Vulnerability of Mineral Resource-Based Cities in the Loess Plateau Region and Their Population Response (Postprint)

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Abstract

Research on the vulnerability of resource-based cities holds significant importance for implementing China' s new-type urbanization strategy and promoting high-quality urban development. This study examines 25 mineral resource-based cities in the Loess Plateau region, constructing an indicator system from four dimensions: economic, social, ecological environment, and resources. Employing the TOPSIS method, grey relational analysis, and Geographical Detector, it investigates the patterns and spatiotemporal evolution of urban vulnerability from 2000 to 2015. Taking population—the most mobile social resource—as the entry point, the analysis focuses on regional effects of vulnerability evolution. The results indicate: (1) From 2000 to 2015, resource-based cities in the Loess Plateau region were predominantly characterized by medium-low vulnerability with an overall upward trend; polarization among cities was significant, but the degree of imbalance tended to moderate; (2) The main vulnerability issues exhibited a transformation characteristic of "ecological environment-economy + society-economy + resources," with problems being particularly prominent in mature and declining cities; both social and ecological environment vulnerabilities generally improved, while areas with increasing resource vulnerability were concentrated in the east and south; (3) The degree of population response to comprehensive vulnerability showed a downward trend; the urban population proportion demonstrated the strongest response, while the responses of population aging, total social dependency ratio, and floating population proportion exhibited phased characteristics; (4) Population responses to vulnerability across different dimensions showed dimensional differences; the population responses to economic and social vulnerabilities were consistent, with the total social dependency ratio being the key explanatory factor; in ecological environment vulnerability, the explanatory power of floating population proportion was relatively strong and increased significantly, while in resource vulnerability, the urban population proportion showed the highest degree of response.

Full Text

Vulnerability and Population Response of Mineral Resource-Based Cities in the Loess Plateau

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Abstract

Research on the vulnerability of resource-based cities is of great significance for implementing China' s new urbanization strategy and promoting high-quality urban development. This study examines 25 mineral resource-based cities in the Loess Plateau region, constructing an evaluation index system from four dimensions: economic, social, ecological environment, and resources. Using the entropy-weighted TOPSIS method, grey correlation analysis, and geographic detector methods, we analyze the spatiotemporal patterns and evolution of urban vulnerability from 2000 to 2015. Taking population—the most mobile social resource—as the entry point, we further examine the regional effects of vulnerability evolution. The results show that: (1) The vulnerability of resource-based cities in this region is primarily characterized by a transition from ecological environment vulnerability to "economic + social" vulnerability, and then to "economic + resource" vulnerability. Cities exhibit a generally rising trend in vulnerability, with significant polarization but gradually easing imbalances. (2) From 2000 to 2015, resource-based cities in the Loess Plateau region were dominated by medium-low vulnerability levels, with an overall upward trend. The social and ecological environment vulnerabilities generally improved, while resource vulnerability increased, particularly in the eastern and southern regions. (3) The population response degree to comprehensive vulnerability showed a declining trend. The urban population proportion demonstrated the strongest response, while population aging, social dependency ratio, and floating population proportion showed stage-specific response characteristics. (4) The population response to dimensional vulnerabilities exhibited significant differences. Economic and social vulnerabilities showed consistent population responses, with the social dependency ratio being the key explanatory factor. In ecological environment vulnerability, the floating population proportion showed strong and significantly increasing explanatory power, while in resource vulnerability, the urban population proportion exhibited the highest response degree.

Keywords: mineral resource-based city; vulnerability; population response; Loess Plateau

Introduction

Resource-based cities are those whose leading industries involve the extraction and processing of local natural resources such as minerals and forests [1]. As a special type of city, they have made tremendous contributions to regional socio-economic development and improving people's living standards. However, under the exploitation and utilization of natural resources, numerous urban problems have become increasingly prominent, including single industrial structures [2], social issues triggered by mining development [3], and ecological restoration and sustainable development in mining areas [4]. Vulnerability, as an important concept for characterizing the sustainable development state of socio-economic systems, has been widely applied in resource-based city research.

