Research Paper

Assessing Urban Resilience for Resource-based cities in Northeast China Based on the Adaptive Cycle Framework

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Abstract

In the process of sustainable development, most of China's resource-based cities, especially those in northeast China, are still unable to eliminate the resource exhaustion dilemma. Resilience is an effective way to deepen sustainable urban development. However, there are no commonly applied quantitative approaches for assessing resilience, and fewer take resource-based cities as the research object. Therefore, this paper constructed an urban resilience assessment based on the adaptive cycle framework for resource-based cities in Northeast China (RBCNC). Firstly, we analyzed the resilience characteristics of 19 resource-based cities in Northeast China and collected relevant statistical data. Secondly, the resilience and risk two-dimensional assessment framework was constructed based on the adaptive cycle theory. Relevant indicators were selected from existing studies and quantified by principal component analysis (PCA). Thirdly, according to the characteristics of the adaptive cycle, the normalized resilience and risk indicator results of 19 RBCNC were divided into four phases, i.e., α, k, r, Ω. The results show 4 cities in the α-phase, 8 in the r-phase, 7 in the Ω-phase, and no city in the k-phase. Finally, we proposed detailed and differentiated urban planning strategies for RBCNC in different phases, through which planners could explore a more specific path of resilience transformation.

Keywords

Urban resilience, Resource-based cities, Adaptive cycle, Assessment

1. Introduction

Due to excessive resource exploitation and inappropriate resource development mode, resource-based cities, especially those in Northeast China, have faced severe social-ecological problems. The Chinese government has issued a series of policies to help resource-based cities transform from the initial dual structure of resource consumption to sustainable urban development, e.g., “Sustainable Development Plan for Resources-Based Cities in China 2013-2020.” However, resources-based cities in Northeast China (RBCNC) have fallen into a bottleneck period. While the problems left over from history have not been solved, new contradictions have emerged gradually, forming complex problems interwoven with ecology, society, economy, and urban infrastructure, such as simple industrial structure, enormous economic downward pressure, prominent livelihood issues, population loss, high unemployment, fragile ecological environment, inadequate urban infrastructure, and so on. Promoting the sustainable development of resource-based cities and building a multi-dimensional development structure with stable, healthy, and resilient is the direction that needs long-term attention and research in the future.

Resilience effectively deepens sustainable urban development (Meerow,S. 2016; Sharifi,A. 2016). Resilience in cities generally refers to the ability to absorbing, adapting and responding to changes in an urban system(Godschalk, 2003;). Therefore, the resilience assessment for resource-based cities is an effective way to promote the transformation and help to put forward more targeted urban development strategies. However, there are no commonly applied quantitative approaches for measuring and assessing resilience (W.C. Chuang, 2018), and fewer of them take resource-based cities as the research object. Therefore, this paper aims to construct an urban resilience assessment model based on the adaptive cycle framework for RBCNC, which is beneficial for scientific measurement and classified guidance, through which planners could explore a more specific path of resilience transformation.

1.1. Urban resilience assessment

Urban resilience assessment can identify the differences in the resilience capacity of cities with different geographical distribution, spatial structure, development statuses, and help guide subsequent decisions. The existing research methods for building urban resilience assessment can be divided into quantitative, qualitative, and combination of them (W.C. Chuang, 2018). In the quantitative method, most research uses the structural-based modelling method to construct an assessment model (Zhang,L. 2021), It uses a statistical method to calculated and assigned the weight of resilience indicators. e.g., Cutter(2014) construct the Baseline Resilience Indicators for Communities (BRIC) model from 6 aspects (social, economic, housing and infrastructure, institutional, community, and environmental.) to measure the resilience of counties in the United States. Furthermore, some scholars use GIS to overlay the indicator data so that the specific value of resilience can be visually expressed (Luo,F. 2018).Qualitative research uses grounded theory and ethnography through a massive amount of field research, observation, and interviews to determine the resilience evaluation level of research objects, mainly applied to social resilience, cultural resilience, and other humanities and social sciences fields(Geoff, A.W. 2018). e.g., Morley(2018) using Community Disaster Resilience Scorecard to assess community resilience for two remote Australian communities. However, city as a complex social-ecological system, using only qualitative or quantitative methods is not comprehensive. Therefore, most of the existing studies on assessing urban resilience choose a combination of the two methods (Odeya,C. 2016; Claire, K. 2015; Yue Y. 2021). Generally, a literature review or questionnaire survey usually selects indicators, then uses statistical analysis to calculate the resilience score.

