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Identification and classification of resource-based cities in China

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Abstract: Resource-dependent cities are cities whose economic development depends on the exploitation and processing of natural resources. Their transformation and sustainable development are an important area of research on regional industrial development, regional economy and urban development. Since the Chinese government launched a pilot project to transform resource-dependent cities, starting with Fuxin in Liaoning Province in 2001, accurately identifying and classifying China's resource-dependent cities has become a focus of geographical research. Based on previous studies, this paper uses the theory and methods of urban function classification to analyze indicators and threshold values for identifying and classifying resource-dependent cities. It has thus identified 262 cities as being resource-dependent. Looking at the development levels, problems, characteristics and developmental direction of such cities, this paper attempts to establish a comprehensive analytical framework using the two evaluation indicators of resource security and sustainable development. It also creates a model to classify the 262 cities identified as resource-dependent cities into four types: growing cities, mature cities, declining cities and regenerating cities. The different connotations and characteristics of the city types were then analyzed. The results of this research support the delineation of scopes and categories of resource-dependent cities set out in the National Sustainable Development Plan for Resource-Dependent Cities published by the State Council, and they serve as a foundation for formulating policies on planning, classification and guidance.

Keywords: resource-dependent cities; identification; classification

1 Introduction

Resource-dependent cities are cities in which mining, forestry or other industries based on natural resources are the dominant industries. There are many resource-dependent cities across the country that have made enormous historical contributions and are of great importance within China. Since the founding of the People's Republic of China in 1949, re-

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source-dependent cities have cumulatively produced 52.9 billion tons of raw coal, 5.5 billion tons of crude oil, 5.8 billion tons of iron ore, and 2 billion m^3 of lumber. Of the 156 national key construction projects in the First Five-Year Plan for National Economic and Social Development of the People's Republic of China (1953–1957), 53 were located in resource-dependent cities and accounted for nearly half of all investment. They therefore played a unique role in helping to set up an independent and complete industrial system in China and boosting national economic development.

Nowadays, however, there is greater international political and economic uncertainty and instability, and issues such as unbalanced, uncoordinated and unsustainable national economic development have come to the fore. These, added to various internal and external factors, have created a patchwork of old and new issues that mean there are severe challenges to the sustainable development of resource-dependent cities. Correctly identifying and analyzing the various features of resource-dependent cities has thus become a prerequisite for deepening research on them and making relevant policies more targeted.

Accurately identifying resource-dependent cities is the first step in analyzing their features and problems. Although the term resource-dependent city is widely used, there are no unified criteria for identifying such cities among governments and scholars in China, resulting in a variety of methods of identification. Methods of identification of scholars range from qualitative to quantitative and can involve single or multiple indicators. Early researchers tended to identify mining cities by the proportion of workers employed by mining industries (Harris, 1943), with indicative threshold values such as 15% (Ma, 1986; Shen and Cheng, 1999) or 10%. Nelson's statistical analysis method differentiated urban functions based on the arithmetic mean (M) and standard deviation (S) of employment in cities (Nelson, 1955). On the basis of these studies, Zhou Yixing *et al*. used a combination of multiple factor analysis and statistical analysis to differentiate the functions of Chinese cities (Zhou and Roy, 1988; Zhou and Sun, 1997). Wu and Ye (2000) considered the connectivity of industries and set the identification standard for resource-dependent cities as those with over 40% of their labor force employed in resource extraction and preliminary processing of resources. Other scholars tend to identify resource-dependent cities by the proportion of their economic output accounted for by industrial output. Fan Jie (1993), Zhou Changqing (1994) and Zhang Yicheng (1999), for example, all identify resource-dependent cities as those with 10% or more of total economic output accounted for by mining industries, though Zhao Yukong (1995) feels that the standard should be set at 20%. On the basis of efforts to identify resource-dependent cities using a single indicator, a number of studies have looked at using multiple indicators. Li Wenyan (1978), for instance, selected the following four indicators: coal mine workers accounting for over 25% of total urban workers, coal accounting for not less than 15% of urban industrial output, coal production in excess of 2 million tons per year, and coal mining being the main reason for the city's development. Other scholars have defined resource-dependent cities by combining the number and proportion of workers employed in extractive industries with the scale and proportion of industrial output of extractive industries (Wang, 2003; Yu and Liu, 2009). Following these studies, Hu Kui (2001) and the Chinese Mining Association's Working Committee of Mining Cities added qualitative indicators to include old mining cities where traditional mining functions still play an important role as well as new mining cities. Zhang and Wang (2003) proposed the concept of “dependence on mining” and defined resource-dependent cities using the weighted results of proportions of mining population and mining output value.