Scholars both domestically and internationally have explored the concept [5], evaluation [6], spatiotemporal patterns [7], influencing factors [8], and prediction and regulation [9] of resource-based city vulnerability, conducting assessments from perspectives of resource type [10], city size [11], and life cycle [12]. Some researchers have proposed the concept of human-land system vulnerability [13]. Fang Chuanglin et al. [14] measured urban vulnerability in China and found that the country is generally in a medium vulnerability stage, with vulnerability in central and western regions higher than in eastern regions. Adger [15] proposed applying the pressure-state-response model to evaluate vulnerability and analyze its influencing factors. Blaikie et al. [16] pointed out that population resources, infrastructure, and social security are three major aspects affecting social systems. Li Bo et al. [17] evaluated the vulnerability of mining cities in Northeast China and analyzed their influencing factors. Other scholars have examined the evolution process and coping timing of economic vulnerability in mining cities [18], social system vulnerability in mining cities [19], and land use planning and environmental impact assessment [20]. Martinez-Fernandez et al. [21] found that as resource advantages weaken, factors such as industrial structure and infrastructure have important impacts on population changes in mining cities. Wang Wei et al. [22] pointed out that resource-based cities are experiencing deepening aging and increasingly prominent population loss issues. However, research combining resource-based city vulnerability with population to explore their relationship remains relatively weak. Therefore, it is particularly necessary to examine the response characteristics of vulnerability from the perspective of multiple population attributes.

The Loess Plateau, as an economically and ecologically vulnerable inland underdeveloped region [23], has numerous resource-based cities, yet research specifically targeting this aspect is lacking, and studies linking urban vulnerability evolution with population characteristics are even rarer. This paper takes 25 resource-based cities in the Loess Plateau region as research objects, using TOPSIS method, grey correlation analysis, and geographic detector methods to explore the spatiotemporal differentiation of resource-based city vulnerability from comprehensive and dimensional perspectives, and analyzes its population response characteristics. The aim is to provide theoretical references for understanding the spatiotemporal patterns and population response models of resource-based city vulnerability in ecologically fragile areas, promoting the transformation and development of resource-based cities, and formulating population policies.

1. Study Area Overview

The Loess Plateau covers a total area of 64.87$\times10^{4}$ km^2, with abundant energy and mineral resources, forming an important component of the national energy security guarantee base and ecological security barrier. The "Comprehensive Management Planning Outline for the Loess Plateau Region (2010-2030)" divides it into six management zones: Loess Plateau gully region, loess hilly-gully region, earth-rock mountain region, valley plain region, sandy land and desert region, and agricultural irrigation region. According to the "National Sustainable Development Planning of Resource-Based Cities (2013-2020)" issued by the State Council, the Loess Plateau region contains 25 resource-based cities [24] (8 prefecture-level cities, 17 counties/cities, and 5 districts). To ensure data availability and administrative unit consistency, this study selects 25 prefecture-level resource-based cities as research objects. In terms of development stages, growth-type and mature-type resource-based cities account for a relatively high proportion. Regarding resource types, coal-based cities dominate, accounting for up to 68%. In 2015, the Loess Plateau region' s GDP reached 789.17$\times10^{8}$ yuan, with a total population of 6,014.07$\times10^{4}$ people, including 5,789.17$\times10^{4}$ urban residents. The industrial structure was 6.85:48.07:45.08.

2.1 Index System Construction

Currently, research indicators for resource-based city vulnerability are not unified. Based on principles of systematicity, data availability, and previous research findings [25-27], this study constructs an evaluation index system for resource-based city vulnerability comprising 4 target layers, 12 criterion layers, and 24 specific indicators (Table 1). The system reflects the proximity between resource-based city vulnerability and the ideal state, calculating comprehensive and dimensional vulnerability indices that are easy to understand and scientifically robust.

2.2 Research Methods

2.2.1 Entropy-Weighted TOPSIS Method TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a multi-objective decision analysis method that judges development levels by comparing the Euclidean distance between the system' s actual state and the ideal state [28]. This study uses the entropy method to determine weights [29] and then applies TOPSIS to reflect the proximity between resource-based city vulnerability and the ideal state.

2.2.2 Grey Correlation Analysis Grey correlation analysis measures the degree of association between factors based on the similarity or dissimilarity of their development trends [30]. This study uses comprehensive vulnerability and dimensional vulnerabilities as reference sequences, and five population indicators—population aging, social dependency ratio, floating population proportion, natural population growth rate, and urban population proportion—as comparative sequences. The grey correlation coefficient is calculated to measure the association between population factors and vulnerability.