1.2. Adaptive Cycle Framework

Resilience has emerged as an attractive perspective to cities, often theorized as highly complex, adaptive systems (Batty, 2008; Meerow, S. 2016). The adaptive cycle is a key model within resilience theory (Allen, C.R., 2010). This theory believes that a dynamic system would undergo four phases (Holling, 1986), i.e., exploitation (r), conservation (K), release (Ω), and reorganization (α). Some researchers have used this theory to divide the resilience phases of social-ecological systems (Li,Y. 2017;). The adaptive cycle can be seen as two parts, the foreloop and the backloop. The foreloop, from r to k phase, is a slow growth and accumulation phase, the connectivity and stability increase gradually. The backloop, from the Ω to the α phase, is a rapid recombination and renewal phase. When the resource accumulation reaches its peak, the connectivity and potential will rapidly decrease to the lowest level and gradually recover to the new phase (Gunderson and Holling, 2002; Folke, C. 2006;).

In resource-based cities, in the exploitation phase(r), the resource industry and urban construction have gradually increased. The population and money began to accumulate and promote urban development.

Resilience is low due to the low connectivity and potential. However, the undeveloped resource reserves and healthy ecological environment also reduce the disaster risk, so characteristic of r phase is low-risk and low-resilience. With the continuous improvement of resource production capacity and rapid urban development, resource-based cities have entered the conservation phase (K), and the rapid accumulation of capital and resources temporarily makes them in a phase of high resilience. However, problems such as excessive resource exploitation and ecological environment destruction gradually derived from economic and social development, increasing cities' risk-bearing probability. When resources are exhausted and environmental problems are intensified, resource-based cities quickly enter the release phase (Ω), bearing a series of chronic and acute shocks such as lagging economic development, prominent social issues, ecological environment destruction and so on. At this time, urban vulnerability increases. The characteristic of Ω phase is high risk and low resilience. Intervention measures are urgently needed to enable resource-based cities to change the previous development mode, enter the reorganization phase(α), get rid of resource dependence, and step into a benign development track with low risk and high resilience.

2. Method

2.1. Study area

According to the Sustainable Development Plan for Resources-Based Cities in China, 19 prefecture-level administrative regions of three provinces in Northeast China are selected as the study area (FIG. 1).

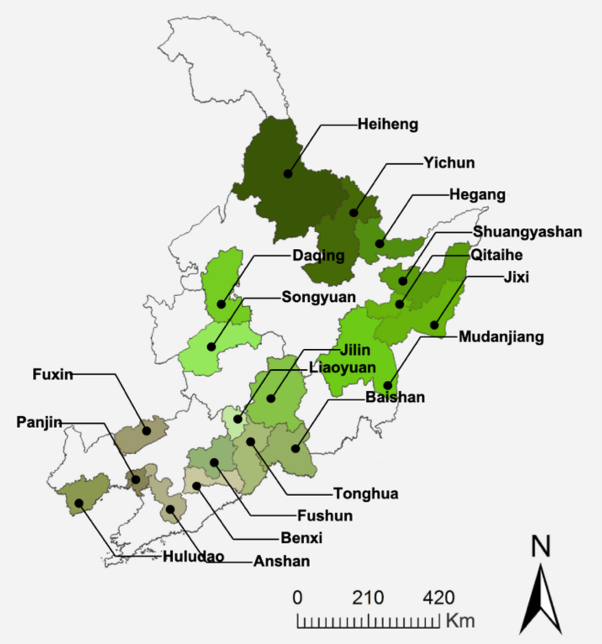

Figure 1. Location of study area.

The characteristics of RBCNC can be stated from four aspects: ecology, economy, society, and infrastructure. In terms of ecology, under the guidance of Chinese policies, the woodland area and forest coverage of RBCNC have increased steadily in recent years, but the total stock of living trees has not increased. There is still a large area of land in a state of abandonment. In addition, due to the over-exploitation of the mining area, the balance of ecosystem is seriously affected, and the regulation function of the forest is weakened. Facing natural disasters such as torrential rain, mountain torrents and debris flows, the newly planted trees have shallow roots and small crowns. It is difficult to form a good blocking effect, increasing the probability of disasters. The inappropriate way of resource exploitation and urbanization have also brought a lot of industrial wastewaters, gas, and underlying impervious surface, which further aggravated the deterioration of the regional ecological environment.

In terms of economy, the industrial structure of RBCNC is simple. e.g., The proportion of resource industries is about 80%, and their primary and tertiary industries are underdeveloped. Therefore, when the resource-based industry began to decline, the overall urban economy was seriously affected. In 2019, the GDP growth rates of three provinces in northeast China were 5.96%, 4.20%, and 5.95%, respectively, all lower than the national average of 7.79%.

