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Research

Assessment of urban resilience based on the transformation of resource-based cities: a case study of Panzhihua, China

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ABSTRACT. Long-term development of resource utilization has caused a series of economic, social, and ecological problems in resource-based cities (RBCs). Thus, in pursuit of sustainable urban development, many RBCs have begun seriously pursuing urban transformation and have achieved good results. However, the RBCs' urban resilience also exhibits evident stage characteristics throughout the processes of urban transformation. Herein, we constructed an evaluation index system to measure the urban resilience of Panzhihua, China and analyzed the resilience time-varying characteristics and influencing factors from 2000 to 2016. The results show that: (1) after undergoing urban transformation, changes in Panzhihua's resilience can be divided into three stages consisting of a slow rising period (2000-2005), a rapidly fluctuating rising period (2006-2010), and a stable development period (2011-2016). (2) Among the four divisions of urban resilience, the largest changes were found in the infrastructure and environment, and economic and social categories; only relatively small changes were observed in health and well-being, and government management capabilities. Nevertheless, all showed an upward trend. (3) Among the 12 indicators, transportation and communication, social security, education development, and comprehensive development ability were found to be closely linked to urban resilience. (4) Under the influence of urban transformation, RBCs' resilience greatly fluctuates, likely in response to actively transitioning the urban system from its previous state to its current state. Our study demonstrates that there is a high degree of correlation between the RBCs' life cycles and adaptation cycles.

Key Words: *adaptive cycle; resource-based cities; urban resilience; urban transformation*

INTRODUCTION

Urban transformation of resource-based cities

Transformation and sustainable development are important issues for resource-based cities (RBCs). The abundance of resources have played an important role in the economic development of RBCs. Thus, RBCs are highly dependent on raw material industries, such as mining and natural resource processing, e.g., minerals and forest wood (Jiao and Lu 2000). However, a series of social, economic, and ecological problems have emerged in RBCs throughout China, in response to unsustainable exploitation of natural resources for economic development. From the perspective of disturbance types of resilience, the problems faced by China's RBCs can be divided into two categories: stresses and shocks. The stresses mainly include: monotonous industrial structure, insufficient capacity of technological innovation, gradually exhausted resources, insufficient impetus of sustainable economic development, increasing number of unemployed and poor people, social security is under great pressure, and environmental pollution is becoming more and more serious. The shocks mainly include: geological disasters, heavy rain, and high temperature, etc. (Zhang 2010, Liu et al. 2011). At present, RBCs are mainly subjected to stresses. These long-term stresses or sudden shocks make the RBCs' urban system more fragile and less adaptable to shocks and changes. To promote sustainable development, many RBCs are applying urban transformation, a method in which an area's economical, societal, and spatial characteristics are used to guide industrial restructuring, as well as to cultivate and expand alternative industries. In the process of urban transformation, some of the RBCs' economies and societies are revitalized. However, because of the superposition of internal and external factors and the interweaving of old and new contradictions, RBCs have little endogenous motivation for promoting sustainable development. As such, facilitating urban transformation is very problematic.

During the development of RBCs, with the resource exploitation's phase variation, RBCs' socioeconomic environment and economic structure also exhibit evident periodic changes. In response, scholars have devised a four-stage classification scheme that includes: development, growth, maturity, and stable periods (Mao and He 2008). Similarly, Ding and Zhang (2008) promoted the idea that RBCs' development generally progresses through periods of development, maturity, decline, and transformation and Fan (1993) assigned five stages to coal RBCs using a mathematical method. However, the above RBCs' development schemes are mostly based on the exploitation and utilization of a single resource. Mao and He (2008) extended their research scope and constructed a new life cycle model considering comprehensive resource exploitation. They proposed that the RBCs' life cycle is a rising spiral. Essentially, as resource exploitation entered the recession stage, a new type of resource exploitation began. In this way, RBCs' economic development will enter a new growth period.

