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Zhao Yong-feng
National University of Uzbekistan
Faculty of Geography and Natural Resources,
Tashkent 100174, People's Republic of Uzbekistan
Faculty of Geography and Planning,
Key Laboratory of Geospatial Big Data Application and Environmental Monitoring,
Jining Normal University, Ulanqab 012000, People's Republic of China

Zheng Hui
National University of Uzbekistan
Faculty of Geography and Natural Resources,
Tashkent 100174, People's Republic of Uzbekistan
Faculty of Geography and Planning,
Key Laboratory of Geospatial Big Data Application and Environmental Monitoring,
Jining Normal University, Ulanqab 012000, People's Republic of China

Zulkhumor Nazarovna Tojiyeva
National University of Uzbekistan
Faculty of Geography and Natural Resources,
Tashkent 100174, People's Republic of Uzbekistan

ANALYSIS OF COUPLING PROCESS AND DECOUPLING BETWEEN NEW-TYPE URBANIZATION AND ECOLOGICAL ENVIRONMENT: A CASE STUDY OF HOHHOT， CHINA

Abstract: *The coordinated development of the new-type urbanization and ecological environment is of great significance for the overall development of regional and urban areas during the new development period of china. Based on 2000 to 2019 panel data from Hohhot City, the coupling coordination degree model and the decoupling model were used to calculate and analyze the interplay between urbanization and ecological environment, and the obstacle factor diagnosis model was used to identify the major obstacles. The results show that: (1) the coupling degree and coupling coordination degree of the system evolve from high level coupling-moderate coordination to high quality coupling-good coordination. The degree of coupling precedes the degree of coupling coordination. The gap between the degree of coupling and the degree of coordination decreases year by year, and there is still a lot of room for improvement in the degree of coordination. (2) In the past 20 years, urbanization and ecological environment have shown a dynamic evolution trajectory with strong decoupling types, diverse types and complex processes, reflecting the complex interaction relationship and dynamic evolution characteristics between urbanization and ecological environment. (3) The scores of subsystems and indicator barrier factors showed a decreasing trend year by year, while the ecological pressure showed an increasing trend. The main obstacles show a complex dynamic evolution with different stages of urbanization development.*

Key words: *new-type urbanization; Ecological environment; Coupling coordination degree; Decoupling analysis; Hohhot.*

Language: *English*

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Introduction

The primary challenge for high-quality regional development in China's new development era is to improve the synergistic sustainable growth of new-type urbanization and ecological environment. In China's new period of development, the coupling between urbanization and complex ecological and environmental systems has emerged as the academic focus of regional sustainable development research. The relationship and mechanism between urbanization and the natural environment has been objectively explained by foreign academics using the EKC curve [1], decoupling theory [2], the PRS analysis framework [3], system dynamics [4], and other techniques. Chinese academics have conducted a diverse range of significant findings based on various regions of China, predominantly concentrating on coupling theory and method [5-8], coupling mechanism, pattern, and prediction [9-12], response relationship [13-15], decoupling [16-18], etc., and have produced a wealth of research findings [19-28]. It provides a significant theoretical foundation and practical reference relevance to lead the investigation of a new model for building regional new-type urbanization and harmonizing regional and urban-rural integrated development.

Based on current research trends, academics have categorized studies on the coordinated development of urbanization and the ecological environment under the umbrella of sustainable development research and applied systematic analysis to empirical studies on issues related to urbanization, including economic, social, demographic, resource and environmental. Research techniques typically demonstrate general trends from theory to experiment, ranging from static temporal cross-section analysis to spatio-temporal integrated dynamic process evolution and spatial pattern analysis, and scientifically suggest corresponding optimal regulatory strategies to appropriately guide regional, urban and rural sustainable development in new development periods. The complexity and breadth of the findings of the present study nevertheless suffer as a whole from the following flaws. (1) From a research standpoint, typical industrial cities in the ecologically vulnerable regions of central and western China receive little academic attention; (2) In terms of research methods, the majority of prior studies concentrated on the spatiotemporal evolution process and pattern analysis of the coupling relationship, and lacked the decoupling analysis and the identification of the main obstacle factors affecting the coordinated development of the coupling relationship.(3) In terms of the study topic, the micro-coupled quantitative analysis of Hohhot city is seldom covered. Instead, most studies have focused on macro-regional studies, such as provinces, urban agglomerations and urban belts.

As a major ecological node city in the Yellow River basin of Inner Mongolia, Hohhot is a comprehensive reflection of the sustainable development characteristics of urbanization and ecological environment in typical research areas. It also has a unique natural environment and historical background, as well as a fragile ecological environment in western China. The objective evaluation of the mutual feed mechanism of urbanization and the ecological environment, the identification of its significant barrier influencing factors, the reduction of ecological environment risks, and the promotion of the high-quality development of urbanization in Hohhot are all aided by scientific judgment of the coupling relationship between urbanization and the ecological environment and its effects in Hohhot. As a result, by using the system coupling angle to create a new-type of framework for analyzing how urbanization and the environment interact, analyzing Hohhot's urbanization and ecological environment's evolution mechanisms and processes in-depth from 2000 to 2019, assessing its decoupling relationship's overall development, and accurately identifying the main obstructive factors. On a theoretical level, it can extend the depth and dimension of coupled system theory in the study of high-quality sustainable development in new types of urbanization, and deepen the understanding of the concept of coupled and coordinated development between urbanization and the natural environment in Hohhot. On a practical level, the paper can provide theoretical support for the high-quality coupling and coordinated development of new-type urbanization and ecological environment in Hohhot, which is both theoretically sound and plausible. It could also provide theoretical and practical support for the construction of new-type urbanization in ecologically vulnerable areas of the Midwest.