In terms of society, after implementing the national urban transformation policy, most RBCNC have experienced significant changes in their social system, accompanied by the severe economic downturn, resulting in the loss of residents and a high unemployment rate. According to the sixth national census, more than 4 million people have left the three northeastern provinces. In addition, structural unemployment caused by the decline of the resource industry is far beyond cities' affordability.

In terms of urban infrastructure, RBCNC advocate land development and urban construction dominated by economic growth during the incremental construction period, which not only erodes the healthy natural environment and breaks the original ecological balance. Moreover, the rationality and safety of urban spatial layout are not considered, which makes the problems of transportation, housing, and public service facilities in the region frequently occur, making the cities more vulnerable to sudden disasters.

2.2. Data resource

The research data are all from the Total Urban Statistical Yearbook of China 2019, And Bulletin of Ecological and Environmental Conditions 2019, Climatic Bulletin 2019, Statistical Yearbook 2019, and Statistical Bulletin of National Economic and Social Development 2019 of the three North-eastern provinces. Due to the absence of individual data, the data are supplemented according to the values of adjacent years.

2.3. Conceptual framework

According to the characteristics of the four phases in the adaptive cycle framework, constructing the resilience and risk two-dimensional assessment framework. i.e., r phase, characterized by low resilience and low risk. K phase, high resilience and high risk; Ω phase, low resilience and high risk; α phase, high resilience and low risk. The horizontal and vertical coordinates represent risk index X and resilience index Y, respectively (FIG. 2). Selecting resilience and risk indicators based on the existing evaluation system combined with the characteristics of RBCNC. Principal component analysis (PCA) was used to define the evaluation system structure and quantify the indicators. Finally, Normalizing the results of the risk and resilience indicators and determining the resilience stage according to the adaptability cycle characteristics (FIG. 3).

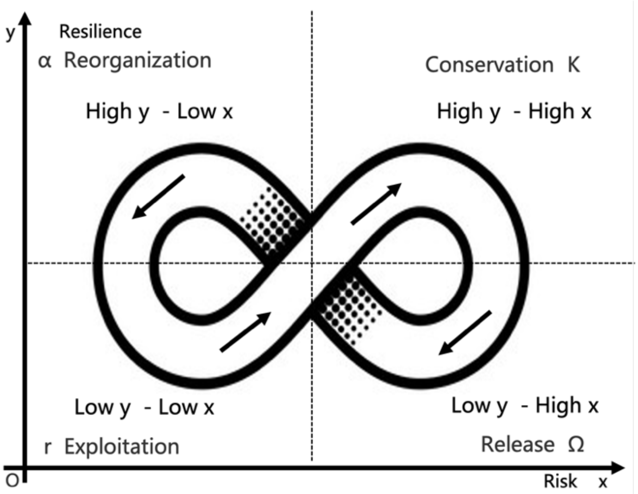

Figure 2. Resilience and risk two-dimensional assessment based on adaptive cycle framework