2.2.3 Geographic Detector The geographic detector is a method for detecting spatial differentiation of geographic phenomena, including factor detection, risk detection, interaction detection, and ecological detection [31]. This study uses the factor detection model to explore the response degree of population factors to comprehensive and dimensional vulnerabilities.

2.2.4 Vulnerability Classification Referring to existing research results [32] and based on the vulnerability status of resource-based cities in the Loess Plateau region, this study uses 0.5 as a benchmark and classifies vulnerability into five levels through the natural breaks method: low, relatively low, medium, relatively high, and high (Table 2).

2.3 Data Sources

This study uses statistical data, spatial data, and monitoring data. Statistical data are obtained from the "China City Statistical Yearbook,""Shaanxi Regional Statistical Yearbook," statistical yearbooks of various provinces and cities, and national economic and social development statistical bulletins. Water resources data come from water resources bulletins, and population data are from census data and national 1% population sampling surveys. Spatial data are from the 1:1,000,000 national fundamental geographic database. Monitoring data are from the Center for International Earth Science Information Network (CIESIN) at Columbia University (https://sedac.ciesin.columbia.edu/).

3. Spatiotemporal Differentiation Characteristics of Resource-Based City Vulnerability in the Loess Plateau

3.1 Spatiotemporal Differentiation of Comprehensive Vulnerability From 2000 to 2015, the comprehensive vulnerability of resource-based cities in the Loess Plateau region was dominated by low vulnerability (Figure 2). High vulnerability areas were distributed in agricultural irrigation regions, where human activity intensity was high. Sandy land and desert regions, as well as earth-rock mountain regions with sparse populations and low human activity intensity, had low comprehensive vulnerability, indicating relatively small development pressure.

From 2000 to 2015, the comprehensive vulnerability of resource-based cities in the Loess Plateau region slightly increased, with significant polarization but decreasing imbalance among cities. During this period, the mean comprehensive vulnerability increased from 0.41 to 0.45, and the coefficient of variation decreased from 41.59% to 35.67%, indicating that while resource-based cities experienced excessive pressure during rapid urbanization, the differences between cities significantly narrowed.

In 2000, medium-high vulnerability areas expanded. The Loess Plateau gully region and the northern part of the valley plain region transformed into high and relatively high vulnerability areas, respectively. The southern part of the earth-rock mountain region saw increased vulnerability, indicating greater urban development pressure and insufficient anti-interference capacity.

Since the implementation of the Western Development Strategy, cities in the Loess Plateau region have transitioned from low vulnerability dominance to medium vulnerability dominance. The eastern part of the loess hilly-gully region, southern part of the earth-rock mountain region, and southern part of the valley plain region showed significant vulnerability increases, presenting a spatial pattern of high in the southeast and low in the northwest.

3.2 Evolution of Dimensional Vulnerability

3.2.1 Temporal Process of Dimensional Vulnerability Evolution The dimensional vulnerabilities of resource-based cities in the Loess Plateau region showed significant differences, with economic vulnerability being the highest, followed by social vulnerability, while ecological environment and resource vulnerabilities were relatively lower (Table 5). During the study period, economic and resource vulnerabilities increased significantly, ecological environment vulnerability improved, and social vulnerability showed a trend of first increasing then decreasing.

In 2000, the proportion of cities with medium-high ecological environment vulnerability reached 64%, indicating that as an ecologically fragile region, resource-based cities in the Loess Plateau faced severe ecological damage and environmental pollution, making ecological environment vulnerability the main regional challenge. Economic, social, and resource vulnerabilities were primarily at medium-low levels, with cities showing significant resource advantages and relatively low development pressure.

By 2015, the proportion of cities with medium-high economic and social vulnerabilities increased to 52% and 48%, respectively, while the proportion of cities with medium-high ecological environment vulnerability decreased to 20%. The main vulnerability issues transformed from "ecological environment" to "economic + resource." With the implementation of the Grain for Green policy, the urban ecological environment improved.