1. Overview of Study Area

The Inner Mongolia autonomous region is centered in Hohhot, which serves as its political, economic, cultural, scientific, educational and financial hub. Geographically, it is located between 110°46'and 112°10'E and 40°51'and 41°8'N. It has a typical temperate continental desert and semi-arid monsoon climate. 17,200 km^2 constitutes its land area. It controls four districts, four counties and one banner, in addition to one banner and one national economic and technical development zone. The built-up area is 260 km^2, while the built-up area's green covered area is 12906.38 hm^2. It is referred to as the "Milk Capital of China" and has received numerous awards, including those for National Historical and Cultural

City, National Forest City, China Excellent Tourism City, National Ten Happy Cities, National Model City of Ethnic Unity and Progress, National Model City of Double Support, and others. As of 2020, there are 3.4542 million permanent residents living in the city, with an urbanization rate of 79.15%. The GDP was 280.068 billion yuan and the GDP per capita was 81,656 yuan. Mongolians made up 11.57% of the population, while Han Chinese made up 85.42%.

Hohhot, a central city along the Yellow River basin, has highlighted the conflict between the rapid and extensive process of urbanization over the past two decades and the natural and ecological environment, with ecological protection becoming increasingly critical as consumption of resources and energy continues to rise. 17.255 million metric tons of standard coal were used in the overall energy consumption of Hohhot in 2019 and a total of 2778.09 million KWH of electricity was used throughout the community. Overall water supply for the year was 169.35 million tonnes, 12.18 times and 1.62 times more than in 2000. It remains part of the economy's heavily regulated coal-based resources sector. There is a serious tension between the need for ecological water and the growing demand for water for daily use and production. Sulfur dioxide from industrial sources accounted for 16,411 tons of the total industrial exhaust gas volume in 2019 (420,2 billion cubic meters). A total of 73 days, or 20 percent of the annual total, saw ambient air pollution in the city. Industrial wastewater and domestic sewage are major sources of surface water pollution. 2019 saw a benchmark rate of 85.7 percent for water quality in areas with surface water environmental functioning. The total amount of industrial waste discharged each year is 22.3 million tons, the amount of chemical oxygen required is 2,785 tons, and the total amount of industrial solid waste used is only 23.9 percent of the total amount produced. Additional research is needed to address the key issues of energy resources, environmental carrying capacity and creation and conservation of Hohhot's natural ecological environment. It is essential and functional for the construction of new types of urbanization and the protection of the ecological environment of urban agglomerations in the Yellow River basin. The new interactive coupling relationship between urbanization and ecological environment in Hohhot, exploring the urban agglomeration along the Yellow River in Inner Mongolia, is a new model for sustainable development during the period of urbanization.

2 Materials and Methods

2.1 Data source

In order to quantitatively calculate the coupling and coordinated spatio-temporal evolution relationship between the urbanization and ecological environment system in Hohhot City of Inner Mongolia from 2000 to 2019, this study uses the data from Hohhot City of Inner Mongolia as the main research area and the urbanization and ecological environment data from 2000 to 2019 as the research time section. The Inner Mongolia Statistical Yearbook (2001-2020), China Urban Statistical Yearbook (2001-2020), and Hohhot Statistical Yearbook (2001-2020) are the sources of all the original data used in the study, which may be used to confirm the validity, reliability, and originality of the information.

2.2 Research method

2.2.1 Indicator system

Urbanization is a complex coupled system involving a wide range of complex factors including population, resources, economy, society, environment and space. A comprehensive evaluation index system for the urbanization and ecological environment of Hohhot has been created to support scientific rigor in research. It is based on regional data, scientific, comprehensive, and easy to get sex principle, combined with the PRS (pressure-state-response) and PES (population, economy, and society) models. (Table 1).

Table 1. Comprehensive evaluation index system of urbanization and ecological environment

System layer	Subsystem layer	Weight	Index layer	Attribute	Weight
Urbanization system	Population urbanization	0.2131	Year-end population（10,000Person）	+	0.4040
			Urbanization rate（%）	+	0.2981
			Natural population growth rate（%）	+	0.2979
	Economic urbanization	0.1942	Per capita GDP（Yuan）	+	0.1863
			Regional GDP growth rate（%）	+	0.1805
			Gross industrial output value above scale（10,000 Yuan）	+	0.1850
			The proportion of output value of secondary industry in GDP（%）	+	0.1553

			The proportion of output value of tertiary industry in GDP（%）	+	0.1232
			Total foreign trade imports and exports （10,000 U.S. dollar）	+	0.1698
	Social urbanization	0.3029	Total fixed asset investment of the whole society（10,000 Yuan）	+	0.1585
			There are buses for every 10,000 people（Unit）	+	0.1425
			Public toilets per 10,000 people（Seat）	-	0.1734
			Number of college students per 10,000 people （Person）	+	0.1294
			Number of beds per 10,000 people（Bed）	+	0.1744
			Number of doctors per 10,000 people（Person）	+	0.2218
	Spatial urbanization	0.2898	Urban construction land area（km^2）	+	0.3747
			Road eara per sitizen（㎡）	+	0.2460
			Urban population density（Person/ km^2）	-	0.3793
Ecological environment system	Ecological environment status	0.3394	Greenery coverage of urban area（%）	+	0.2403
			Park green land area per capita（㎡）	+	0.2492
			Total annual precipitation（mm）	+	0.2314
			Average annual urban temperature（℃）	+	0.2790
	Ecological environment pressure	0.3334	Annual water supply（t）	-	0.1559
			Total annual electricity consumption (KWH)	-	0.1614
			Industrial Waste Water Discharged（t）	-	0.1424
			Industrial sulfur dioxide emissions（t）	-	0.1864
			Industrial soot (powder) emissions（t）	-	0.1585
			Industrial exhaust emission（m^3）	-	0.1952
	Ecological environment response	0.3272	Comprehensive utilization rate of industrial solid waste（%）	+	0.2693
			Percentage of Sewage Disposed（%）	+	0.2651
			Harmless disposal rate of household garbage（%）	+	0.1993
			Afforestation area（ha）	+	0.2663

2.2.2 Evaluation model

The deviation standardized data processing method is used to normalize the original data of new-type urbanization and ecological environment in Hohhot, eliminate the unit difference and order of magnitude difference between data indicators, and calculate the following formula for different nature indicators [24].

Positive index standardization formula：

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

Inverse index standardization formula：

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

Where: X'_{ij} is the index value after standardization treatment; X_{ij} is the original index value before standardization treatment; $\min X_j$ and $\max X_j$ respectively for the first j indicators of minimum and maximum.