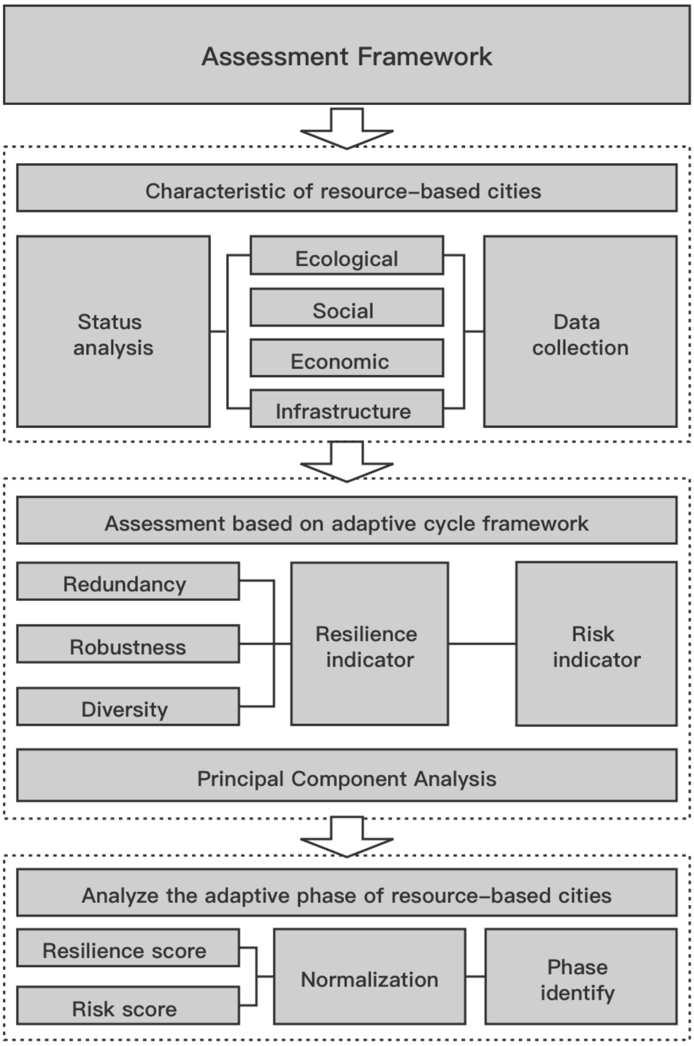

Figure 3. Analytical framework for urban resilience assessment of RBCNC

2.4. Constructing the assessment framework

By combing the existing research, combined with the above-mentioned characteristic factors of RBCNC, a total of 10 risk indicators and 37 resilience indicators are selected, including 14 redundancy indicators, 12 robustness indicators, and 11 diversity indicators. All indicators are positive, i.e., the higher resilience indicator score, the better the resilience. The higher the risk indicator score, the greater the risk the city will bear. Kaiser-Meyer-Olkin (KMO) is one of the validity tests of PCA. Kaiser (1974) recommends accepting values greater than 0.5 as acceptable. The KMO statistics obtained by SPSS of the RBCNC data are shown in Table 1, and the results are all acceptable for PCA.

Table 1. KMO of 19 RBCNC data

Categories	Risk	Redundancy	Robustness	Diversity
KMO	0.6	0.615	0.62	0.63

After calculating the initial factor load coefficient (F_{ij}) of each indicator by SPSS, the linear combination coefficient (a_{ij}) is calculated as follows:

$$a_{ij} = \frac{f_{ij}}{\sqrt{\lambda_j}}$$

In the formula, f_{ij} is the factor loading of the i-th indicator in the j-th principal component, and λj is the initial characteristic root of the j-th principal component.

And the weight of indicators can be calculated by the following formula:

$$W_i = \sum_{j=1}^{k} a_{ij} \cdot E_j$$

In the formula, E_j is the variance contribution rate of the j-th principal component.

Then the initial weights were normalized by the following formula:

$$W_i' = \frac{W_i}{\sum_{i=1}^{p} W_i}$$

Finally, The PCA results and variance contribution rate are shown in Table 2. The weights of resilience and risk assessment are shown in Table 3 and Table 4. Bring in the standardized data and get the final score.

Table 2. PCA results and variance contribution rate of resilience and risk indicators

Categories	Cumulative contribution rate (%)	principal components	variance contribution rate (%)
Risk	82.28	1	25.063
		2	21.642
		3	18.553
		4	17.026
Redundancy	86.843	1	47.611
		2	16.652
		3	13.475
		4	9.106
Robustness	82.623	1	39.153
		2	15.907
		3	15.682
		4	11.881
Diversity	78.007	1	29.084
		2	21.051
		3	13.948
		4	13.924

Table 3. The initial and normalization weights of resilience indicators

Categories	Indicators	Initial weights	Normalization weights
Redundancy	number of hospital beds (bed)	0.240	0.094
	number of large wholesale and retail (units)	0.254	0.099
	household deposit balance (10k yuan)	0.184	0.072
	total postal business (100m yuan)	0.206	0.081
	number of practicing physicians (persons)	0.245	0.096
	number of hospitals (units)	0.258	0.101
	number of social service facilities (units)	0.193	0.075
	number of large hotels and restaurants (units)	0.179	0.070
	length of highway(km)	0.179	0.070
	total water resources (100m m3)	0.035	0.014
	number of health facilities (units)	0.224	0.088
	total telecom service (100m yuan)	0.019	0.007
	employment in social security facilities (persons)	0.215	0.084
	per capita housing floor area (m2)	0.123	0.048
Robustness	per capita disposable income (yuan)	0.191	0.100
	number of lighting facilities (lamps)	0.191	0.100
	government public financial revenue (10k yuan)	0.197	0.103
	per capita gdp (yuan)	0.200	0.104
	total retail sales of consumer goods (10k yuan)	0.190	0.099
	density of drainage pipe in built-up area	0.124	0.065
	standing wood stock(10k m3)	0.107	0.056
	forest coverage (%)	0.085	0.045
	the proportion of medical insurance (%)	0.148	0.077
	growth rate of regional fixed asset investment (%)	0.230	0.120
	natural growth rate (%)	0.058	0.030
	the proportion of old-age insurance (%)	0.194	0.101
Diversity	senior high school (units)	0.185	0.135
	sports center (units)	0.232	0.170
	one hundred households own automobiles	0.007	0.005
	universities (units)	0.287	0.209
	the proportion of tertiary industry (%)	0.054	0.039

	the proportion of forest land (%)	0.155	0.113
	the proportion of wetland (%)	-0.056	-0.041
	museums (units)	0.189	0.138
	the proportion of nature reserves (%)	0.089	0.065
	libraries (units)	0.151	0.110
	green coverage rate in built-up area (%)	0.076	0.055

