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Short Communication

Analysis of Sustainable Development Level for Resource-Exhausted Cities in China from Perspective of Resilience

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Abstract

How to improve the sustainability of resource-exhausted cities has become a difficult problem for China to implement the sustainable development strategy, and the construction of resilient cities has become the best way to solve this problem. This paper constructed an evaluation indicator system of the sustainable development for resource-exhausted cities from the perspective of resilient cities. The entropy weight-TOPSIS-grey relational degree model was used to quantitatively analyze the sustainable development capacity of 23 resource-exhausted cities in China from 2010 to 2020. And the coupling coordination degree model was further used to analyze the relationship between urban resilience and the dimensions of economy, environment, society and resource respectively. The weak links affecting their sustainable development was explored through obstacle degree model. The research results are helpful to fully understand the current situation and obstacle factors of the sustainable development of resource-exhausted cities in China, and promote the sustainable development of cities through the construction of resilient cities.

Keywords: resource-exhausted city, resilience, sustainable development, entropy weight-TOPSIS-grey relational degree, coupling coordination, obstacle model

Introduction

Resource-exhausted city refers to the city whose mineral resources are in the final stage of exploitation, specifically, it refers to the city whose mineral resources can be exploited less than 30% of the total amount measured at the beginning or the remaining resources can only be exploited for 5 years [1-2]. The Sustainable Development Plan for Resource-based Cities in China (2013-2020) (SDPRCC (2013-2020)) points out that there are 67 resource-exhausted cities in China, including 24 prefecture level cities. With economic globalization, the sustainable development of cities is not only of great significance to the sustainable survival and development of mankind itself, but also a necessary condition for the realization of urbanization and urban modernization [3]. However, due to a series of structural contradictions and deep-seated problems such as the single industrial structure and extensive development mode, which not only makes resource-exhausted cities less resilient, but also leads to unprecedented problems in the sustainable development of these cities [4]. As one of the themes

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of sustainability research, the enhancement of resilience can improve sustainability [5-6]. However, few studies have highlighted the impact of urban resilience on the sustainable development of urban economy, society, environment and other dimensions [7].

The city is a typical social-economic-natural complex ecosystem and the concept of sustainable urban development requires that economic development should be within a tolerable range to ensure the protection of natural resources and environment, and that resource allocation and social development should conform to the premise of social equality [8]. Previous studies have considered that resilience is the prerequisite for sustainability, and that comprehensively improving urban resilience is the key to achieving urban sustainable development goals [9-10]. Urban resilience refers to the ability of a city (including economic, social and environmental systems) to resist external interference and restore its initial state in the face of natural or man-made disasters, as well as the ability to adapt to various changes [11]. Urban systems that lack resilience are considered to be fragile sustainability or unsustainable [12]. Therefore, promoting the sustainability of resource-exhausted cities through urban resilience is of great significance to the construction of modern cities and the implementation of sustainable development strategies in China.

The fundamental reason for the decline of resource-based cities in China is not the exhaustion of resources, but the cumulative impact of the planned economic system and the lack of historical compensation mechanism for resource development [13]. Some scholars have analyzed the sustainable development capacity of resource-exhausted cities. Li [14] constructed an evaluation index system of sustainable development covering economy, society, resource and environment for resource-exhausted cities, and put forward the quantitative evaluation using factor analysis method. Later scholars used principal component analysis to measure and analyze the sustainable development capacity of Baiyin city from 1990 to 2005, 17 resource-exhausted cities in China from 2004 to 2009, Huangshi city and Qianjiang city from 2008 to 2015 [2, 15-16]. But the evaluation methods of these studies are relatively simple, and some studies take a single resource-exhausted city or resource-exhausted cities in a single province as example, which makes the evaluation results lack of contrast.

To sum up, the existing literature have analyzed the evaluation indicator system and sustainable development capacity of resource-exhausted cities, but there are also deficiencies. First, the impact of resilience on urban sustainable development is ignored in the evaluation indicators. Second, the evaluation and analysis method is single, and there is no in-depth analysis of the obstacle factors to the sustainable development capacity of resource-exhausted cities. Based on this, taking 23 prefecture level resource-exhausted cities (excluding the Da Hinggan Ling Prefecture) in China as examples, this paper constructed an evaluation indicator system of sustainable development capacity covering 35 specific indicators in five dimensions of economy, society, environment, resource and resilience, and then used the entropy weight-TOPSIS-grey relational method to calculate their sustainable development capacity from 2010 to 2020. The coupling coordination degree model was further used to quantitatively analyze the relationship between urban resilience and the other four dimensions. Finally, the weak links of sustainable development were explored through the obstacle degree model. This study can provide a reference for understanding the current situation of sustainable development of resource-exhausted cities in China, identifying the obstacle factors that restrict their sustainable development, and building resilient cities to promote the sustainable development of these cities.