The weight of each subsystem and index factor is calculated using the entropy weighting method, and the calculation formula is as follows [22]:

$$P_{ij}=Y_{ij}/\sum_{i=1}^{n}y_{ij},$$

$$E_j=-\ln(n)^{-1}\sum_{i=1}^{n}P_{ij}\ln P_{ij},$$

$$w_i=\frac{1-E_i}{n-\sum E_i}$$

Where W_i is the index weight, E_j is the information entropy of j index, and P_{ij} is the proportion of j index in the ith city.

$U(x)$ and $E(y)$ respectively represent the comprehensive development index of urbanization and ecological environment, which is calculated by the comprehensive linear weighted sum of subsystems. Where, n and m represent the number of specific indicators in the subsystem of urbanization and ecological environment respectively [29].

$$U(x)=\sum_{i=1}^{n}w_i x_{ij},\ E(y)=\sum_{i=1}^{m}w_i y_{ij}$$

2.2.3 Coupling degree model

The coupling degree model of new-type urbanization and ecological environment is constructed by referring to coupling theory, and the calculation formula is as follows [29] :

$$C = \sqrt{\frac{U(X)\cdot E(y)}{\left(\frac{U(X)+E(y)}{2}\right)^2}}$$

The magnitude of C value of coupling degree represents the degree of related influence between systems, and the change of C value from 0 to 1 indicates the benign resonance between elements within the system from disorder to order. Based on relevant research results, the coupling degree level is divided into five levels [30] (Table 2).

Table 2. Classification of coupling coordination degree

Coupling degree C	Coupling stage	Coupling coordination degree ***D***	Coupling coordination level
0.000＜***C***≤ 0.300	Low level coupling	0.000＜***D***≤ 0.300	Severe disorder
0.300＜***C***≤ 0.500	Antagonistic stage	0.300＜***D***≤ 0.500	Mild disorder
0.500＜***C***≤ 0.700	Running-in stage	0.500＜***D***≤ 0.700	Moderate coordination
0.700＜***C***≤ 0.900	High level coupling	0.700＜***D***≤ 0.900	Good coordination
0.900＜***C***≤ 1.00	High quality coupling	0.900＜***D***≤ 1.00	High quality coordination

2.2.3 Coupling coordination degree model

In order to accurately evaluate the development degree of synergy and interaction between Hohhot's urbanization and ecological environment systems, the coupling coordination degree model is introduced for calculation, and the calculation formula [29] is as follows:

$$T = \alpha U(x) + \beta E(y)$$

$$D = \sqrt{C \times T}$$

Where: ***T*** represents the comprehensive development index; ***D*** is coupling coordination degree; α, β are undetermined coefficients, $\alpha+\beta = 1$. In this paper, urbanization and ecological environment are of equal importance, so $\alpha = \beta = 0.5$. Based on relevant studies, the coupling coordination degree types of urbanization and ecological environment in Hohhot were divided into five levels [30] (Table 2).

2.2.4 Decoupling model

In order to further objectively evaluate the functional relationship between urbanization and ecological environment system, Tapio's research results [31] were used for reference to construct a decoupling model of urbanization and ecological environment in Hohhot.

$$DI_t = \frac{(E_t - E_{t-1})/E_{t-1}}{(U_t - U_{t-1})/U_{t-1}}$$

Where: DI_t represents the decoupling index of ecological environment to urban development in period t; E_t and E_{t-1} represent the ecological environment comprehensive index of year t and year $t-1$, respectively. U_t and U_{t-1} represent the comprehensive urbanization index in year t and year $t-1$, respectively. $\triangle E = (E_t - E_{t-1}) / E_{t-1}$, denotes the change rate of ecological environment comprehensive index in year t; $\triangle U = (U_t - U_{t-1}) / U_{t-1}$ represents the change rate of the urbanization composite index in year t. According to the research results of Liu Hehe and Yang Qingshan, the decoupling state types are divided into 3 categories and 8 states [17] (Table 3).

Table 3. Classification criteria for decoupling state types

Degree of decoupling	**Decoupling**			**Inter-linking**		**Negative decoupling**		
	Strong decoupling	**Weak decoupling**	**Recessive decoupling**	**Recessive Inter-linking**	**Expansive Inter-linking**	**Expansive negative decoupling**	**Weak negative decoupling**	**Strong negative decoupling**
△***U***	△***U>0***	△***U>0***	△***U<0***	△***U<0***	△***U>0***	△***U>0***	△***U<0***	△***U<0***
△***E***	△***E<0***	△***E>0***	△***E<0***	△***E<0***	△***E>0***	△***E>0***	△***E<0***	△***E>0***
DI	***DI<0***	***0<DI<0.8***	***DI>1.2***	***0.8<DI<1.2***	***0.8<DI<1.2***	***DI>1.2***	***0<DI<0.8***	***DI<0***

2.2.5 Obstacle factor diagnosis model

The obstacle factor diagnosis model is an important econometric analysis tool for scientific diagnosis and identification of the impact degree of indicator factors in urbanization and ecological environment system on the system. The calculation formula is as follows [32-33] :

$$O_j = \frac{I_j \times \omega_j}{\sum_{j=1}^{m} I_j \times \omega_j}$$

Where: ω_j is the weight of item j; I_j is the difference between the optimal target value and the actual value of each indicator, which can be expressed as 1- r_{ij}(the difference between the standardized value of each indicator and 1).