There are many resource-dependent cities in China at different stages of resource development. Their levels of economic and social development vary considerably, and they face myriad and often dissimilar problems. To properly understand the situations of resource-dependent cities, it is necessary to classify and differentiate target cities. Previous attempts at classifying resource-dependent cities have tended to involve the basic method of identifying the main type of resource affecting a city’s economic and social development (MRGNPC, 2002; Xiao and Li, 2009). Liu Yungang (2006; 2009), for example, came up with five urban function classifications for resource-dependent cities based on types of resources: coal, petroleum, metal, non-metal and forestry, which were used to discuss the various tendencies of different cities in their evolution. Based on the S-shaped curve of development in resource-dependent cities, such cities were classified as being in their infancy, middle age or old age.

In general, though, a history of large-scale industrial mining and mining intensity are used as the standards for calculating which stage a city is in. Han and Wan (2014) proceeded from the lifecycle of resource-dependent cities and used reserve and production ratios, changes in the scale of extractive industries or resource-related industries, changes in employment levels and other indicators to divide cities into early-stage, mature and depleted resource-dependent cities. Other scholars have classified cities based on their dependence on resource extraction activities into lightly, mildly and heavily dependent cities (Zhao and Zhao, 2011). These traditional classification methods of differentiating by dominant resource type or urban development cycle highlight certain features of resource- dependent cities. However, these classifications still lack sufficient accuracy for policymaking.

In 2013, the State Council promulgated the National Sustainable Development Plan for Resource-Dependent Cities (hereinafter “Resource-Dependent Cities Plan”), which systematically laid out tasks for resource-dependent cities to achieve sustainable development over a period of time, including first identifying their number and scope and classifying them. As preliminary research connected to the Resource-Dependent Cities Plan, this study focuses on indicators and threshold values for identifying China’s resource-dependent cities and discusses a comprehensive classification framework. It also analyzes the identification and classification of the 262 cities in the Resource-Dependent Cities Plan (Figure 1).

2 Identifying resource-dependent cities

The key to identifying resource-dependent cities is differentiating urban functions. Judging from the definition of resource-dependent cities given above, such cities have several basic features: first, they have an importance that corresponds to remarkable achievements in basic urban functions, mainly the external roles played by people (extractive industrial workers) and goods (resource products), which is measured by such indicators as specialization and level of resource output of extractive industries; second, they make huge contributions, either historical or potential (i.e. they have made or will make a significant contribution to national resource requirements over an extended period). Based on the foregoing, resource-dependent cities can be identified using three indicators: extraction function intensity, output coefficient and level of resource contribution.

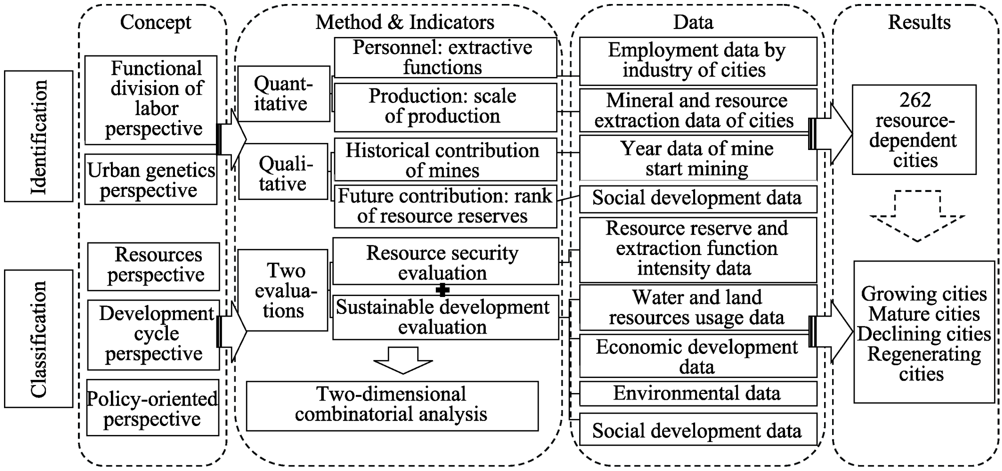

Figure 1 Identification and classification framework for resource-dependent cities

Based on the division of national administrative units, this study first identified China's 334 prefectural administrative units, as well as its 2,851 county-level administrative units for cases where prefectural administrative units fail to meet the standard, which were combined to identify the specific scopes of China's resource-dependent cities. Data was sourced from *China City Statistical Yearbook*, with survey data from the National Development and Reform Commission and the National Bureau of Statistics.