Resource-based cities can be divided into different types according to the resource exploitation phase. Classifying RBCs into specific types helps elucidate the city's development direction and define key tasks. Resource-based cities' development is based on the supply of natural resources. Because resource exploitation is periodic (Han and Wan 2014), many scholars classify the RBCs according to their level of maturity. Ding and Zhang (2008) tried to divide the RBCs into three types: growing, grown-up, and

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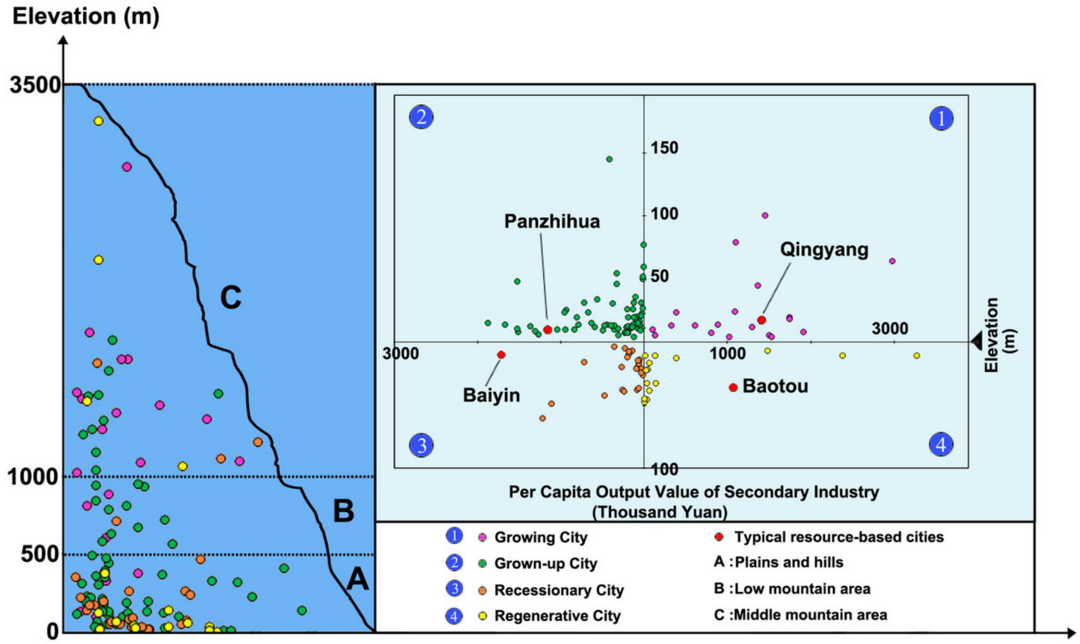
Fig. 1. Distribution of different elevations and different types of RBCs.



transformation or recession cities. Other classification methods include: the type of resource exploitation, e.g., coal, oil, metallurgical, or forest industry RBCs (Dong et al. 2007); implementation of resource exploitation processes, e.g., "city before mining" and "city after mining" (Liu and Wang 2009); and city size, e.g., mega, large, medium-sized, and small (Dong et al. 2007). These different classification methods all reflect the resource dependence and long-term development of RBCs.

In 2013, The Chinese government issued "The National Sustainable Development of Resource-based Cities," in which RBCs are divided into four types based on urban transformation: growing, grown-up, recessionary, and regenerative. This classification scheme attempts to emphasize that certain cities have alleviated their resource dependency after transformation into recessionary cities, which highlights the effect of RBCs' urban transformation and the pursuit of sustainable development. In terms of different RBC types, growing RBCs have a low economic development level, a high economic development potential, and a high dependence on resource. Grown-up RBCs have a relatively high level of economic development and a stable urban system, whereas recessionary RBCs cannot provide lasting impetus for the development of the urban system with backward development. Regenerative RBCs, on the other hand, revitalize the society and economy, and enter a new development track through urban transformation. The development phase of different types of RBCs, such as growing, grown-up, recessionary, and regenerative reflect the adaptive cycle and the path evolution of system resilience from rapid growth, maturity, decline, and transformation (i.e., entering a new stable state).