3. Results and Analysis

3.1 Time series analysis of comprehensive level of urbanization and ecological environment

3.1.1 Time series analysis of urbanization comprehensive development level

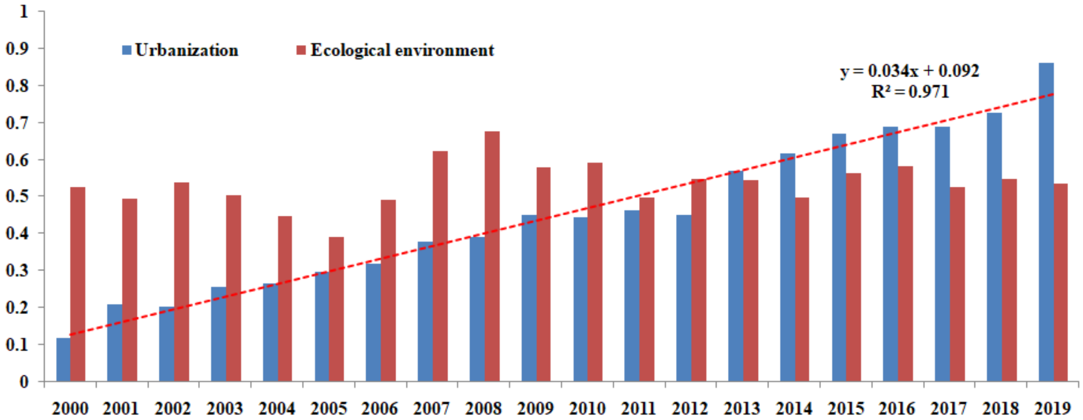

Figure 1. Change trend of comprehensive development index of urbanization and ecological environment system in Hohhot City

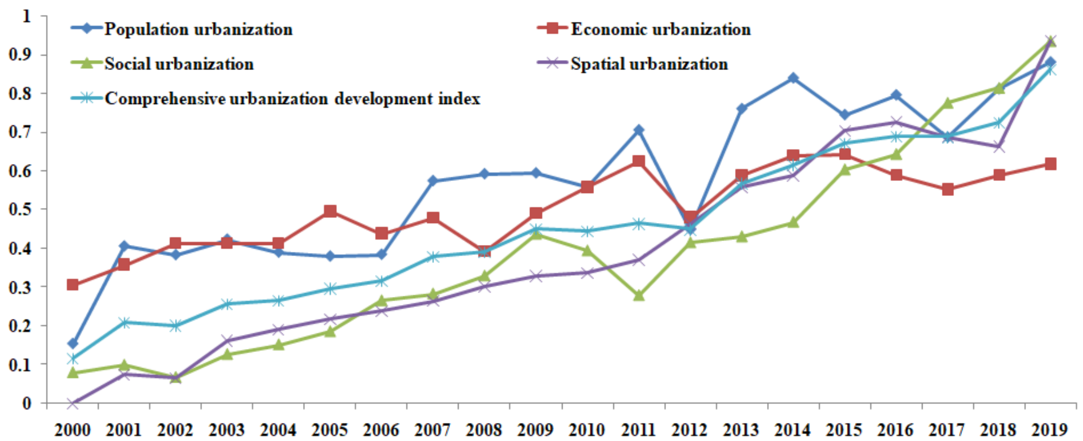

Figure 2. Change trend of Hohhot's urbanization system comprehensive index

The entire integrated urbanization system index for Hohhot shows a moderately fluctuating and rising pattern from 2000 to 2019 as shown in Figs. 1 and 2. The following equation is the result of fitting the urbanization curve linearly: the shape of the curve shifts from 0.1164 in 2000 to 0.8611 in 2019, representing an average annual growth rate of 3.72%. Y = 0.034x + 0.092, and $R^2 = 0.971$. The urbanization index has been significantly affected by urbanization, and Hohhot's rapid urbanization is mostly driven by economic development. Due to significant periodic oscillations in the adjustment of regional economic and industrial structural transformation and upgrading, changes in population urbanization and economic urbanization indicators have a significant impact. Three minor changes were made in 2010, 2012, and 2017, corresponding to. After 2012, the regional economy gradually reverted to its previous pattern of cyclical growth. Together, Hohhot's average annual growth rate of 1.578 percent between 2000 and 2019 indicates that economic urbanization is a crucial component of the construction of a new type of urbanization and will be the backbone of the sector's future prosperity. However, the sustained pace of economic growth is insufficient, necessitating the upgrading of the industrial structure through transitional iterations to improve the overall competitiveness of the sector. The rapid development of new-type urbanization in Hohhot in the subsequent period was greatly aided by social urbanization, which from 2011 demonstrated significant capacity for continued expansion.

3.1.2 Time series analysis of comprehensive development level of ecological environment

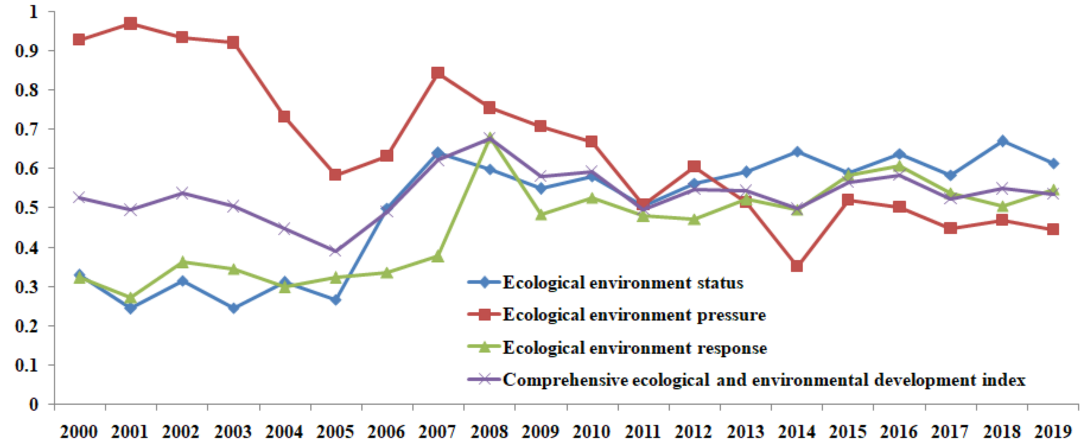

Figure 3. Change trend of comprehensive development index of ecological environment system in Hohhot City

The ecological environment system of Hohhot has seen fluctuations in its overall development index from 2000 to 2019 as shown in Fig. 1 and 3. They showed a distinct upward trend from 2005 to 2008, and from 2009 to 2019, the threshold interval of 0.5 to 0.6 was continuously maintained, displaying the characteristics of a multi-oscillation "W" wave pattern. The ecological pressure index is the most volatile, showing more significant oscillations in its downward trend and accurately reflecting Hohhot's ecological preservation and management. The pressure on the ecological environment will continue to diminish over time, highlighting its advantages, as long as the creation of the ecological environment has been a great success and the total amount of all industrial pollutants has been adequately regulated. The ecological environment status index, the ecological environment response index, and the ecological environment integrated evaluation index can all be seen in Fig. 3, as well as the close mutual constraints and synergistic development and evolution relations among the three. Hohhot has seen significant urbanization since 2012, rising energy and resource use, ongoing industrial restructuring and modernization, and efficient ecological environment integrated development index operation. However, Hohhot still has to improve its capacity for sustainable growth, so its only concern is the long-term and sustainable management of the city's ecological environment. We will increase that capacity.