Methods

Research Methods

Entropy weight method is to calculate the entropy weight of the indicator by using information entropy according to the dispersion of the data of each evaluation indicator, so as to obtain a more objective indicator weight [17-18]. TOPSIS is a multi-objective decision analysis method that sorts the advantages and disadvantages of the evaluation object according to the closeness of the Euclidean distance between evaluation object and idealized goals [19]. Grey relational analysis is based on the geometric similarity of the curves of each evaluation sequence and the reference sequence to judge the tightness of the relationship between each data sequence [20]. The combination of TOPSIS method and grey relational degree not only considers the closeness of the Euclidean distance between evaluation object and idealized goals, but also considers the relational degree between evaluation object and idealized goals. Hence, this paper first determines the weight of each evaluation indicator by entropy weight method, and then comprehensively measures the advantages and disadvantages of sustainable development of resource-exhausted cities based on TOPSIS-grey relational degree model. Finally, the coupling coordination model is used to measure the relationship between urban resilience and the other dimensions, and the obstacle degree model is used to diagnose the obstacle factors of sustainable development for these cities.

Construction of Index System

Urban sustainability has “three pillars” or “three dimensions”- economy, society and environment [21]. Resilience can be understood as the fourth dimension of sustainability because it has the potential to reconcile the paradox of sustainable urban morphology [22]. In 1994, China’s Agenda 21 proposed the goal of promoting sustainable and coordinated development of economy and society, combining rational utilization of resources with environmental protection [23]. SDPRCC (2013-2020) also puts forward requirements about the utilization and guarantee of urban resources to maintain China's resource security and build a resource

Table 1. Evaluation indicator system and corresponding weights of sustainable development for resource-exhausted cities.

Primary indicator	Secondary indicator	Tertiary indicator	Weight	Indicator attribute
Economy	Economic development	Per capita GDP	0.03885	Positive
		GDP growth rate	0.00517	Positive
		Foreign trade coefficient	0.08635	Positive
		Average wages of employees	0.02110	Positive
	Industrial structure	Proportion of secondary industry in GDP	0.02745	Negative
		Proportion of tertiary industry in GDP	0.02285	Positive
		Proportion of mining personnel in the total population	0.00814	Negative
Society	Living standard	Urban per capita consumption expenditure	0.02595	Positive
		Consumer price index	0.00859	Negative
		Urbanization rate	0.01953	Positive
	Social security	Hospital beds per 10,000 people	0.01909	Positive
		Number of doctors per 10,000 people	0.01886	Positive
		Urban registered unemployment rate	0.00709	Negative
Environment	Environmental protection	Urban area green coverage rate	0.00658	Positive
		Comprehensive utilization rate of general industrial solid waste	0.01086	Positive
		Sewage treatment rate	0.00513	Positive
		Harmless treatment rate of domestic waste	0.00445	Positive
	Environmental pollution	Industrial wastewater discharge per 10,000 yuan GDP	0.00432	Negative
		Industrial fumes emission per 10,000 yuan GDP	0.00575	Negative
		Industrial SO_2 emission per 10,000 yuan GDP	0.00758	Negative
Resource	Per capita resources	Per capita green area	0.03808	Positive
		Per capita available water resources	0.03839	Positive
		Per capita household electricity consumption	0.03049	Positive
	Resource utilization	Energy consumption per 10,000 yuan GDP	0.00452	Negative
		Total gas supply (artificial, natural gas)	0.08002	Positive
		Flexibility coefficient of energy consumption	0.00379	Negative
Resilience	Recovery	Urban engel coefficient	0.00875	Negative
		Per capita resident RMB savings deposit balance	0.03193	Positive
		Ratio of total retail sales of consumer goods to regional GDP	0.03061	Positive
	Resistance	Industrial upgrading index	0.05669	Positive
		Foreign capital dependence	0.08156	Positive
		Financial self-sufficiency rate	0.02863	Positive
	Evolution	Proportion of science and technology practitioners in the total population	0.07616	Positive
		Number of authorized patents per 10,000 people	0.06692	Positive
		Proportion of science and technology expenditure in Finance	0.06972	Positive

conserving and environment-friendly society. Resources sustainability is crucial for China, the world's second largest economy and the largest energy consumer. Therefore, this paper constructed an evaluation index system for sustainable development of resource-exhausted cities, which covers 11 secondary indicators and 35 specific indicators in five dimensions of economy, society, environment, resource and resilience, as shown in Table 1.