2.1 Extraction function intensity

The intensity of extraction functions is an indicator for measuring the level of employment in extractive industries in resource-dependent cities. The Nelson method is commonly used to measure this. The Nelson method is a method commonly used to measure the intensity of a function in urban function classification studies. The method essentially uses standard deviation to measure the deviation rate of various urban functions. The calculation method is as follows:

$$s_D = \sqrt{\frac{\Sigma_{i=1}^{n} d_i^2}{N}} \tag{1}$$

where d_i is the percentage of a city's employed population employed in industry i minus the mean value of the percentages of employed populations in cities throughout China that are employed in the same industry. Since the focus of this paper is resource-dependent cities, industry i refers only to extractive industries. N is the number of cities. The mean (M) and standard deviation (S_D) of the percentage of employed people working in extractive industries were calculated for each city. One standard deviation above the mean (M+ S_D) was used as the minimum intensity standard for measuring if cities have specialized functions. Any value a few standard deviations above the mean indicates strong specialization. Some studies have argued that one standard deviation above the mean in the Nelson method is too high. From the perspective of analysis on China's urban data, the standard of one standard deviation above the mean is indeed too high. The mean proportion of people employed in extractive industries in national prefecture-level cities is 4.8%; whereas, the standard deviation is 8.7%.

Even if China's cities are measured using the criterion of 0.5 standard deviations above the mean, some cities recognized by academics as being resource-dependent, such as Handan (0.71), Pingxiang (0.78) and Jiaozuo (0.72), do not meet the standard.

Using the standard of between 0.3 and 0.5 standard deviations above the mean to identify cities in China, it is discovered that the following cities, which are widely recognized as having resource-dependent features, do not fall between the two thresholds: Taiyuan, Wienan, Laiwu, Pingxiang, Chenzhou, Jiaozuo, Chifeng, Handan and Hulunbuir. However, cities with standard deviations of below 0.3, such as Leshan and Shangqiu, are generally recognized as not having resource-dependent features. As a result, this article considers an accurate threshold value for identifying resource-dependent cities in China to be those that are more than 0.3 standard deviations above the mean (Figure 2).

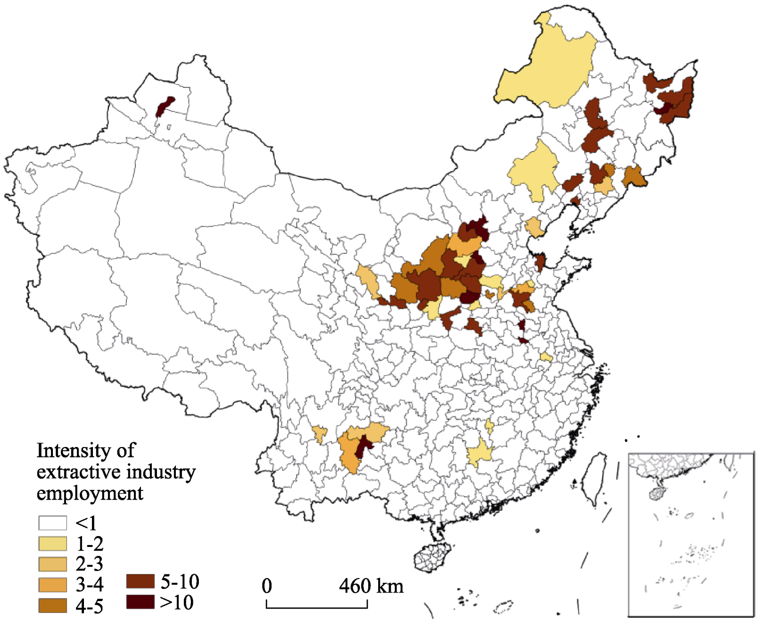

Figure 2 Intensity of extractive industry employment in China

2.2 Output coefficient

The output coefficient measures the external role of resource or mineral products of cities. It essentially measures the difference between resource products as a proportion of a city's output and resource products as a proportion of a city's economy. The calculation method is as follows:

$$C_i = \frac{m_i / M}{g_i / G} \tag{2}$$

here C_i is the output coefficient for resource products of city *i*, *m* is the output volume of resource products of city *i* for the current year, *M* is the national output value for the corresponding resource product, g_i is the gross metropolitan product (GMP) of city *i* for the current year, and *G* is China's gross domestic product (GDP) for the current year. When C_i is greater than one, the resource products of city *i* are considered to have external supply capabilities, and the basic functions of urban extractive industries are considered to be significant, meaning the city can be identified as a resource-dependent city (Figure 3).