Table 4. The initial and normalization weights of risk indicators

Categories	Indicators	Initial weights	Normalization weights
Risk	the proportion of urban construction land (%)	0.176	0.191
	the proportion of days with substandard air quality (%)	0.198	0.215
	the proportion of primary industry (%)	-0.206	-0.224
	so^{2} emissions (10k tons)	0.269	0.292
	unemployment rate (%)	0.100	0.109
	the proportion of employed in resource-based industries (%)	-0.245	-0.266
	discharge of industrial wastewater (10k tons)	0.202	0.219
	the proportion of land in flood areas (%)	0.083	0.090
	maximum annual precipitation (mm)	0.136	0.148
	slope	0.207	0.225

3. Results

3.1. Urban resilience analysis

The urban resilience indicators scores of 19 RBCNC are shown in figure 4. It can be seen that Jilin has the highest scores in redundancy and diversity, Panjin has the highest robustness score. Qitaihe has the lowest scores in redundancy and diversity, Shuangyashan has the lowest robustness score. There is a big gap in the results of the three resilience indicators of 19 RBCNC, and the differences are 3.14, 2.09, and 2.59 for redundancy, robustness, and diversity, respectively. The results of the above indicators were superimposed to obtain the total resilience score (FIG. 5). The highest score is Jilin (4.7), and the lowest is Qitaihe (-2.2), the inflection point of 19 RBCNC is at Tonghua (0.5), and the difference between Tonghua and Mudanjiang is 0.89. Therefore, four cities with scores above 0.5, namely, Jilin, Daqing, Anshan and Mudanjiang, can be identified as high resilience abilities, while the other 15 cities are low resilience abilities.

The transformation of four cities with higher resilience abilities was earlier and more successful. e.g., Daqing, which takes petroleum as its pillar industry, has gradually reduced its oil reserves due to excessive exploitation of resources in the past few years and caused disasters such as subsidence and water pollution. However, In the process of transformation of the past five years, the industrial structure of Daqing city has been optimized continuously. The proportion of the secondary industry has decreased from 58.4% (2016) to 46.7% (2020), and the proportion of the tertiary industry has increased from 34.4% (2016) to 42.7%

(2020). Increase wetland, forest parks and other nature reserves to protect the ecological environment and promote the development of tourism. On the contrary, Qitaihe still takes coal as its pillar industry. Due to the rise of new energy industry and the decline of original coal reserves, the urban economy has suffered a considerable blow, followed by the loss of residents and a high unemployment rate. According to the national census, from 2010 to 2020, the population decreased by 25.08%, and the average annual growth rate was -2.85%.