"The National Resource-based Cities Sustainable Development Planning (2013-2030)" states that there are 126 municipal RBCs in China, and that the resource-based cities are divided into four types based on differences in resource protection stringency and sustainable development capability: growing, grown-up, recessionary, and regenerative (Fig. 1). Grown-up RBCs represent the largest fraction, accounting for 52.38%. With respect to vertical spatial distribution, RBCs are concentrated in the plains and hilly areas. The number of plain RBCs accounted for 64.29%, whereas mountain RBCs accounted for 35.71%. As the elevation gradually increases, the number of RBCs decreases in parallel. The mountain RBCs face greater pressure than those of the plains because of the specificity and complexity of the geographical environment.

Different types of RBCs exhibit different levels of resource exploitation, economic and social development, and conflicts and challenges. Two indicators, elevation and secondary industry output value per capita, were used to graph the distribution of the four RBC types. Herein, we have chosen Panzhihua and three other relatively similar RBCs that belong to different types, and we have compared the economic and social development, population density, economic density, and industrial structure, etc. The results show that all of the indicators are strongly consistent with the degree of resource exploitation (Table 1). As the resource exploitation degree fluctuates from "rising→stable →recession→regeneration," the indicators of all four RBCs also reflect a "rising→higher→falling→rising again" trend. We tried to use the industrial structure of four RBCs as an example; the output value of the secondary industry accounts for a high proportion of GDP in RBCs industrial structure, but the output value of the secondary industry accounts for a different proportion in different types of RBCs. The proportion of secondary industry in grown-up RBCs is higher than that in growing RBCs. The proportion of secondary industry in recessionary RBCs has a falling trend whereas the proportion in regenerative RBCs rises again. Regenerative RBCs have

Table 1. Comparison of the basic situation of different types of resource-based cities (RBCs; 2019).

Types	Growing	Grown-up	Recessionary	Regenerative
Resource exploitation stage	rising	stable	exhausted	basically get rid of resource dependence
Typical RBC	Qingyang	Panzhihua	Baiyin	Baotou
Elevation of the seat of government (m)	1409	1156	1723	1065
Per capital GDP (Yuan)	32,690	82,500	27,990	93,835
Industrial structure	12:50:38	9:55:36	18:37:45	4:39:57
Input intensity of R&D (2018)	0.07%	1.43%	1.08%	0.004%
Per capita disposable income (Yuan)	32,107	41,864	31,769	44,748
Population density (people/km²)	84.03	145.66	82.27	104.33
Economic density (10,000 yuan/km²)	273.96	1357.7	229.85	977.56
Characteristics of economic and social development	high potential	high level	backward	revitalized

undergone a transformation, and the proportion of secondary industry is relatively low whereas the proportion of tertiary industry is relatively high. Because of the significant development potential, growing RBCs' economic development occurs during the rising period; followed by relatively high economic and social development during the grown-up RBCs. Recessionary RBCs experience economic decline and development lag, whereas regenerative RBCs undergo a new rising stage in response to economic and social development transformation.

For many years, RBCs' research has focused on specific, individual city's subsystems that contribute to and strongly impact the whole, e.g., economic and industrial development, social development, community construction, urban planning and design, and public policy implementation (Liu et al. 2011). However, less attention has been paid to the resilience of RBCs from the standpoint of a complete and cohesive urban system. Because of the unique development environment and economic foundation, RBCs resilience is greatly affected by volatility and obvious characteristics of development. Thus, investigating RBCs resilience can elucidate the periodic changes encountered by developing RBCs. As such, analysis of the periodic resilience characteristics, development tendency, and key influencing factors aids in determining the resilience mechanism in long-term development of RBCs and exploring the associated development principles.

Assessing urban resilience

The concept of urban resilience

"Resilience" is an ecology term that emerged in the 1970s to describe the ability of an ecosystem to maintain or recover its functionality following exposure to damage or disturbances (Holling 1973). As research on resilience expanded, investigations have evolved from ecological resilience to engineering resilience, and ultimately to social-ecological resilience (Table 2; Sun et al. 2007, Shao and Xu 2015). Cities, as social-ecological systems, are becoming increasingly complex and fragile. Social-ecological resilience, which emphasizes comprehensive feedback and cross-scale dynamic interaction, provides an innovative contribution to urban development and governance.

