behind A_{33}
$0.8 < D \le 1$	Highly coordinated A_4	$U(X) > f(Y)$	Highly coordinated development, ecological safety development A_{41}
		$U(X) = f(Y)$	Highly coordinated development, simultaneous development of the two systems A_{42}
		$U(X) < f(Y)$	Highly coordinated development, urbanization development is lagging A_{43}

4.2 Analysis of urbanization system results and changes in urban area ecological security system

The weights of each index of each subsystem of urbanization and the three sub-systems of urban area ecological security are obtained by Matlab.

For the urbanization system, the population urbanization subsystem has the greatest weight, followed by the social urbanization subsystem and the economic urbanization subsystem, and the smallest is the spatial urbanization subsystem. It also shows that it is reasonable to use the proportion of urban population to reflect the overall development level of urbanization. According to the 13 individual indicators of the urbanization system, the three indicators that have the greatest impact on the urbanization system are the per capita urban road area, the number of beds per 10,000 people, and the per capita industrial output value.

In the urban regional ecological security system, the response subsystem has the largest weight, followed by the pressure subsystem, and the state subsystem has the least effect in the urban regional ecological security system because of the least indicators. Through this result, we can draw the conclusion that the specific measures for ecological security issues are the most important for improving and maintaining ecological security.

For China with a large population, the urbanization process is accelerating and the urban population density is increasing. Improving urban infrastructure construction, improving laws and regulations, and introducing corresponding supporting safeguard measures have become the key factors determining whether urban ecology is safe. Therefore, in the process of exploring the coordinated development of urbanization and ecological security, the ecological security response must be considered.

4.3 Analysis of Coupling Changes between Urbanization and Urban Regional Ecological Security

Regarding the quantitative study of the coupling relationship between the two systems, most of the literature [15-16] directly gives the same weight to the two systems（p=0.5,q=0.5）.In this paper, by changing the values of p and q, three different scenarios are set to analyze the changes in the coupling relationship between urbanization and urban ecological security. The specific results are shown in Table 4.

Table 4 Results of urbanization and ecological security coupling types under different weights

Years	Scenario 1：p=0.3，q=0.7		Scenario 2：p=0.5，q=0.5		Scenario 3：p=0.7，q=0.3	
	D1	Coordination type	D2	Coordination type	D3	Coordination type
2005	0.2781	A_{13}	0.2225	A_{13}	0.1668	A_{13}
2006	0.3381	A_{23}	0.2954	A_{13}	0.2526	A_{13}
2007	0.3419	A_{23}	0.3219	A_{23}	0.3019	A_{23}
2008	0.3635	A_{23}	0.3461	A_{23}	0.3287	A_{23}
2009	0.4906	A_{23}	0.4620	A_{23}	0.4335	A_{23}
2010	0.4135	A_{21}	0.4306	A_{21}	0.4477	A_{21}
2011	0.4174	A_{21}	0.4552	A_{21}	0.4929	A_{21}

2012	0.4612	A_{21}	0.4979	A_{21}	0.5346	A_{31}
2013	0.6339	A_{31}	0.6648	A_{31}	0.6957	A_{31}
2014	0.6004	A_{31}	0.6420	A_{31}	0.6836	A_{31}
2015	0.6996	A_{31}	0.7283	A_{31}	0.7571	A_{31}
2016	0.8031	A_{41}	0.8228	A_{41}	0.8426	A_{41}

Comparing the coupling situation between urbanization and urban regional ecological security system under three conditions, the development trend of the coupling coordination degree of the two systems under different weights is very small, and the types of coordinated development are basically the same, which indicates the urbanization system and ecology. The coordination degree of the security system is not sensitive to the weight change it gives, which proves that most of the existing researches are reasonable only for the equal weight processing of the two systems.

From Figure 1, during the period of 2005-2016, the coordination degree of urbanization and ecological security systems in China showed a general growth trend. From Table 3, it can be concluded that, according to the degree of coordination and the comprehensive development value of the urbanization system and the ecological security system, the coordinated development has experienced four stages: from uncoordinated recession to high degree of coordination:

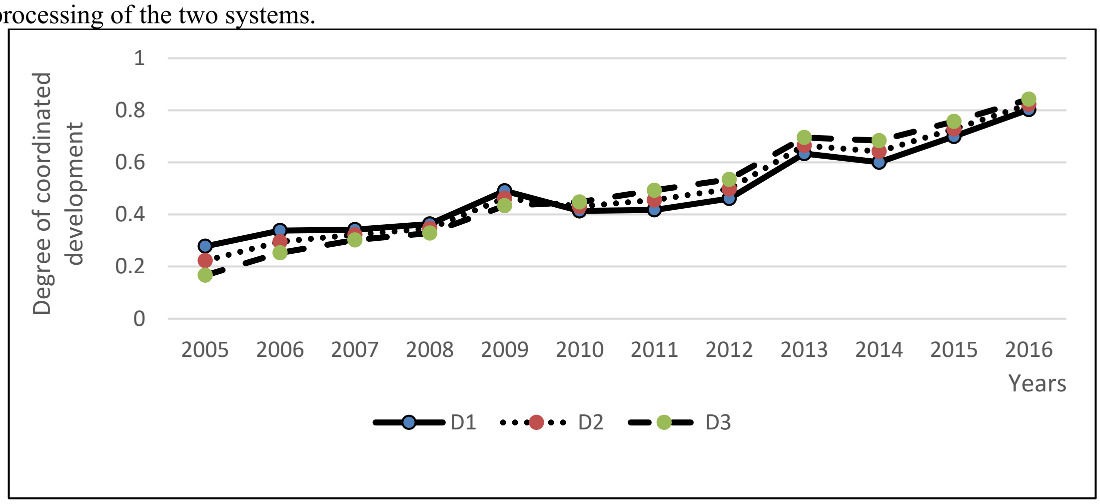

Figure 1 Changes in the coordinated development of urbanization and ecological security in Shaanxi Province

(1) In 2005, D=0.2225 (p=0.5, q=0.5), the urbanization system and the ecological security system belonged to the uncoordinated recession development, and the degree of urbanization development was slightly lower.

(2) In 2006-2012, the two systems belonged to a low-level coordinated development stage. Further analysis, from 2006 to 2009, urbanization development lags behind ecological security development, and from 2009 to 2012, the urbanization process accelerated, and the development of ecological security lags behind urbanization.

(3) In 2013-2015, the coordinated development of the two systems has improved and is in a moderately coordinated development stage. However, in the past three years, the development of urban ecological security has lagged behind the development of urbanization.

(4) In 2016, the urbanization process and urban ecological security reached a stage of highly coordinated development, but they still could not develop simultaneously, and the development of the ecological security system still lags behind the development of urbanization. In recent years, the level of urbanization in Shaanxi Province has been accelerating. As of 2016, the urbanization rate of permanent residents has reached 55.34%, and people's awareness of environmental protection has also increased. However, compared with the speed of urbanization, the development speed of ecological security is still need to be further improved. In the future economic and social development process, ecological security will be the main limiting factor for the coupling system of urbanization and ecological security. Therefore, accelerating ecological security construction is the first problem to be solved in the future realization of sustainable economic development in Shaanxi Province.

5 Conclusions

Urbanization promotes social progress, promotes economic growth, promotes the improvement and perfection of urban functions, and enhances urban ecological security. However, many urban diseases brought by urbanization seriously affect the ecological security of urban areas. This paper establishes a coupled measure model by identifying the relationship between urbanization and urban regional ecological security. Shaanxi Province was selected as an empirical research object to analyze the coupling relationship between urbanization and urban regional ecological security from 2005 to 2016. The research conclusions are as follows:

(1) The positive impact of urbanization on urban ecological security. With its resource advantages, the city attracts people from rural to urban areas. The urban population has increased, the city has expanded in scale, and the level of urban economic development has improved. As a result, the investment in all aspects of the city has increased and the urban economic structure has been continuously optimized. All of this contributes to improving the ecological security of urban areas.

The negative impact of urbanization on urban ecological security. The urban population has increased, the amount of domestic garbage generated has increased significantly, and garbage disposal has not been timely, which has had a great impact on the ecological environment. The expansion of urban area, the reduction of land area such as wetlands and forest land, led to the imbalance of ecosystem functions. A reduction in the area of cultivated land will lead to a decline in food production and will threaten the survival of our people in the long run.

(2) As a city in western China, Shaanxi is less urbanized and economically developed than in the east, and its ecological environment is relatively fragile. Despite this, from 2005 to 2016, the coupling and coordination degree between urbanization and urban ecological security in Shaanxi Province has been continuously improved. From the uncoordinated recession phase in 2005 to the low-coordinated development phase in 2006-2012, to the moderately coordinated development phase in 2013-2015, and to the highly coordinated development phase in 2016. This shows that although urbanization and urban ecological security are contradictory in some respects, overall, the coordination between urbanization and urban ecological security continues to increase. This shows that urbanization development has a positive role in promoting urban ecological security. This also explains why many developed countries have high levels of urbanization, but urban ecological security has improved.

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