Results

Evaluation of Sustainable Development Capacity

Urban Sustainable Development Analysis

The comprehensive level of sustainable development and its average value of each resource-exhausted city from 2010 to 2020 are shown in Fig. 1. It can be found that Tongling has the highest level of sustainable development, with an average comprehensive score of 0.53168. The sustainable development level of Baiyin is the lowest, with an average of 0.37422. According to the average value of the comprehensive level, these cities are further divided into four types: strong sustainable development, relatively strong sustainable development, basic sustainable development and weak sustainable development [24]. Only Tongling is in a strong sustainable development, and Fushun and Xinyu are cities with relatively strong sustainable development. Meanwhile, the number of cities in basic sustainable development is equal to that in weak sustainable development, both of which are 10. And resource-exhausted cities in weak sustainable development are cities in the west or northeast. In general, the sustainable development situation of most resource-exhausted cities is still severe, and there is still much room to improve the sustainable development level of these cities.

Regional Sustainable Development Analysis

Resource-exhausted cities are divided into four regions: the east (Huaibei, Tongling, Jingdezhen, Pingxiang, Xinyu, Zaozhuang, Shaoguan), the middle (Jiaozuo, Puyang, Huangshi), the west (Wuhai, Luzhou, Baiyin, Tongchuan, Shizuishan) and the northeast (Fushun, Liaoyuan, Baishan, Fuxin, Hegang, Shuangyashan, Yichun, Qitaihe).

The sustainable development level of each region shows an increasing trend, of which the middle region has the highest annual average growth rate of 0.71561%, followed by the east and west, and finally the northeast. In terms of the average comprehensive score, the sustainable development level of resource-exhausted cities in the east region is the highest, with a value of 0.44481, followed by the middle region (0.42186), the west region (0.40052) and the northeast region (0.39605). The sustainable development level of the east and middle regions is higher than the overall average, while the sustainable development level of the west and northeast regions is lower than the overall average, and the gap between these two regions and the eastern and middle regions is widening. The reason is that the west region developed late due to its geographical location. Although it has the policy support of the Development