3.1.3 Time series analysis of comprehensive evaluation index of urbanization and ecological environment

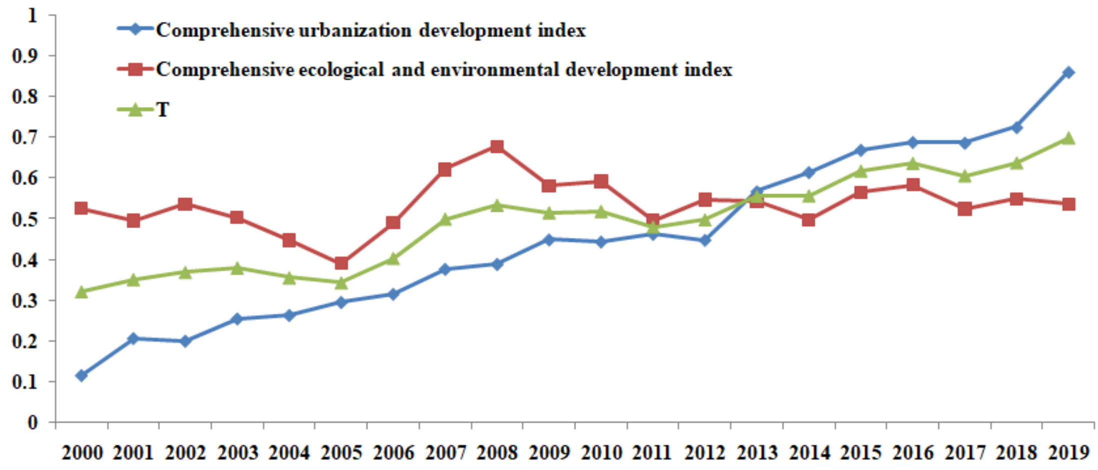

Figure 4. Change trend of comprehensive development index of urbanization and ecological environment system in Hohhot City

Figure 4 demonstrates that from 2000 to 2019, the composite index of Hohhot's new-type urbanization and ecological environment system is consistent with the composite index of urbanization and ecological environment, and the overall trend is consistent with both composite indices. T values are also consistently maintained within the threshold range of 0.3 − 0.7. The significant time nodes for this are 2005 and 2013. Rapid urbanization and development increased pressure on the environment from 2000 to 2005, and the overall development index of the ecological environment showed a downward trend as environmental pollution from broad economic development increasingly came to the fore. Ecological environmental governance and construction began to provide benefits between 2005 and 2013. The integrated development index of the ecological environment has shifted upward, maintaining a consistent pattern of shifting development. The complete index of contemporary urbanization and ecological environmental systems is currently undergoing a period of continuous growth. Following the stabilization of urbanization in 13a, the integrated urbanization index began to outpace the integrated ecological environment index in 2013 and the gap between the two gradually widened after 2017. The ecological environment is a major obstacle to the high-quality growth of new types of urbanization.

3.2 Time series analysis of coupling degree between urbanization and ecological environment

Table 4. Evaluation results of coupling coordination degree between urbanization and ecological environment in Hohhot City

Year	coupling degree	Coupling type	Coupling coordination degree	Coordination type	Year	coupling degree	Coupling type	Coupling coordination degree	Coordination type
2000	0.7704	High level coupling	0.4974	Mild disorder	2010	0.9898	High quality coupling	0.7162	Good coordination
2001	0.9125	High quality coupling	0.5660	Moderate coordination	2011	0.9994	High quality coupling	0.6927	Moderate coordination
2002	0.8905	High level coupling	0.5730	Moderate coordination	2012	0.9951	High quality coupling	0.7037	Good coordination
2003	0.9453	High quality coupling	0.5990	Moderate coordination	2013	0.9997	High quality coupling	0.7450	Good coordination
2004	0.9665	High quality coupling	0.5861	Moderate coordination	2014	0.9944	High quality coupling	0.7438	Good coordination
2005	0.9905	High quality coupling	0.5830	Moderate coordination	2015	0.9964	High quality coupling	0.7841	Good coordination
2006	0.9765	High quality coupling	0.6273	Moderate coordination	2016	0.9965	High quality coupling	0.7961	Good coordination
2007	0.9697	High quality coupling	0.6960	Moderate coordination	2017	0.9909	High quality coupling	0.7746	Good coordination
2008	0.9629	High quality coupling	0.7166	Good coordination	2018	0.9903	High quality coupling	0.7942	Good coordination
2009	0.9919	High quality coupling	0.7146	Good coordination	2019	0.9724	High quality coupling	0.8240	Good coordination