From the perspective of resource-based city development stages (Figure 3), all four types of cities had high ecological environment vulnerability in 2000. By 2015, with the Western Development Strategy and pilot work for resource-exhausted cities, the ecological environment vulnerability of all city types decreased significantly, consistent with the above conclusions. During 2005-2010, all city types were in a transition period, with all dimensional vulnerabilities increasing. By 2015, resource vulnerability of all city types increased substantially, with vulnerability issues shifting to "economic + resource." Mature-type cities had the highest economic and social vulnerabilities, indicating poor economic development environments and insufficient social security levels.

3.2.2 Spatial Differentiation of Dimensional Vulnerability Evolution From 2000 to 2015, spatial variation characteristics differed across dimensions. Economic vulnerability showed small changes, while social, ecological environment, and resource vulnerabilities changed significantly (Figure 4). Economic vulnerability decreased from southeast and northeast to northwest, with significant increases in most regions except for Ordos and Yulin. Social vulnerability showed a pattern of first increasing then decreasing, with substantial increases in most cities during 2005-2010, and significant decreases in most cities except Pingliang and Qingyang after 2010.

Ecological environment vulnerability showed large changes, decreasing overall. After 2010, except for Ordos and Pingliang, other cities saw improvements. Resource vulnerability increased most significantly in eastern and southern regions, with cities facing heavy resource pressure. Under the Western Development Strategy and Grain for Green policy, social and ecological environment vulnerabilities in the Loess Plateau region improved, but resource vulnerability increased substantially, especially in eastern and southern regions. The main vulnerability issues showed a transition from "ecological environment" to "economic + social" and then to "economic + resource." Regarding city development stages, attention should be paid to the economic and social vulnerability issues of mature-type cities and the economic and resource vulnerability issues of decline-type cities.

4. Population Response of Resource-Based City Vulnerability in the Loess Plateau

In the process of new urbanization, population, as the most dynamic element in resource-based city development, has a particularly prominent response to vulnerability [33]. To clarify the population response characteristics of resource-based city vulnerability in the Loess Plateau region, this study first uses grey correlation analysis to identify population factors closely related to vulnerability, and then employs the factor detection model of geographic detector to explore the response degree of population factors to comprehensive and dimensional vulnerabilities.

4.1 Grey Correlation Between Resource-Based City Vulnerability and Population Attribute Indicators Using comprehensive vulnerability and dimensional vulnerabilities as reference sequences, this study selects five important indicators characterizing regional population features as comparative sequences: population aging, social dependency ratio, floating population proportion, natural population growth rate, and urban population proportion. The correlation coefficients are calculated (Table 6). Population aging and social dependency ratio characterize population age structure and dependency burden, while floating population proportion and urban population proportion reflect urban population absorption capacity. The results show that resource-based city vulnerability in the Loess Plateau region has high correlation coefficients with population aging, social dependency ratio, floating population proportion, and urban population proportion, but low correlation with natural population growth rate. Therefore, this study analyzes the population effect of vulnerability evolution based on these four indicators.

4.2 Population Response to Comprehensive Vulnerability Factor detection analysis of the four indicators (X_1: population aging, X_2: social dependency ratio, X_3: floating population proportion, X_4: urban population proportion) shows that the explanatory power (q-values) of all four population indicators for comprehensive vulnerability generally decreased (Table 7). The response degree of population aging to comprehensive vulnerability first increased then decreased, peaking in 2010, with q-values dropping to 0.11 by 2015, indicating significantly weakened explanatory power. The social dependency ratio and floating population proportion showed inverted U-shaped patterns, with q-values at relatively high levels in 2010. Cities with high vulnerability had heavy population burdens and low population attractiveness. The urban population proportion showed an M-shaped fluctuation pattern and, overall, had higher explanatory power for comprehensive vulnerability than other indicators, indicating that urban development level had a high response degree to comprehensive vulnerability. Cities with low vulnerability experienced rapid population expansion, while high-vulnerability cities such as Baiyin and Weinan faced population contraction.

4.3 Population Response to Dimensional Vulnerability Building on the population response to comprehensive vulnerability, this study further explores the population response characteristics to dimensional vulnerabilities and plots the q-value trends of population factors' explanatory power for dimensional vulnerabilities (Figure 5) to analyze response differences.