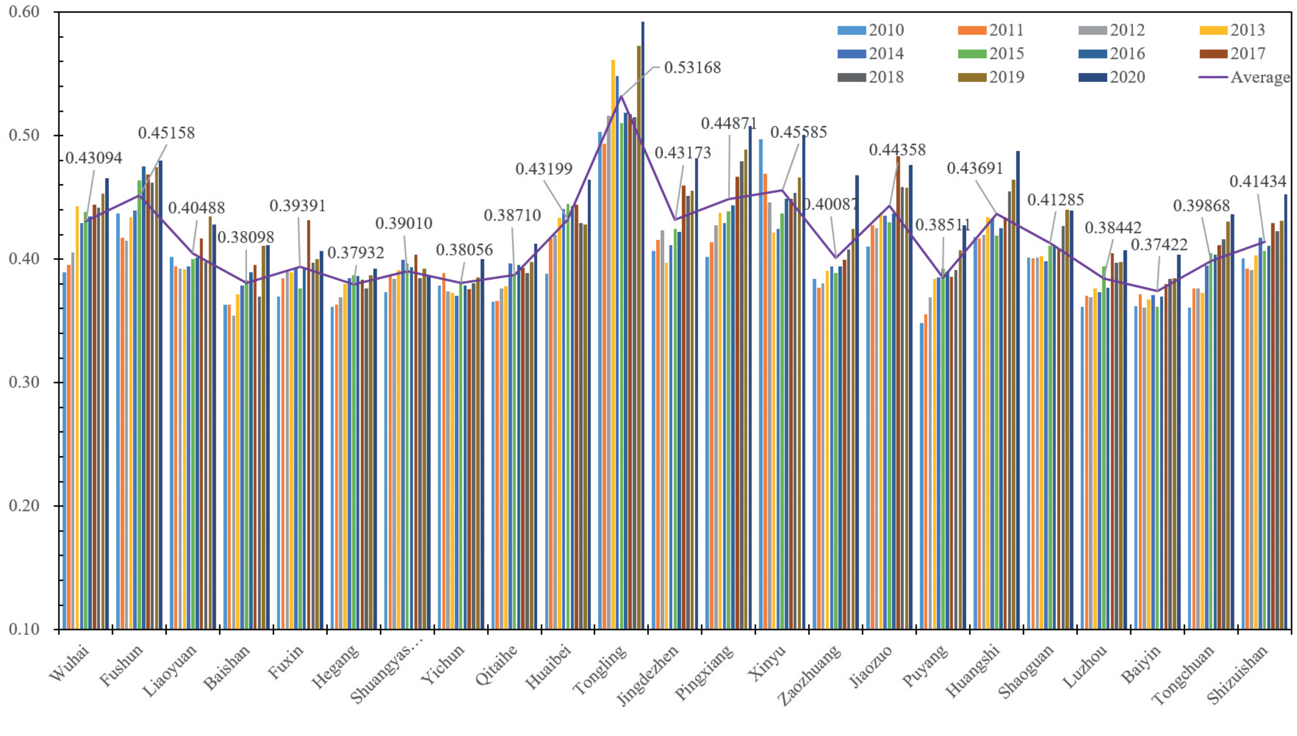

Fig. 1. Sustainable development capacity of resource-exhausted cities from 2010 to 2020.

of the Western Region in China, it still needs time to develop to reach the average level. The overall sustainable development level of resource-exhausted cities in northeast is lowest, which is related to the fact that the northeast region, as China's heavy industry base, is dominated by coal resource-based cities, and the difficulty of industrial structure upgrading and transformation.

Dimensional Sustainable Development Analysis

The dynamic variation of the five dimensions of sustainable development in resource-exhausted cities from 2010 to 2020 are compared, and the trend is shown in Fig. 2. From the economic perspective, the sustainable development of economy in resource-exhausted cities has been in a state of growth during these 11 years, with an average annual growth rate of 0.11721%, but its sustainability lags behind that of the other four dimensions. While the average annual growth rate of social sustainability in resource-exhausted cities is 1.60961%, with the largest growth rate. Its average level ranks second in the five dimensions, and its sustainable development level exceeds that of the environment after 2018, becoming the first. During the research period, the environmental sustainability in resource-exhausted cities has shown an up-down-up trend, the overall fluctuation range is relatively gentle. And before 2018, the environmental sustainability is higher than other dimensions. The sustainable development level of resource and resilience is in a slow growth trend, with an average annual growth rate of 0.69195% and 0.80162% respectively. Their level of sustainable development ranks fourth and third in the five dimensions. It can be seen that only the economic sustainability lags behind comprehensive sustainable development level in resource-exhausted city; the trend of resource sustainability is basically consistent with the trend of comprehensive sustainable development level; the sustainable development trend of society and resilience is good; the trend of environmental sustainability is relatively stable; the comprehensive sustainable development level is in the growth trend.

Coupling Coordination Analysis

Analysis of Coupling Coordination Mechanism

The urban system is considered to be mainly composed of four subsystems: economy, society, environment and resources [14-16]. The sustainability in these four subsystems affects the level of urban sustainable development. Meanwhile, urban resilience is a prerequisite for urban sustainable development. Therefore, the coupling and coordinated development of urban resilience and the other four dimensions is crucial to urban sustainability. This is mainly reflected in the fact that fragile urban systems are more vulnerable to external shocks and difficult to recover in the face of natural disasters (drought, typhoon, earthquake, etc.) and man-made disasters (resource depletion, environmental pollution, economic crisis, etc.), while urban resilience makes economic, social, environmental and resource subsystems more resistant to risks, easier to recover after disasters, and more adaptable to changes to maintain the sustainable development of the city. On the other hand, as urban resilience mainly involves economy, society, ecology and infrastructure [25], the development level of urban subsystem also has a two-way impact on urban resilience. The development of urban economy can provide stable financial support for the prevention, control and governance of urban disasters, as well as reserve funds after disasters. The perfection of urban social security system