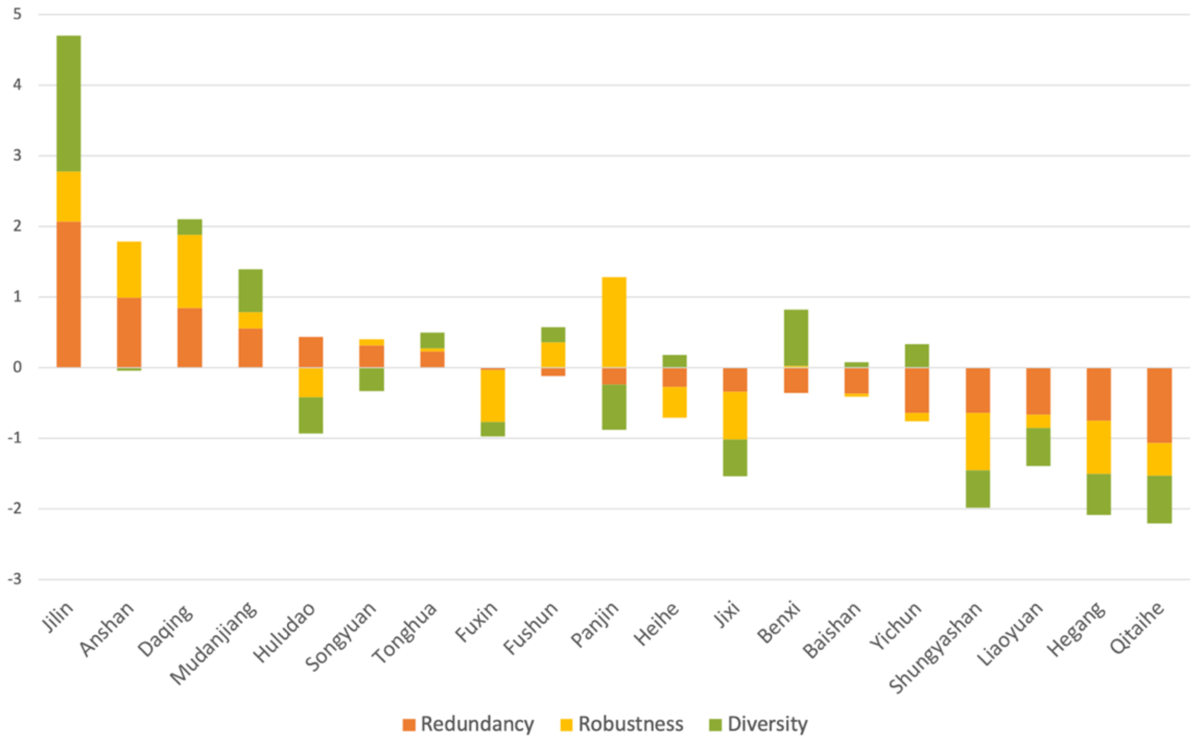

Figure 4. The urban resilience indicators scores of 19 RBCNC

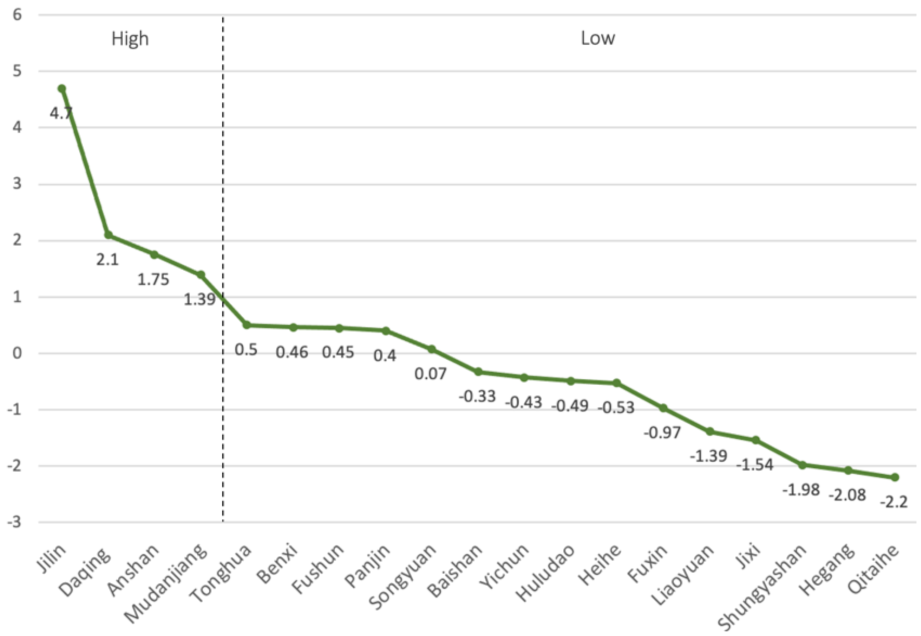

Figure 5. Overall resilience indicator scores rank and analysis of 19 RBCNC

3.2. Risk analysis

The risk indicator scores of 19 RBCNC are shown in figure 6. Qitaihe has the highest score (2.06), while Daqing has the lowest score (- 1.88). The inflection point of risk indicator score of 19 RBCNC is Yichun (0.09), and the difference is 0.65. Therefore, seven cities with a risk score greater than 0.09 can be considered high-risk, while the remaining 12 are considered low-risk. It can be seen that the overall trend of the risk indicator score is slightly better than the resilience indicator, and the results are opposite, i.e., cities with higher resilience scores have lower risk scores and vice versa. Among them, Qitaihe, Shuangyashan, Jixi, and Hegang face increased risks and have low resilience abilities. If appropriate measures are not timely adopted to intervene, it is likely to lead to the decline of the entire urban system.