Table 2. The system state reflected by different resiliences.

Type	System state
Engineering resilience	Cities absorb changes or stresses and return to the previous state (Holling 1973)
Ecological resilience	The ability of a city to adapt to shocks or disasters without seriously damaging existing structures and relationships (Holling 1996, Pickett et al. 2004)
Social-ecological resilience	Urban systems are constantly adapting, learning, and transforming to cope with change (Folke et al. 2010, Davoudi et al. 2012, Wilkinson 2012)

Related studies have put forward numerous and varied definitions of resilience, which have been organized into four categories (Zhou 2016) consisting of: ability recovery theory, disturbance theory, system theory, and empowerment theory. Two typical, commonly used definitions were advanced by the Rockefeller Foundation (2014) and the Resilience Alliance (2015; Ilmola 2016). The Rockefeller Foundation defined urban resilience as the capacity of individuals, communities, institutions, businesses, and systems within the city to survive, adapt, and grow despite experiencing chronic stresses and acute disturbances. The Resilience Alliance defined resilience as the ability of a system to absorb disturbances and reorganize in response to the changes, while essentially retaining the same function, structure, identity, and feedbacks (Holling 1973, Walker et al. 2004). Table 3 compares these two definitions from the perspective of subjects, objects, and responses. As shown, the Resilience Alliance treats the urban systems as a whole; acknowledges that city development is encountering disturbance, but does not explicitly state the intensity and duration; and places more emphasis on the ability of the urban system to maintain its original state. In contrast, the Rockefeller Foundation focuses primarily on the urban system components, such as individuals, communities, and institutions; acknowledges the presence of disturbance and describes the intensity and duration with descriptors such as "chronic" and "acute"; and emphasizes the urban systems' ability to adapt, change, and further develop in response to gradual and sudden disturbances.

Table 3. Varied interpretations of urban resilience definitions based on perspectives.

Organization	Rockefeller Foundation	Resilience Alliance
Subject	Individuals, communities, institutions, businesses, and systems	Urban system
Object	Chronic stresses and acute shocks	External disturbances
Response	Survive, adapt, and grow	Maintains its original features, structure, and key functions

Modern urban resilience research

Most contemporary urban resilience research concerns urban ecosystems resilience (Holling 1996, Yan et al. 2012), urban disaster resilience (Hobor 2015, Koren et al. 2017, Rus et al. 2018), urban economic resilience (Hill et al. 2008, Simmie and Martin 2010, Leichenko 2011), and urban social resilience (Adger 2000, Swalheim and Dodman 2008). Urban ecosystem resilience considers the whole city as an ecosystem. Thus, numerous ecological indicators are selected to establish an evaluation index system, which is used to build a comprehensive evaluation model and to calculate the city's resilience (Wang and Lu 2011, Wang et al. 2015). Cities face both acute shocks and chronic pressures during development; although most urban resilience studies focus on the sudden shock aspect, such as floods (ADB 2016), earthquakes (Guo 2012), extreme climatic events (Duxbury and Dickinson 2007), and hurricanes (Hobor 2015). In addition, other studies target persistent, long-term changes, such as sea-level rise (Abdrabo and Hassaan 2015) or climate change (Wang et al. 2016, Fang et al. 2021). In studies investigating urban economic resilience, the city is regarded as a complex and diverse self-organizing system, in which resilience is explored with respect to the whole city, region, or industrial system. Furthermore, urban economic resilience can be divided into dynamic and static economic resilience (Rose 2007), which are distinguished based on the ability or speed of the urban system to return to its original state. Urban social resilience is mainly studied in the context of social governance and institutional resilience in which the role of community participation and civic organizations is emphasized (Oliva and Lazzeretti 2017).