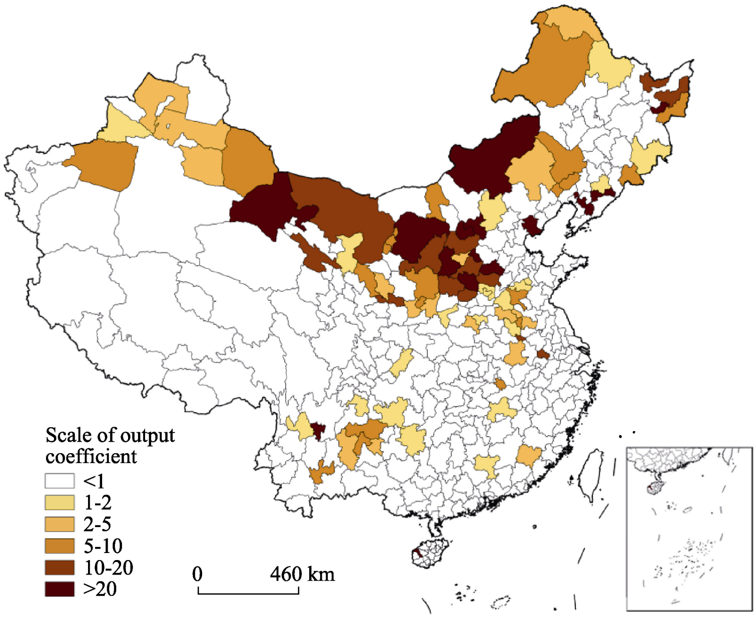

Figure 3 Resource output coefficients of cities in China

2.3 Level of resource contribution

The industrial economic structures of Chinese cities are generally characterized by low levels of specialization, with many cities having multiple developed sectors. As a result, some cities with relatively obvious resource-dependent features cannot be screened out using quantitative indicators. This requires the supplementation of qualitative characteristics. The city of Jinchang, for example, is known as the "nickel capital" of China for having the second largest nickel reserves in the world and the largest in China, but its extraction function intensity value is –1.75, far below the threshold value. The reason for this is not that the city's extraction functions are weak, but that its overall development is strong as a result of being driven on by its mining industry, which reduces the proportion of resource-related activities.

Level of resource contribution is a qualitative measure that mainly measures contributions in two areas: significant contributions to national resource requirements over a long period of history and significant contributions to national resource requirements in the foreseeable future. From the perspective of urban genetics, thriving resource exploitation or the presence of large and medium-sized resource enterprises or mines within cities can serve as qualitative indicators of historical contributions (Table 1), while world-class or nationally significant reserves of mineral resources can serve as qualitative indicators of future contributions (Table 2). Only one of these conditions needs to be met. As such, this study looked at China's famous historical mines and the cities they are located in and included those cities on the list of resource-dependent cities. We also researched and drew up a list of cities with known reserves of mineral resources that are globally or nationally significant as cities that will make significant contributions in the future and included them on the list of resource-dependent cities as well.

Table 1 China's historically significant mines and their cities

City	Mine and year extraction began	City	Mine and year extraction began
Hegang	Hegang Coal Mine (1917)	Datong	Datong Coal Mine (1907)
Jixi	Jixi Coal Mine (1925)	Tangshan	Kailuan Coal Mine (1881)
Liaoyuan	Xi'an Coal Mine (1912)	Hebi	Hebi Coal Mine (1912)
Anshan	Qidashan Iron Mine (1918)	Jiaozuo	Jiaozuo Coal Mine (1898)
Benxi	Benxihu Iron Mine (1904)	Yima*	Yima Coal Mine (1919)
Fushun	Fushun Coal Mine (1901)	Zaozhuang	Zaozhuang Coal Mine (1818)
Fuxin	Fuxin Coal Mine (1936)	Huainan	Huainan Coal Mine (1911)
Beipiao*	Beipiao Coal Mine (1921)	Pingxiang	Pingxiang Coal Mine (1898)
Ruichang	Tongling Copper Mine (Shang Dynasty)	Zigong	salt mining (Ming Dynasty)
Hancheng*	Hancheng Coal Mine (1931)	Yumen*	Yumen Oilfield (1939)
Shizuishan	Shizuishan Coal Mine (1949)	Gejiu *	Gejiu Tin Mine (1886)
Lengshuijiang*	Xikuangshan Antimony and Coal Mine (1860)	Jingdezhen	Yetao (1,800+ years)
Tongling	Tongguanshan Copper Mine (Shang Dynasty)	Daye	Daye Iron Mine (1890)
Tongren	Wanshan Mercury Mine (Tang Dynasty)	Heshan*	Heshan Coal Mine (1919)

Note: * indicates a county-level city. The rest are prefecture-level cities.

2.4 Identification results

The indicator-based identification of resource-dependent cities was conducted using an aggregated indices method, which means that cities that met any one of the three indicators (extraction function intensity, output coefficient or level of resource contribution) were deemed to be resource-dependent cities. Using this method, 262 resource-dependent cities (or regions) were identified from cities across China (Figure 4), including 128 prefecture-level cities (prefecture-level divisions, autonomous prefectures, leagues, etc.), 62 county-level cities, 58 counties (autonomous counties, banners, etc.) and 14 municipal districts. Together they account for 3.8 million km^2 (40%) of China's total land area and contain 440 million people, 33% of China's total population.