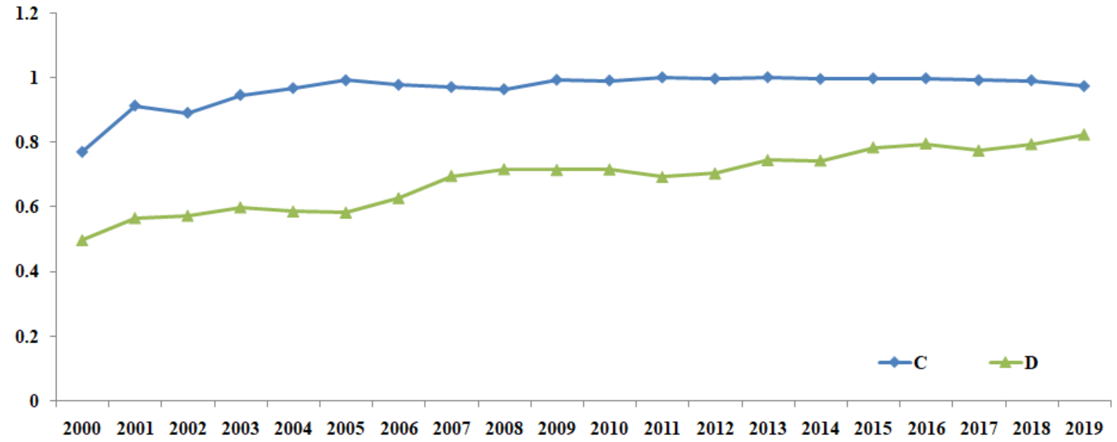

Figure 5. Change trend of coupling degree and coupling coordination degree of urbanization and ecological environment system in Hohhot City

According to the comprehensive analysis in Table 4 and Figure 5, from 2000 to 2019, the coupling degree of urbanization and ecological environment system in Hohhot has been in the development trend of high-quality coupling for a long time after experiencing the interactive evolution process of high-level coupling -- high-quality coupling -- high-level coupling -- high-quality coupling. Comprehensive reflects the Hohhot system of urbanization and ecological environment system since 2002, coordinate with each other for a long time, collaborative development evolution characteristics, excellent natural ecological environment constitute the essential material basis for the development of Hohhot rapid urbanization, urban economy continues to grow, feedback in culture, education, medical treatment, health and other basic facilities construction, Urban residents' living environment and community greening environment have been considerably improved, urban comprehensive social service functions have been continuously enhanced, and ecological environmental protection and governance have achieved results, gradually stepping into the coordinated development and evolution process of urbanization system and ecological environment system. However, despite being in the phase of coupling the quality systems of urbanization and ecological environment, the overall level of development of urbanization and ecological environment is still in the period of adjustment for cooperative optimization. The future still calls for the coordinated development of the composite system towards a sustainable future through continuous urbanization and integrated development of the ecological environment.

Table 4 and Figure 5 show that the coordination system of urbanization and ecological environment coupling in Hohhot increased from 0.4974 in 2000 to 0.8240 in 2019, an increase of 0.3266 and an annual growth rate of 1.63 percent. The growth process is continuous and mainly stable. The system is in the process of dynamically responding to oscillatory variations, as seen by the progressive rise in the trend of the coupling coordination shift. Coupling coordination type experience from junior to senior phase of evolution and development of coupling coordination evolution process, the coupling coordination degree affected and restricted by the ecological environment evolution in the late stage, continued growth momentum is insufficient, the evolution process is relatively slow, the coupling coordination degree after 4 significant time node implementation to a higher stage of the evolution and development: Mild disorder (2000) -- Moderate coordination (2001-2007) -- Good coordination (2008-2010) -- Moderate coordination (2011) -- Good coordination (2012-2019), with moderate coordination and good coordination as the main types. This is a thorough reflection that despite the ongoing optimization and adjustment of the coupling coordination between the urbanization system and the ecological environment system in Hohhot 20a, there is still a significant gap to be closed before high-quality coordination can be achieved. In addition, it was found that 2013 marked a significant turning point in the coupling interactions of complex systems, and that the type of coupling coordination from 2000 to 2012 demonstrated a type of urbanization lag and ecological environment dominated development. The findings come from a comparative analysis of the comprehensive evaluation index of Hohhot's urbanization system and ecological environment system from 2000 to 2019 . From 2013 to 2019, it revealed a lagging ecological environment system and advancing urbanization, with the ecological environment starting to be a major restraint on urbanization development. The ecological environment provides crucial environmental support for urbanization.

3.3 Decoupling path of urbanization and ecological environment

Table 5. Growth rate and decoupling relationship between urbanization and ecological environment comprehensive development index of Hohhot.

Year	△*E*	△*U*	*DI*	Degree of decoupling	Year	△*E*	△*U*	*DI*	Degree of decoupling
2000-2001	-0.0311	0.0911	-0.0756	Strong decoupling	2010-2011	-0.0951	0.0190	-3.7489	Strong decoupling
2001-2002	0.0418	-0.0065	-2.6844	Strong negative decoupling	2011-2012	0.0497	-0.0149	-3.1145	Strong negative decoupling
2002-2003	-0.0331	0.0547	-0.2268	Strong decoupling	2012-2013	-0.0038	0.1190	-0.0263	Strong decoupling
2003-2004	-0.0568	0.0085	-3.3991	Strong decoupling	2013-2014	-0.0451	0.0475	-0.9946	Strong decoupling
2004-2005	-0.0563	0.0318	-1.0462	Strong decoupling	2014-2015	0.0668	0.0546	1.5120	Strong negative decoupling
2005-2006	0.0994	0.0202	3.7312	Strong negative decoupling	2015-2016	0.0185	0.0193	1.1404	Expansive Inter-linking
2006-2007	0.1319	0.0613	1.3893	Strong negative decoupling	2016-2017	-0.0589	-0.0019	36.4093	Recessive decoupling
2007-2008	0.0558	0.0119	2.8408	Strong negative decoupling	2017-2018	0.0245	0.0382	0.8420	Expansive Inter-linking
2008-2009	-0.0972	0.0602	-0.9284	Strong decoupling	2018-2019	-0.0131	0.1358	-0.1277	Strong decoupling
2009-2010	0.0118	-0.0051	-1.7797	Strong negative decoupling	Average	0.0005	0.0392	1.5638	Strong negative decoupling