In economic vulnerability, the explanatory power of population aging showed a decreasing trend, while the social dependency ratio remained at a high and stable level with q-values around 0.2. The floating population proportion and urban population proportion showed inverted U-shaped and M-shaped patterns, respectively. The floating population proportion' s explanatory power for economic vulnerability peaked in 2010 at 0.16. Cities with high economic vulnerability had single-industry dominance, prominent economic development issues, and insufficient population absorption, while low-vulnerability cities had strong economic development momentum with large population inflows, providing powerful endogenous momentum for urban development.

In social vulnerability, the q-value of population aging increased significantly but remained at a low overall level with weak response degree. The social dependency ratio showed strong explanatory power without significant changes.

For example, Pingliang, as a high social vulnerability city, had high urban registered unemployment rates with prominent miner unemployment and heavy social burdens. The floating population proportion and urban population proportion showed fluctuating q-values, with response degrees changing significantly over time.

In ecological environment vulnerability, the explanatory power of population aging remained at a low and stable level. The q-value of social dependency ratio decreased from 0.18 to 0.11, showing a weakening response to ecological environment vulnerability. The explanatory power of floating population proportion and urban population proportion for this dimensional vulnerability showed an increasing trend, with growth rates of 30.30% and 72.22%, respectively. Cities with low ecological environment vulnerability had high environmental quality and strong population attractiveness, while high-vulnerability cities showed the opposite pattern.

In resource vulnerability, the q-values of population aging, social dependency ratio, and urban population proportion showed fluctuating decreasing trends, with weakening response degrees. In contrast, the response degree of floating population proportion gradually strengthened. The urban population proportion had the highest explanatory power and strongest response to resource vulnerability. High-vulnerability cities had large resource consumption and small development potential in resource-based industries, resulting in significantly decreased population attractiveness and entry into a development decline period.

Overall, economic and social vulnerabilities showed consistent population responses, while ecological environment and resource vulnerabilities showed significant differences. The social dependency ratio was the key explanatory factor for economic and social vulnerabilities, with relatively low explanatory power of population aging. In ecological environment vulnerability, the response degree of floating population proportion fluctuated and increased, reaching the highest level by 2015. In resource vulnerability, the explanatory power of urban population proportion was most significant but showed a fluctuating decreasing trend. As urban resource dependence weakened, the impact of resource vulnerability on population attractiveness decreased.

5. Discussion

Based on the measurement of resource-based city vulnerability in the Loess Plateau, this study analyzes the spatiotemporal differentiation patterns of vulnerability and focuses on characterizing the response features of population factors to vulnerability. Compared with previous studies, this research deeply explores the response relationship between population factors and resource-based city vulnerability, helping to reveal the internal mechanism of population response to vulnerability. During the study period, high-vulnerability cities in the Loess Plateau region showed weakened population absorption capacity and heavy population burdens, which is consistent with the population issues in resource-based cities identified by existing research [34].

Against the background of increasingly prominent vulnerability issues in mineral resource-based cities, promoting high-quality development of resource-based cities is particularly important. The following optimization measures are recommended: (1) Adjust economic structure and improve economic development quality. Promote flexible industrial transformation and enhance proactive transformation awareness to strengthen economic development stability. (2) Adjust development direction and avoid high vulnerability risks. Strengthen policy support for decline-type cities to transform from industrial to service-oriented; mature-type cities can use their economic advantages to cultivate emerging industries. (3) Improve social security systems, optimize employment environments, and enhance human resource attractiveness. Strengthen social welfare construction in high-vulnerability cities to support reemployment of laid-off miners; low-vulnerability cities should seize the demographic dividend opportunity, pay attention to the management and settlement of floating populations, and improve urbanization quality. Due to data limitations, the population response indicators selected in this study focus on macro characteristics. Future research should analyze micro-indicators from humanistic perspectives such as residents' happiness index and health status to further investigate the population response characteristics and mechanisms of resource-based city vulnerability.

6. Conclusions

Using spatial analysis, grey correlation analysis, and geographic detector methods, this study examines the spatiotemporal differentiation and population response characteristics of mineral resource-based city vulnerability in the Loess Plateau from comprehensive and dimensional perspectives. The main conclusions are as follows:

(1) From 2000 to 2015, the comprehensive vulnerability of resource-based cities in the Loess Plateau region was dominated by medium-low levels, with a slight overall upward trend, significant differences between cities, but gradually easing imbalances. Dimensionally, the evolution followed a pattern of "ecological environment → economic + social → economic + resource." Special attention should be paid to the economic and social vulnerability issues of mature-type cities and the economic and resource vulnerability issues of decline-type cities.