Of the 128 prefecture-level cities (prefecture-level divisions, autonomous prefectures, leagues, etc.) identified as resource-dependent cities, the densest concentration is in China's western region (50 cities or 39.1%), followed by the central region (37 cities, 28.9%), the northeastern region (21 cities, 16.4%) and the eastern region (20 cities, 15.6%). Of the 62 county-level cities identified as resource-dependent cities, the densest concentration occurs in the central region (43.6%), followed by the western region (25.8%), the eastern region (16.1%) and the northeastern region (14.5%). Of the 58 resource-dependent counties, over half (31 counties, 53.5%) are in the western region, 24.1% are in the eastern region, 17.2% are in the central region and 5.2% are in the northeastern region. There are only a few (14) resource-dependent municipal districts, and they are mainly found in the eastern and western regions.

3 Classification of resource-dependent cities

3.1 Classification framework

Resource-dependent cities are affected by a "resource curse", as urban development is ham

Table 2 List of places with significant mineral resource reserves

Place	Resource type	Location of reserves		Place	Resource type	Location of reserves	
		Global significance	National significance			Global significance	National significance
Ningwu County	Bauxite		√	Yingcheng City	Gypsum		√
Yuanqu County	Copper		√	Chenzhou City	Tungsten, Bismuth, Molybdenum, Tin, Zinc		√
Baotou City	Rare earth	√		Changning City	Lead, Zinc, Tin, Boron, Wollastonite		√
Xilinhot City	Germanium		√	Hechi City	Indium	√	
Anshan City	Iron		√	Pinggui District	Calcium		√
Yangjiazhangzi District	Molybdenum		√	Cenxi City	Granite		√
Xiuyan Manchu Autonomous County	Magnestite, Jade		√	Changjiang County	Iron ore		√
Kuandian County	Boron		√	Ya'an City	Asbestos		√
Haicheng City	Talc	√		Mianzhu City	Phosphorus		√
Fengcheng City	Boron, Andalusite		√	Kaiyang County	Phosphorus		√
Linjiang City	Diatomite, Dolomite		√	Qingzhen City	Bauxite		√
Daxinganling Region	Lumber		√	Lanping County	Lead-zinc ore	√	
Xunke County	Pearlite		√	Maguan County	Indium, Tin		√
Longyan Iron	Iron, Copper, Kaolinite		√	Qusong County	Chromium		√
Nanping City	Niobium-tantalum	√		Weinan City	Molybdenum, Lead, Copper, Niobium, Selenium, Iron, Bauxite, Rhenium		√
Ganzhou City	Tungsten	√		Tongguan County	Gold		√
Dexing City	Copper		√	Golmud City	Potassium, Magnesium, Lithium, Boron, Bromine, Iodine, Rubidium		√
Pingdu City	Graphite		√	Fuyun County	Non-ferrous metal		√
Xingtai City	Kyanite		√	Ruoqiang County	Potassium Chloride		√
Luanchuan County	Molybdenum, Tungsten		√	Hami City	Nickel, Copper		√
Zhongxiang City	Phosphorus		√				

Note: Globally or nationally significant means top-five reserves in the world or in China.