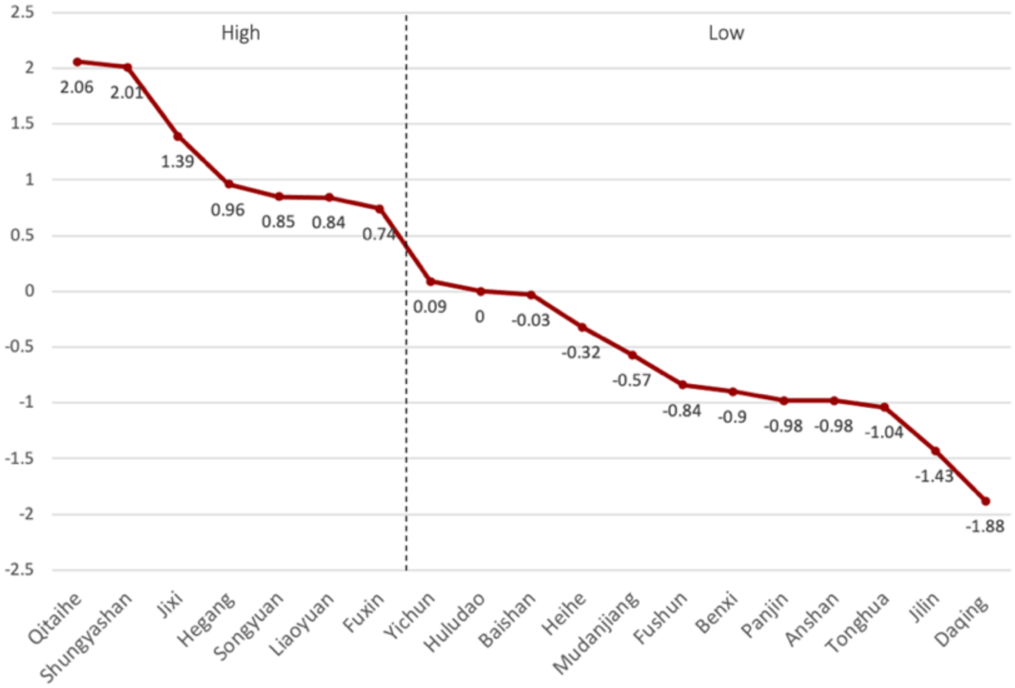

Figure 6. Overall risk indicator scores rank and analysis of 19 RBCNC

3.3. Adaptive cycle phases identification

Based on the resilience and risk indicators, the resilience phases of 19 RBCNC are identified based on the adaptive cycle theory (FIG. 7). It can be seen that there are 4 cities in the reorganization phase (α), i.e., high-resilience and low-risk scores. In this phase, the resource-based industries have been successfully transformed. The cities develop steadily and upward and beer less development risk. 8 cities are in the exploitation phase (r), i.e., both resilience and risk scores are low. It shows that the urban resource-based industry is still in the rising stage at this time. As the urban development is still in the early stage and the social and economic level is low, the resilience of the city is below the middle level. With the continuous accumulation of various elements, future development will face great risks. And there are 7 cities in the release phase (Ω), i.e., low-resilience and high-risk scores. In this phase, the urban system bears multiple pressures from social, economic, and ecological issues. The vulnerable urban system makes its resilience to the lowest level, accompanied by high risks. The identification results show no cities in the conservation phase (k), i.e., both high resilience and risk scores. Among them, the characteristics of Songyuan tend to the k phase, but due to the decline of resilience abilities, it finally moves towards the Ω phase.