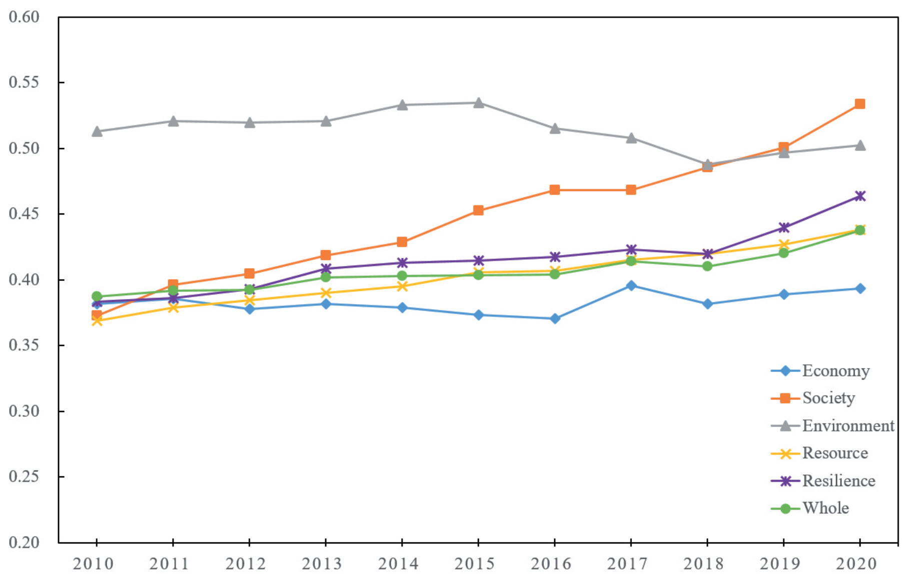

Fig. 2. Trends of the five dimensions of sustainable development in resource-exhausted cities from 2010 to 2020.