In order to further reveal the interaction relationship between urbanization and ecological environment in Hohhot, ***ΔE***, ***ΔU*** and ***DI*** from 2000 to 2019 were calculated using the aforementioned decoupling model, and the decoupling relationship between urbanization and ecological environment was determined according to the classification criteria of decoupling state types. As can be seen from Table 5, the average decoupling index of Hohhot over the last 20 years is 1.5638, indicating that the growth rate of urbanization lags far behind the growth rate of the ecological environment, and the average decoupling state is the degree of decoupling. The degree of decoupling between urbanization and ecological environment underwent a complicated transition between 2000 and 2019. It provides strong decoupling, strong negative decoupling, expansive negative decoupling, expansive inter-linking, and reactivity. The five decoupling regimes, such as the decoupling of urban and ecological systems, exhibit long-lasting and repetitive processes of interaction and adjustment. There are three decoupling regimes in the process of strong decoupling, dilated negative decoupling and strong negative decoupling. Although the coupled coordination of urbanization and ecological environment in Hohhot shows a gradual growth trend, its nature is the result of the continuous rise of the urbanization index and the fluctuating decline of the ecological environment index. From 2000 to 2001, 2002 to 2005, 2008 to 2009, 2010 to 2011, 2012 to 2014, and 2018 to 2019, there is a strong decoupling between urbanization and the ecological environment. Urbanization has positive growth characteristics, while ecological environments have negative growth characteristics. This shows that urbanization puts great ecological pressure on the ecological environment. From 2005 to 2008 and 2014 to 2015, urbanization and the ecological environment showed a strong state of decoupling, indicating a relatively coordinated and progressive growth process. In different years, urbanization and the ecological environment have exhibited a process of mutual adaptation and regulatory shift. Together, Hohhot 2000-2019, the urbanization development on the ecological environment in the process of the negative effects of regulation for a long time in the ecological environment carrying capacity threshold range, did not reach the limit bearing capacity of the ecological environment, but the future in the new-type urbanization process for ecological environment caused by the negative effects must be long-term focus and sustained attention.

3.4 Diagnosis of urbanization and ecological environment barrier factors

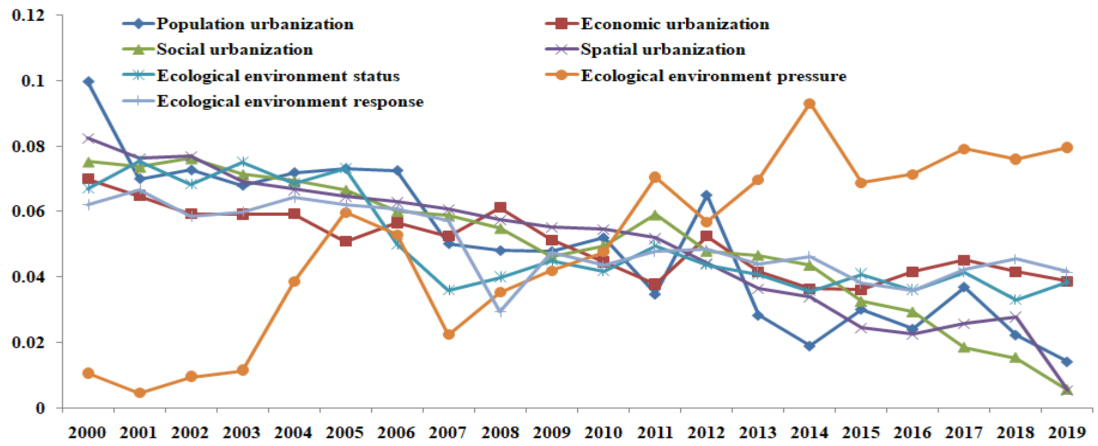

Figure 6. Change trend of urbanization and barrier subsystem of ecological environment system in Hohhot

The urbanization and ecological environment systems of Hohhot from 2000 to 2019 were used as study subjects. Using the obstacle degree diagnosis method, the urbanization and ecological environment subsystem of Hohhot and certain index components were quantitatively measured and analyzed (Figure 6). The obstacle degree of each subsystem to the coordinated development of urbanization and ecological environment of Hohhot city typically exhibits a trend of fluctuation and decrease, and this indicates that the main obstacle factors of the subsystem have characteristics of different stages in different urbanization processes. This is shown by the plot of the trends of the barrier factors for the urbanization system and the ecological environment system. Overall evolution is embodied in the continued ascent of coordinated development between subsystems, but at the same time, the ecological environment pressure subsystem is characterized by abnormal fluctuations rise, comprehensively reflects the rapid development of urbanization and ecological environment suffers from the co-existence of stress is an essential contradiction, forever keep in the process of new type of urbanization construction ecological environment construction, management and protection in the first place.

From the analysis of barriers to urbanization and specific indicators of the ecological environment, it can be seen that the main barriers that limited urbanization in Hohhot from 2000 to 2019 were: industry, foreign trade, population and cultural quality of residents; in the medium term: GDP per capita, urban construction land and health services; later stages: natural population growth rate, GDP growth rate, proportion of secondary industries. Major impediments limiting the ecological environment of Hohhot City, early years: Urban living environment, ecological environment governance; in the medium term: annual precipitation, industrial pollution discharge, sewage treatment rates; later stage: annual average urban temperature, annual water supply, industrial soot (powder), and total exhaust emission. in general, the major obstacles in the development stages of different cities are essentially in line with the actual evolution and development process of urbanization in Hohhot. Therefore, the current development of new types of urbanization in the future period, improving Hohhot city first degrees, enhancing the capacity of urban service functions and agglomeration, vigorously developing modern service economy, speed up the ecological environment management and protection, ecological priority, green development is the inevitable path of realization of Hohhot high quality development.