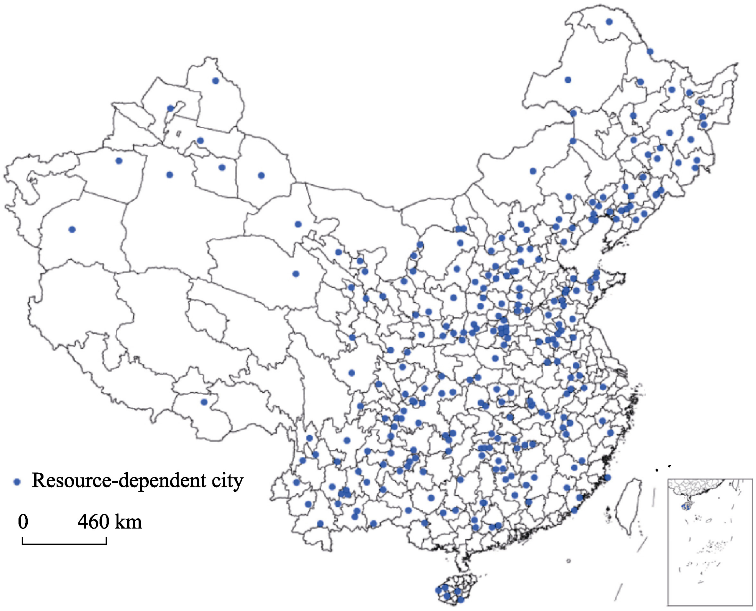

Figure 4 Distribution of resource-dependent cities

pered by factors such as accelerated environmental deterioration and waning economic momentum, making them significantly more vulnerable than other cities (Fang and Wang, 2015). These problem-oriented characteristics make it important to classify cities for the sake of policy guidance. As such, resource security and urban development issues should dominate the classification of resource-dependent cities for policy guidance. The relationship between these two things is used to comprehensively classify cities as follows. Cities with high levels of resource security and few development issues are in a period of growth and are referred to here as growing cities; cities with declining resource security and accumulating development issues are referred to as mature cities; cities whose resources are nearly depleted and with relatively many development issues are referred to as declining cities; and cities with practically depleted resources and extremely low resource security but with good transformation and development prospects and that are addressing their various problems are referred to as regenerating cities.

There is a direct correlation between the number of development issues and strength of sustainable development in resource-dependent cities. To facilitate better and more intuitive understanding, the negative indicator system of accumulated development issues was converted into the positive indicator system of urban sustainable development capacity. As such, the classification of resource-dependent cities into the aforementioned four categories was based on evaluations of their resource security and capacity for sustainable development. First, values for these two indicators were calculated separately using different index systems. Then, a cluster analysis method was used to perform two-dimensional combinatorial analysis on the two values and divide cities into the four categories (Figure 5).

Using the above classification framework, the 262 Chinese cities identified as resource-dependent cities were classified as either growing cities, mature cities, declining cities or regenerating cities. In total, 31 are classified as growing cities, including 20 prefecture-level administrative districts, seven county-level cities and four counties (autonomous

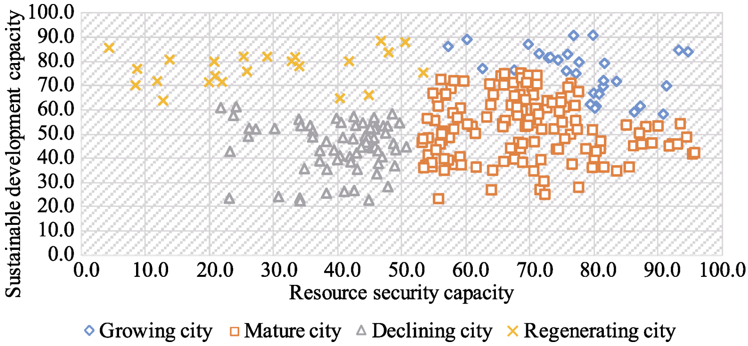

Figure 5 Two-dimensional combinations of the 262 resource-dependent cities

counties and autonomous banners); 141 as mature cities, including 66 prefecture-level administrative districts, 29 county-level cities and 46 counties (autonomous counties and autonomous banners); 67 as declining cities, including 26 prefecture-level administrative districts, 22 county-level cities, and five counties (autonomous counties and autonomous banners); and 23 as regenerating cities, including 16 prefecture-level administrative districts, four county-level cities and three counties (autonomous counties and autonomous banners) (Table 3).

Table 3 Administrative status of resource-dependent cities

City category	Pref-level city		County-level city		County		Municipal district	
	No.	Ratio	No.	Ratio	No.	Ratio	No.	Ratio
Growing	20	15.6%	7	11.3%	4	6.9%	0	0.0%
Mature	66	51.6%	29	46.8%	46	79.3%	0	0.0%
Declining	26	20.3%	22	35.5%	5	8.6%	14	100.0%
Regenerating	16	12.5%	4	6.5%	3	5.2%	0	0.0%
Total	128	100.0%	62	100.0%	58	100.0%	14	100.0%

3.2 Differences between the four categories of cities

In terms of resource security and sustainable development, growing cities have the following characteristics: first is strong resource security as they are in the stage of increasing resource exploitation, with large reserves and many years to exploit their resource(s); second is rapid economic growth, with extractive industries driving exponential growth in the wider urban economy. However, growing cities generally also have to deal with significant issues including irregulated resource extraction and unbalanced economic development.

The following are the characteristics of mature cities: first, resource exploitation has peaked and been stable for a number of years, so there is a mature system of resource extraction, transportation and processing; second, urban development is relatively mature and levels of various types of urban construction are relatively high. Nevertheless, having extracted resources for a relatively long time, mature resource-dependent cities suffer from severe environmental damage and usually many conflicts over the distribution of benefits arising from land acquisitions and clearing for the sake of resource exploitation.