(2) The comprehensive vulnerability of resource-based cities in the Loess Plateau region showed a spatial pattern of high in the southeast and low in the northwest, with high-vulnerability areas concentrated in the Loess Plateau gully region and agricultural irrigation region. Dimensionally, most cities saw improvements in social and ecological environment vulnerabilities, while resource vulnerability increased in the eastern and southern regions. The range of change in economic vulnerability in the eastern and southern regions was relatively small.

(3) The population response degree to comprehensive vulnerability showed an overall declining trend. Population aging, social dependency ratio, and floating population proportion showed stage-specific response characteristics. The urban population proportion was the key explanatory factor. Cities with low vulnerability experienced rapid population expansion, while high-vulnerability cities such as Baiyin and Weinan faced population contraction.

(4) The population response to dimensional vulnerabilities showed significant differences. Economic and social vulnerabilities exhibited consistent population responses, with the social dependency ratio being the key explanatory factor. In ecological environment vulnerability, the explanatory power of floating population proportion increased significantly, with population outflow from high ecological environment vulnerability cities. In resource vulnerability, the urban population proportion was the key explanatory factor, with large population agglomeration in low resource vulnerability cities.

References

[1] National sustainable development planning of resource-based cities (2013–2020) [EB/OL]. [2013-12-03]. http://www.gov.cn/zwgk/2013-12/03/content_{2540070}.htm.

[2] WANG Tao, WANG Qingqing, ZHAO Dan, et al. Problems of industrial diversification in resource-based areas: Taking Shanxi Province as an example[J]. Arid Land Geography, 2019, 42(5): 1221-1228.

[3] BEBBINGTON A, HINOJOSA L, BEBBINGTON D H, et al. Contention and ambiguity: Mining and the possibilities of development[J]. Development and Change, 2008, 39(6): 887-914.

[4] PEGG S. Mining and poverty reduction: Transforming rhetoric into reality[J]. Journal of Cleaner Production, 2006, 14(3): 376-387.

[5] ADGER W N. Vulnerability[J]. Global Environmental Change, 2006, 16(3): 268-281.

[6] BLAIKIE P, CANNON T, DAVIS I, et al. At risk: Natural hazards, people' s vulnerability and disasters[M]. London: Routledge, 1994.

[7] TURNER B L, KASPERSON R E, MATSON P A, et al. A framework for vulnerability analysis in sustainability science[J]. Proceedings of the National Academy of Sciences, 2003, 100(14): 8074-8079.

[8] FANG Chuanglin, WANG Yan. A comprehensive assessment of urban vulnerability and its spatial differentiation in China[J]. Acta Geographica Sinica, 2015, 70(2): 234-247.

[9] LI Bo, TONG Lianjun, HAN Zenglin. Vulnerability and sustainable development model of coal mining cities in northeast China[J]. Geographical Research, 2010, 29(2): 361-372.

[10] SU Fei, ZHANG Pingyu. Primary analysis on the combination of land use planning and environmental impact assessment[J]. Areal Research and Development, 2009, 28(2): 71-74.

[11] NA Wei, LIU Jisheng. Research on the vulnerability and the evaluation of the human-earth system in mining cities[J]. Urban Problems, 2007, (7): 43-48.

[12] YANG Dongfeng, YIN Chengzhi. How to save the shrinking cities: Old industrial cities transition in the UK[J]. Urban Planning International, 2013, (6): 50-56.

[13] MARTINEZ-FERNANDEZ C, WU C T, SCHATZ L K, et al. The shrinking mining city: Urban dynamics and contested territory[J]. International Journal of Urban and Regional Research, 2012, 36(2): 245-260.

[14] WANG Wei, LU Chunyan, WANG Yingzhe. Problems and countermeasures of population loss in resource-based cities in Heilongjiang[J]. China Population, Resources and Environment, 2018, 28(S2): 63-66.

[15] ZHANG Mei, LUO Huailiang, CHEN Lin. Vulnerability assessment of resource-based city: A case study of Panzhihua[J]. Resources and Environment in the Yangtze Basin, 2018, 27(5): 1170-1178.