4. Conclusion and Suggestions

4.1Conclusion

A thorough evaluation index system based on PRS and PES models has been scientifically created for Hohhot using panel data from 2000 to 2019 as a study subject. The integrated development phase, coupled coordination evolution process and decoupling path of the Hohhot system from 2000 to 2019 are thoroughly and comprehensively analyzed using coupled coordination model, decoupling model and obstacle factor diagnostic model. An in-depth analysis and discussion of the major roadblocks to the development of the two in concert. The following are the primary conclusions:

(1) The level of urbanization in Hohhot has maintained a strong linear growth trend from 2000 to 2019, and the levels of urbanization and ecological environment have exhibited a staggered increase trend from the point of view of the integrated development level of the system. The two sub-systems show uneven and insufficient development conditions after 2013, indicating a lagging phase of ecological environment development. Urbanization is currently being hampered in significant ways by the ecological environment. A later phase of urbanization and development has now begun in Hohhot. Accelerating the creation of natural ecological habitats, enhancing and continuously improving the ecological environment, and strengthening the long-term

treatment of ecological contaminants are among the urgent needs. We will continue to promote high-quality development in newly urbanized areas;

(2) Urbanization and ecological environment experience high levels of coupling - high quality coupling - coupling of high-quality coupling interactive evolution process, keep for a long time in high quality coupling stages after 2003, reflecting the relationship between urbanization and ecological environment is constantly in a collaborative interactive development phase, but still have further can improve the space; the coupling coordination degree showed a slowly fluctuating trend of increasing year by year, and the coupling coordination types experienced a coupling coordination evolution process such as mild imbalance (2000) - moderate coordination (2001) - good coordination (2002-2010) - moderate coordination (2011) - good coordination (2012-2019). Although the coupling coordination reaches a maximum of 0.8240 in 2019, there is still a gap from the massive coordination phase.

(3) From the perspective of the correlation and change trend between urbanization and ecological environment, urbanization and ecological environment in Hohhot City show a Strong decoupling-Strong negative decoupling-Strong decoupling-Expansive negative decoupling-Strong decoupling- Strong negative decoupling-Strong decoupling- Strong negative decoupling-Strong decoupling-Expansive negative decoupling-Expansive Inter-linking-Recessive decoupling-Expansive Inter-linking-Strong decoupling complex interactive evolution trajectory. It mainly presents the wave evolution of strong decoupling, strong negative decoupling, and expanding negative decoupling interactions, indicating that the ecological environment has a strong negative effect on urbanization. In the future, more attention should be paid to the construction of sustainable new ecological urbanization.

(4) According to the thorough analysis of barrier factors, the pressure on the ecological environment showed an upward trend, reflecting urbanization's detrimental effects on the environment, while the score of subsystem and indicator barrier factors showed an evolutionary trend of decreasing fluctuation year after year. The main obstacles to the coordinated growth of the complex system in recent years have been environmental indicators such as the use of natural resources, secondary industries, population development, GDP growth rate and industrial pollutant discharge. The only way to achieve coordinated development of new-type urbanization and ecological environment is to effectively improve the quality of urbanization and ecological and environmental benefits.

4.2 Countermeasures and Suggestions

For Hohhot, the new development phase is a crucial time for transformation and growth in order to support the growth of high-quality new-type urbanization. The following policy recommendations are put out in light of the current reality in Hohhot:

First, we should establish the concept of prioritizing ecological and green development, and accelerate the development model of a green, energy-efficient and circular economy. Through analysis on the previous research results, the Hohhot ecological environment comprehensive evaluation index in the process of development of shock wave for a long time, after 2013, due to long-term being affected by the traditional economic development model elements drive, increasing energy resources consumption and the ecological environment pollution control, ecological environment pressure continues to increase. The complex system has gradually changed into an urbanized development model with a lagging ecological environment. In the future, the treatment of pollutants in the ecological environment needs to be sustained over a prolonged period of time, and the green transformation and development of the city's economy is a daunting task. To strengthen ecological and environmental construction, environmental governance and environmental protection, accelerate the transformation of the urban economy into an intensive, green and circular development model driven by efficiency improvement in the direction of modern scientific and technological innovation and energy revolution, and continue to enhance regional ecological and environmental carrying capacity based on scientific and technological progress. To ensure that the intensity of new-type urbanization construction can always be maintained within the threshold range of ecological, resource and environmental system carrying capacity, effectively improve the connotation and quality of new-type urbanization construction, enhance the endogenous driving force and resilient development of urbanization, and scientifically build a coordinated and sustainable man-land relationship.

Second, we will formulate special plans for municipal ecological and environmental protection in a scientific manner to safeguard the bottom line of ecological and environmental safety. In the Inner Mongolia autonomous region ecological protection and high quality development plan "the Yellow River basin and the Inner Mongolia national spatial planning (2021-2035), as the important development opportunity, with the aid of spatial planning lead resource utilization and the ecological environment governance, scientific planning and strictly controlled within the scope of the urban green space, establishing the compensation mechanism of environmental pollution, Perfect the natural ecological environment regulations and policies, strictly according to the state environmental protection standards for ecological environment monitoring and supervision, strengthen the negative list key high polluting enterprises management, policy guide and promote the technology innovation of industrial enterprises, strengthen ecological environmental protection science and technology support and financial support, guide and encourage enterprises to improve resource utilization efficiency of energy, To energy conservation and environmental protection, green, clean industry development, improve the processing capacity of urban sewage treatment plants, strict control of industrial pollution and industrial waste emissions, guide the industrial and agricultural production efficiency of water resources sustainable utilization, improve regional ecological environmental governance, fully pays attention to natural ecological environment restoration, strong motherland northern border ecological security barrier.

Third, we need to use scientific and technological innovation to guide the construction of a new type of urbanization and comprehensively improve the weak points in urbanization development. We should focus on cultivating the capacity of cities for scientific and technological innovation and sustainable industrial development, and make the development of scientific and technological innovation an essential strategic support to stimulate the driving force of urban innovation and achieve a new path of high-quality sustainable development. Comprehensive optimization of Hohhot regional productivity layout, focus on the production quality of the mass transfer efficiency, speed up the iterative transformation and upgrading of industrial structure of regional economy, energy conservation and emissions reduction for the polluting energy of the city and the environment comprehensive treatment, and enhance the regional collaborative innovation development ability and core competitiveness, take the path of sustainable development of high quality, Through effective policies to guide implementation within the urban area of complementary advantages, stage, differentiation of regional coordinated development strategy, focus on improving urban modern service function, the center of the capital, the depth of the optimization of Hohhot urban and rural human resource quality and structure, accelerate regional ecology civilization construction and the quality of basic public services, gradually narrow the income gap between urban and rural areas, We will continue to promote the coordinated and sustainable development of new-type urbanization and the ecological environment, and take the path of high-quality development of new-type urbanization.

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