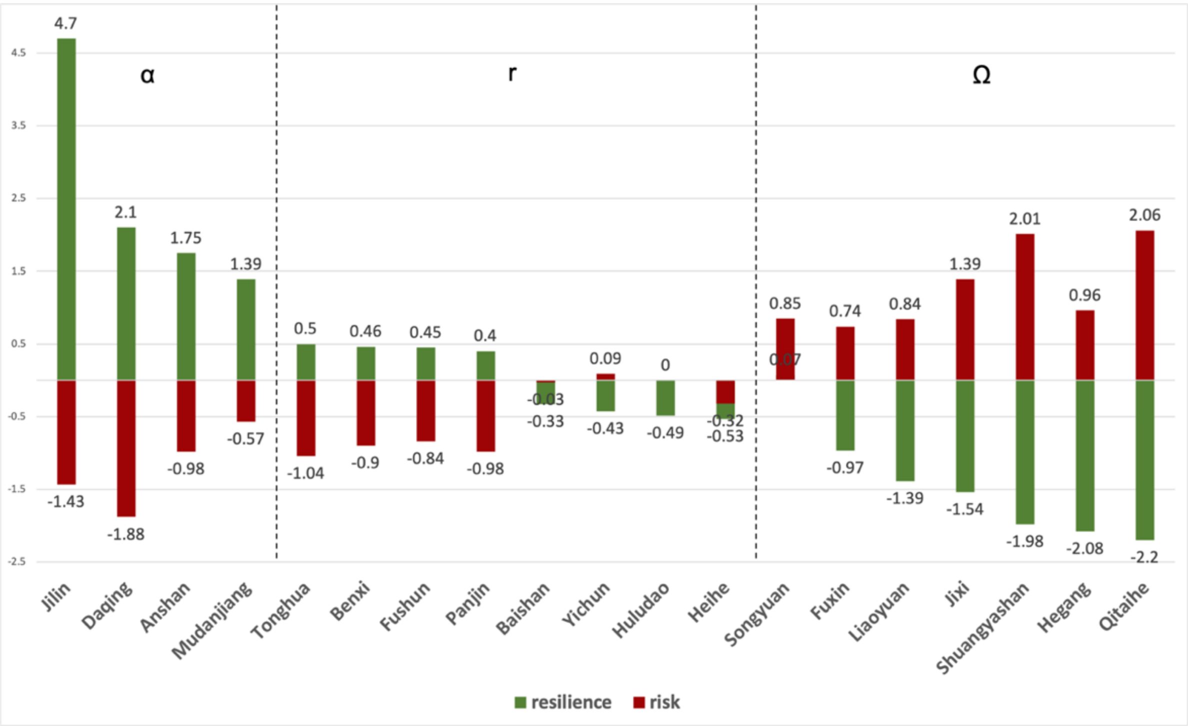

Figure 7. Resilience phases of 19 RBCNC identification based on the adaptive cycle theory

4. Discussion

The corresponding transformation path analysis is put forward according to the identification of the resilience phases of 19 RBCNC mentioned above. In general, the transformation path of RBCNC can be considered from two aspects: risk response and resilience improvement. RBCNC in the α-phase can be used as successful cases to share transformation experiences and methods with cities in other phases. RBCNC in the r-phase should keep more focus on improving resilience and maintaining low risk. The Ω-phase cities with low resilience and the most significant problems should be given priority to transition, taking into account the improvement of resilience and risk response.

4.1. Strategies for enhancing urban resilience for RBCNC in different phases

Cities in different adaptive cycle phases have different resilience promotion strategies. For the α-phase RBCNC such as Jilin and Daqing, which have been successfully transformed and almost eliminated the resource-dependent development mode. Therefore, the resilience enhancement strategies should deepen the urban transformation from a more open and innovative perspective and gradually enter a new adaptive cycle, showing an upward spiral trend. Specifically, to further improve the quality of economic development, strengthen foreign economic and trade, relax policies for enterprises and investors. At the same time, focus on fostering high-tech industries, developing sustainable renewable resource industries with potential for development, and accumulating more efficient and sustainable social capital to achieve the goal of enhancing resilience. The RBCNC in the r-phase (e.g., Yichun and Heihe) should accelerate the upgrading of industrial structure and form the redundancy of resources and capital, pay more attention to the green and innovative development of resource-based industries, extend the industrial chain. Coordinate the relationship between urban development and ecological environment, ensure the sustainability of urban development, and gradually improve resilience; For RBCNC in the Ω-phase (e.g., Qitaihe and Hegang), resilience enhancement should be combined with risk response. A series of urban problems and risks caused by rapid decline should be resolved first, and urban renewal and reconstruction should be carried out with resilience development as a long-term goal. The declining resource-based industries should be rapidly transformed by technological innovation and increasing alternative industries. At the same time, the national government should provide policy feedback from both resource and capital, quickly restore the redundancy of resource-based cities, reduce the additional pressure caused by rapid transformation, and help soon get out of the release phase.

4.2. Risk management strategies for RBCNC

RBCNC should improve the urban infrastructure and service facilities in terms of risk response and build an interconnected urban network. Resources and capital can be quickly mobilized and used flexibly when faced with risks. Moreover, paying attention to coordinating the relationship between ecological civilization and social-economic development, building a more ecologically livable urban environment, maintaining the balance of regional ecosystems, and forming a natural barrier against risks. In addition, for RBCNC in the Ω-phase, it is necessary to speed up the transformation of old urban areas and strengthen the comprehensive management of areas with hidden disasters. Carrying out reclamation and ecological restoration of abandoned mining and urban areas wasteland to ensure a good ecological system. Reduce the risk of natural disasters caused by over-exploitation of resources.

5. Conclusion

This study combined qualitative and quantitative research methods to build a resilience assessment of 19 RBCNC based on the adaptive cycle. Results show that there are 4 cities in the α-phase, 8 in the r-phase, 7 in the Ω-phase, and no city in the k-phase. Then, based on the identification results, detailed and differentiated urban planning strategies are proposed from two aspects of urban resilience enhancement and risk management respectively. In addition, this study can only identify the resilience phases of RBCNC in the year of data. The time-series changes of urban resilience due to the dynamics of the adaptive cycle are not considered, which requires to deepen study in the future.

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