Declining cities can be characterized as follows: first, resources are reaching depletion and some mines have been closed; second, internal drivers of urban development are weak, and economic, social and environmental developments are waning. Affected by the

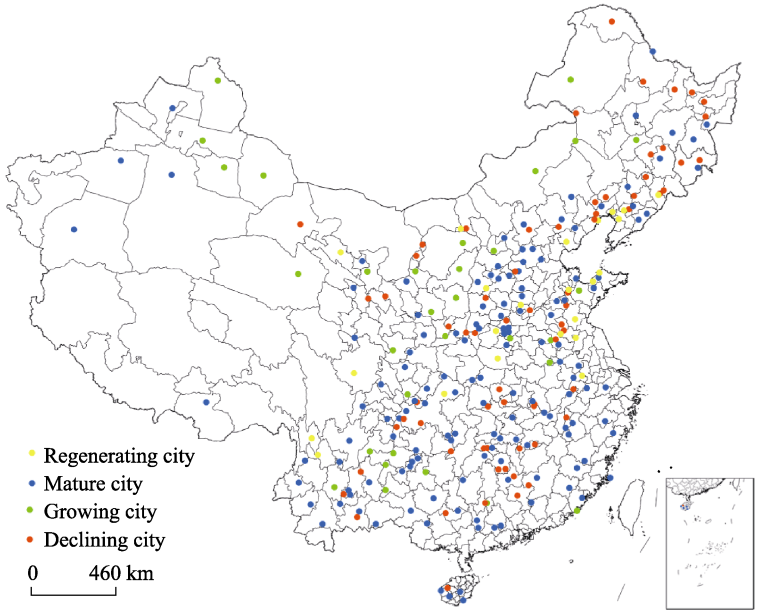

Figure 6 Distribution of the four categories of resource-dependent cities

slowdown in resource-based economic development, many declining cities suffer from deteriorating living conditions for miners and high unemployment and they are plagued by historical legacies such as slums, social security debt and geological disasters. The recovery and treatment rate of the geological environment in 75% of declining resource-dependent cities remains below 50%, and the recovery and treatment rate is below 10% in the other quarter of cities. There is still 5,800 km^2 of land suffering from subsidence as a result of underground coal-mining, along with many other outstanding historical issues affecting declining cities.

Regenerating cities generally have the following features: first, they have a long history of resource exploitation activities, though the vast majority of activities have now ceased; second, urban development is no longer as dependent on resources, with the economy and society moving onto a healthy development track. Regenerating cities are undergoing a change in their industrial structure as non-resource industries become the new mainstays of urban economic development and steps are taken to resolve historical economic, social and environmental issues caused by resource exploitation (Table 4).

Several indicators were selected to analyze the differences between the four categories of resource-dependent cities from the perspectives of economic development, location, industrial division of labor, social development and environmental protection (Table 5), including the following: the ratio of mining to manufacturing (i.e. the ratio of workers in extractive industries to workers in manufacturing industries) is used to determine the extent of urban resource-related industry chains; a management function specialization coefficient (i.e. the ratio of management to production personnel) is used to determine the management-production function link in the process of industrial upgrading in resource-dependent cities; a diversity coefficient was used to determine the diversity level of the industrial development of cities; the degree of industrial concentration (i.e. the proportion of urban industrial output value

Table 4 Characteristics, problems and transformations of the four categories of resource-dependent cities

City category	Main characteristics	Main problems	Transformations
Growing	Large reserves, large-scale exploitation, rapid economic growth	Unregulated resource extraction and unbalanced economic development	Regulating extraction, managing development, expanding resource industry chain
Mature	Large, stable resource exploitation, mature system of resource extraction, transportation and processing	Severe environmental damage and multiple conflicts over distribution of benefits from resource exploitation	Greater environmental governance and increased social undertakings
Declining	Resources reaching depletion and weak internal drivers of development	Deteriorating living conditions for miners and high unemployment, plagued by historical legacies such as slums, social security debt and geological disasters	Stimulating re-employment, transforming slums, supporting social security, recovery and treatment of mining areas
Regenerating	Vast majority of mining activities have ceased and development no longer dependent on resources	Limited innovative development and incomplete development of urban functions	Improving quality of economic development, increased levels of openness and innovation, improved urban functions

Table 5 Comparison of indicators for four categories of resource-dependent cities

Type	Indicator	Growing	Mature	Declining	Regenerating
General	Average GDP (100 million yuan)	1402	1313	844	2590
	Public financial pressure coefficient	2.58	2.58	2.44	1.76
	Average distance to the nearest provincial capital (km)	233	171	184	199
Industrial	Management function specialization coefficient	0.55	0.61	0.38	0.64
	Mining and manufacturing ratio	1.71	0.86	1.23	0.34
	Diversity coefficient	3.00	3.82	4.10	5.83
	Industrial agglomeration	32.76%	38.05%	54.24%	49.44%
Social	Average per capita road area (m^2)	9.92	12.17	11.79	12.74
	Logistical connectivity	7.05	16.30	10.54	8.40
Environmental	Sulfur dioxide emissions (tons/100 million yuan)	45.4	41.3	51.3	32.6
	Industrial wastewater discharge (tons/100 million yuan)	2.42	3.69	4.71	2.70

Data source: China City Statistical Yearbook 2016

accounted for by municipal districts) is used to determine the level of agglomeration of urban industries in urban areas; and logistical transportation intensity (i.e. the total volume of passenger and freight transport per unit of GDP) is used to determine the degree of connectivity between a city's passenger and freight transport.