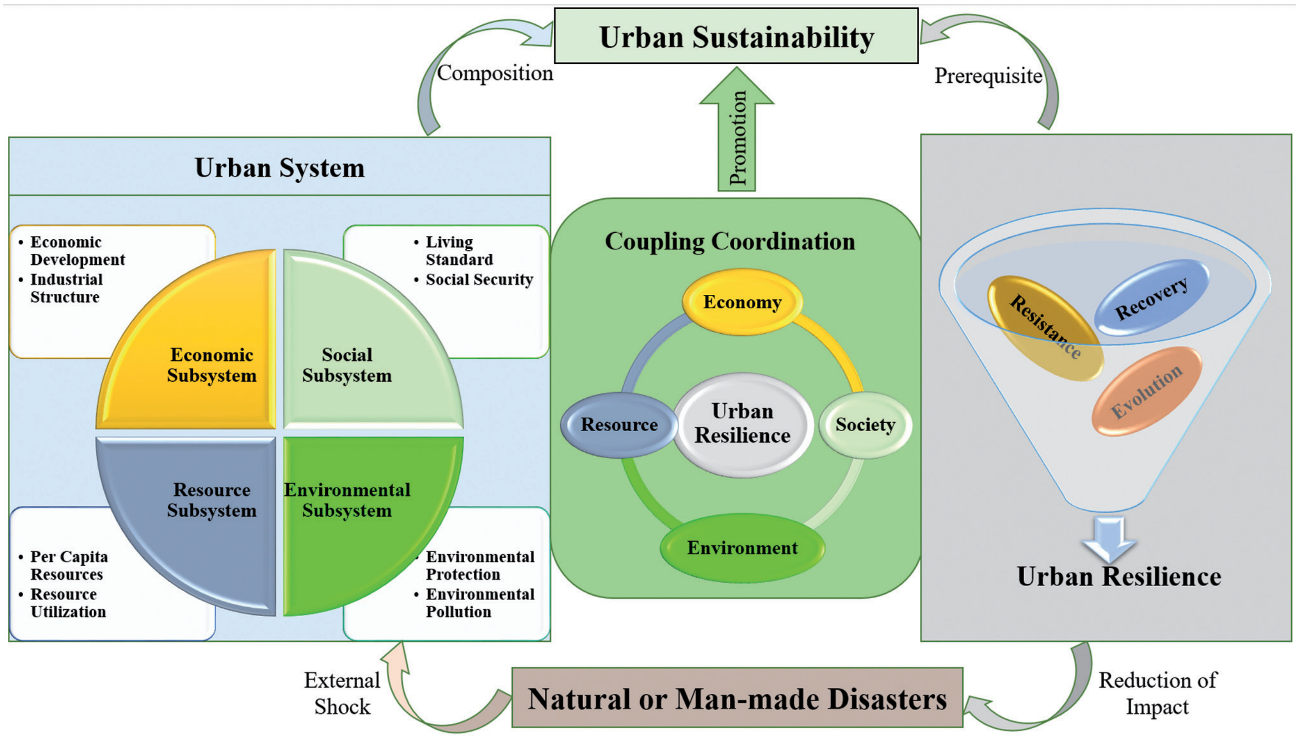

Fig. 3. Coupling coordination mechanism of urban resilience and the other four dimensions.

can provide help for urban disaster relief. Urban environmental protection and pollution control can reduce the impact of disasters on the ecological environment. A well-established urban resource supply guarantee system is conducive to the construction and maintenance of urban infrastructure. Therefore, the coupling and coordinated development of urban resilience and the other four dimensions can promote urban sustainability. Fig. 3 reflects the visual coupling coordination mechanism of urban resilience and other dimensions.

Analysis on Coupling and Coordination of Each City

This paper classifies the coupling coordination level between urban resilience and the other four dimensions with reference to the division standard of coupling coordination degree by Zhu et al. [26]. From the perspective of the coupling coordination level between economy and resilience, Yichun, Hegang and Baiyin are in the stage of reluctant coupling coordination, indicating that the correlation and interdependence between economy and resilience of these three cities are weak. And Hegang city has the lowest coupling coordination degree, with a value of 0.59505. Only Tongling city is in the middle coupling coordination stage, and its coupling coordination degree value is 0.75297, indicating that Tongling city has a strong interaction effect between economy and resilience, and the two can promote and coordinate the development of each other. The coupling coordination level of economy and resilience in other cities is in the primary coupling coordination stage. In terms of the coupling coordination level between society and resilience, only Baiyin city is in the stage of reluctant coupling coordination, and 86.96% of the cities are in the stage of primary coupling coordination. Tongling and Wuhai are in the middle coupling coordination stage. For the coupling coordination level of environment and resilience, the coupling coordination level of all cities is greater than 0.6, of which 82.61% are in the primary coupling coordination stage, and Tongling, Huaibei, Pingxiang and Xinyu are in the middle coupling coordination stage. In terms of the coupling coordination level of resource and resilience, Baishan and Baiyin are in the stage of reluctant coupling coordination, 86.96% of the cities are in the primary coupling coordination stage, and Tongling city is in the middle coupling coordination stage. It can be found that among the 23 cities, Tongling is the only city with the middle coupling coordination levels between resilience and the four dimensions. On the whole, the levels of coupling coordination between the resilience and the dimensions of economy, society, resources and environment in resource-exhausted cities are all in the primary coupling coordination stage.

Obstacle Factor Analysis

Due to the excessive number of tertiary indicators, this paper selects tertiary indicators with an obstacle degree of more than 5% to analyze the weak links of the sustainable development in resource-exhausted cities. There are 7 indicators that meet the requirements, namely, the foreign trade coefficient (10.38776%), the dependence on foreign capital (9.36212%), the total gas supply (artificial, natural gas) (9.13644%), the proportion of scientific expenditure in finance (8.39663%), the number of patents authorized by 10,000 people (8.05596%), the proportion of science and technology practitioners in the total population (7.94985%), and the industrial upgrading index (6.03481%). This shows that for resource-exhausted cities, the sustainable development level of these seven indicators is relatively poor compared with other tertiary indicators, and most of the obstacle factors with larger obstacle degrees are indicators of urban resilience.

Conclusions

This paper measured and analyzed the sustainable development level of 23 resource-exhausted cities in China. The main results show that:

(1) The sustainable development capacity of resource-exhausted cities gradually decreases from east to west, with the lowest in the northeast.

(2) From the five dimensions, the environmental sustainability of resource-exhausted cities is the highest, the economic sustainability is the lowest, and the comprehensive sustainability shows a growth trend.

(3) The levels of coupling coordination between the resilience and the other dimensions of most resource-exhausted cities are all in the primary coupling coordination level, and a few cities are in the reluctant level or the middle level.

(4) The indicators of urban resilience are the main obstacle factors to the sustainable development of resource-exhausted cities.

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Conflict of Interest

The authors declare no conflict of interest.

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