[16] HAN Mengmeng, YE Yuanyuan, et al. Perception of environmental pollution in the residents of the tail mining area[J]. Arid Land Geography, 2020, 43(4): 1108-1116.

[17] YANG Weige, GOU Ruiling, TONG Lianjun, TONG Weiming, et al. Research on vulnerability assessment of human-land system of Anshan City based on set pair analysis[J]. Progress in Geography, 2012, 31(3): 344-352.

[18] LI He, ZHANG Pingyu. The evolution and coping timing of economic vulnerability of mining cities: A case study in northeast China[J]. Economic Geography, 2014, 34(1): 82-88.

[19] SUN Pingjun, XIU Chunliang. Capacity and vulnerability assessment for the economic system of mining city in Liaoning Province[J]. Journal of Arid Resources and Environment, 2011, 25(4): 22-27.

[20] SU Fei, ZHANG Pingyu, LI He. Vulnerability assessment of coal mining cities' economic systems in China[J]. Geographical Research, 2008, 27(4): 907-916.

[21] SONG Yongyong, XUE Dongqian, DAI Lanhai. The spatial differentiation and determinants of urban vulnerability in northwest China under the background of the Silk Road Economic Belt[J]. Economic Geography, 2018, 38(2): 66-73.

[22] SONG Yongyong, XUE Dongqian, DAI Lanhai, et al. Land cover change and eco-environmental quality response of different geomorphic units on the Chinese Loess Plateau[J]. Journal of Arid Land, 2020, 12(1): 1-12.

[23] LI Wubin, SONG Yongyong, XUE Dongqian, et al. Data set on urbanization and urban development in the Loess Plateau region from 1990 to 2015[DB/OL]. Xi' an: Shaanxi Normal University, 2018-12-25.

[24] ZHU Wei, ZHOU Hongfei, LI Lanhai, et al. Evaluation on carrying capacity of agricultural water and land resources and identification of affecting factors in Kazakhstan[J]. Arid Zone Research, 2020, 37(1): 254-263.

[25] XU Jun, LI Guifang, WANG Yuhong. Review and prospect of resource-based city vulnerability in China and abroad[J]. Resources Science, 2015, 37(6): 1266-1278.

[26] DENG Julong. The course of grey system theory[M]. Wuhan: Huazhong University of Science and Technology Press, 1990: 53-84.

[27] WANG Jinfeng, XU Xiangdong. Geodetector: Principle and prospective[J]. Acta Geographica Sinica, 2017, 72(1): 116-134.

[28] YANG Zhenshan, SUN Yiyun. City shrinking: Phenomenon, progress and problems[J]. Human Geography, 2015, 30(4): 6-10.

[29] ZHANG Yida, LIU Xuelu, FAN Yahong, et al. Multi-functional evaluation on land use in Lanzhou City based on the improved TOPSIS[J]. Arid Land Geography, 2019, 42(2): 444-451.

[30] State Council. National sustainable development planning of resource-based cities (2013–2020) [EB/OL]. [2013-12-03]. http://www.gov.cn/zwgk/2013-12/03/content_{2540070}.htm.

Table 1 Evaluation index system of vulnerability of resource-based cities

Table 2 Vulnerability classification of resource-based cities

Table 3 Descriptive statistics of comprehensive vulnerability of resource-based cities from 2000 to 2015

Table 4 Comprehensive management of the vulnerability of resource-based cities in Loess Plateau regions from 2000 to 2015

Table 5 Dimension vulnerability of resource-based cities from 2000 to 2015

Table 6 Correlation coefficient between vulnerability and population factors of resource-based cities in 2015

Table 7 Determinants of population factors on the comprehensive vulnerability

Figure 1 [Figure 1: see original paper] Development stage and resource type of resource-based cities in the Loess Plateau area

Figure 2 [Figure 2: see original paper] Comprehensive vulnerability of resource-based cities from 2000 to 2015

Figure 3 [Figure 3: see original paper] Relationship between multidimensional vulnerability and city type

Figure 4 [Figure 4: see original paper] Variation degree of multidimensional vulnerability of resource-based cities

Figure 5 [Figure 5: see original paper] Results and changes of q-values of population factors

Note: Figure translations are in progress. See original paper for figures.

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