The management function specialization coefficient is based on the method of Bade *et al*. (2004), whereby leasing and business services employees are considered management personnel and personnel involved in extractive industries, manufacturing, and the production and supply of electricity, gas and water are considered production personnel.

The diversity index draws on the Gini specialization coefficient used by Duranton and Puga (2001, 2004, 2005), which is expressed as an inverse proportion of the specialization coefficient. The formula is as follows:

$$DD_i = \frac{1}{\sum_j \left| D_{ij} - D_j \right|} \tag{3}$$

where D_{ij} denotes the proportion of people employed in industry j of city i, D is the proportion of people employed nationwide in industry j, and the value range of DD_i is [1, +]. The larger the value, the more diverse a city's industry.

Looking at overall development and location indicators, regenerating cities have the largest economies and declining cities have the smallest, with a nearly threefold difference in size between them. Growing cities have the highest economic growth rate. Between 2005 and 2015, the average growth rate of growing cities was 13.29%, much higher than the national average for resource-dependent cities of 9.58%. Resource-dependent cities other than regenerating cities have a higher coefficient of public financial pressure than the national average of 1.69. Taking distance from a provincial capital as an example, mature and declining cities are in relatively close proximity, below the average of 198 km for cities nationwide, whereas growing cities tend to be relatively far from provincial capitals, 62 km further away on average than mature cities. This supports the theory that distance from economic and social centers affects resource exploitation activities.

According to the results from measuring the management function specialization coefficient, regenerating cities and mature cities have more obvious management functions, but declining cities are relatively weak in this regard. This shows that, compared with the proportion of production personnel, the decline of an urban economy significantly affects the number of management personnel.

Mature resource-dependent cities have relatively well-established systems of resource-related industries as well as extensive processing industry chains. This is also reflected by the ratio of extractive to manufacturing industries. Excluding regenerating cities, only mature cities had a ratio of less than 1. Both growing and declining cities have much larger extractive industry employment than manufacturing industry employment. Despite a general decline in the proportion of the national working population employed in extractive industries in China between 2005 and 2015, the proportion of people employed in those industries in growing resource-dependent cities is continuing to increase.

Changing the diversity of a city is a gradual process. Resource-dependent cities can be listed from least diverse to most diverse according to the diversity coefficients as follows: growing cities, mature cities, declining cities, generating cities. This is inverse to dependence on the resource-related economy. The dispersed nature of resource extraction activities means that growing cities and mature cities have comparatively low levels, and declining and regenerating cities have relatively high levels, of industrial agglomeration.

In terms of social development indicators, mature cities performed best, with higher per capita road area and logistical connectivity than other city categories, with growing cities performing particularly badly. This confirms that growing cities tend to have unbalanced economic and social development.

Finally, looking at environmental indicators, declining cities have the highest levels of wastewater discharge and sulfur dioxide emissions, though growing cities have relatively high sulfur dioxide emissions due to the prevalence of coal-mining, coal-fired power generation and other coal-based industries. Meanwhile, regenerating cities have relatively low levels of wastewater discharge and sulfur dioxide emissions.

4 Conclusion and discussion

This problem-oriented study constructed a system for recognizing and classifying resource-dependent cities for the sake of policy implementation. Its methodology differs from traditional studies that use single indicators or quantitative indicators to identify such cities or that use urban lifecycle or main resources to classify them, instead using a combination of quantitative and qualitative methods, thereby improving identification accuracy. This system also focuses on measuring the external contributions of mineral products, but cities with relatively large volumes of mineral processing, such as cities with both iron ore mining and steel production, score poorly on the indicators of strength of extraction functions and output coefficient. Identifying such cities more accurately is key to optimizing the identification system.

As China's economic and social development deepens, the role resource-dependent cities play in supporting national development will become increasingly apparent, the conflict between rigid expansion in demand for national resources and diverse development in resource-dependent cities will intensify, and development issues in resource-dependent cities will become more severe. This is especially true as resource extraction continues. Resource-dependent cities currently classified as growing and mature will move into the next stage of their development, meaning they will face more acute development problems. It is likely that a deeper analysis of development problems of resource-dependent cities from economic, social, environmental and other perspectives, as well as refinement of the problem-oriented classification method for resource-dependent cities, will become important areas of study in the future. Targeted research of different regions and different categories of resource-dependent cities constitute important approaches for furthering our understanding of different types of resource-dependent cities.

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