Assessment of urban resilience

The assessment of urban resilience should be based on the interaction of system vulnerability and coping capacity. Under these circumstances, the results are more conducive to aiding in social-ecosystem track identification, and thereby promoting favorable system development (Wang 2008, Wang et al. 2016). The assessment of resilience can be divided into two categories: qualitative and quantitative. Qualitative methods tend to assess the system's resilience without using statistical data, by providing a conceptual framework or using semi-quantitative indicators. The Resilience Alliance put forward a resilience assessment framework that includes five main stages consisting of: (1) describing the system, (2) understanding system dynamics, (3) probing system interactions, (4) evaluating governance, and (5) acting on the assessment. The actual process is iterative and reflexive at each stage and requires referring back to earlier steps and revising as necessary. Jabareen (2013) established a basic pluralistic theoretical approach mainly consisting of vulnerability analysis, urban governance, protection, and uncertainty-oriented planning. Ainuddin and Routray (2012) proposed a community resilience framework that includes: (1) identifying disaster types and characteristics; (2) identifying individual or community vulnerability; (3) risk prevention awareness; and (4) improving social, economic, and material resources. The qualitative assessment method can be summarized as a scenario analysis method (Gallopín 2006), which is a comprehensive analysis and interpretation of resilience based on an in-depth understanding of system characteristics and evolution pathways. However, because of the limitations of the evaluators' understanding of the concept of resilience, experience cognition and understanding of regional social and economic development, the accuracy of the qualitative measurement results of resilience may be affected during the implementation of qualitative assessment. Moreover, because qualitative description cannot quantitatively grade resilience, comparison between regions cannot be made, thus limiting the use of the qualitative assessment method (Zhao and Fang 2017).

Quantitative methods include the general resilience evaluation method and the structural-based modeling method (Hosseini et al. 2016*a*). The general resilience evaluation method is through select indicators, which construct an evaluation system to calculate the score of resilience. Because of the different connotation definition and research perspective, there are many different dimensions to construct the index system. The Rockefeller Foundation (2015) divides urban resilience into the following four categories: health and well-being of individuals (people), economy and society (organization), urban systems and services (place), and leadership and strategy (knowledge). Each category comprises three indicators and numerous sub-indicators. Abdrabo and Hassaan (2015) proposed five resilience indicators including socioeconomic, physical, environment, institution, and climate change. Cutter et al. (2008) identified the following five indicators as the resilience expression of settlements to natural disasters: economy, infrastructure, society, community capital, and system. Bruneau et al. (2003) proposed a technically-organization-society-economy (TOSE) framework, which has been cited by many scholars, and on this basis, sub-indicators are selected to conduct urban resilience assessment. As for the structural-based modeling method, this is mainly to study the structural system from the perspective of a mathematical model. Fang et al. (2019) used the structural dynamics method to analyze how permafrost influencee the resilience of a social-ecological system in the region of the Yangtze and Yellow rivers. A correlation study characterizes structural-based models into three kinds of approaches: optimization models, simulation models, and fuzzy logic models (Hosseini et al. 2016*a*). Hosseini went on to further develop a Bayesian network model, which can be used to quantify the resilience of supply chains and infrastructure (Hosseini and Barker 2016, Hosseini et al. 2019). A Bayesian network provides insights to achieve a specific level of resilience (Hosseini et al. 2016*b*).

At present, research on resilience is currently transitioning from qualitative to quantitative methodology (Zhao and Fang 2017). In essence, the quantification of urban resilience is applied to plan the mitigation, adaptation, and recovery of urban physical systems, whereas the evaluation is aimed at better understanding what makes cities more resilient (Bozza et al. 2017). As social-ecological systems, cities will undergo reorganization(α), exploitation (r), conservation (K), and release (Ω) phases, which ultimately constitute an adaptive cycle (Holling 2001). Resilience is one of the attributes of the adaptive cycle, and it is also the attribute of the development process of the social-ecological system of city. With the running of the system, it constantly changes, showing different states, such as strengthening or decreasing. Panarchy refers to adaptive cycles connected on multiple scales (Gunderson and Holling 2002). Through the assessment of resilience, we can not only better understand what make cities more resilient (Bozza et al. 2017), but we can also distinguish at which stage the city is in an adaptive cycle, and what is its next development trend, and thus provide adaptive countermeasures for urban governance and to promote sustainable urban development (Tanner et al. 2009). However, due to the complex characteristics of the social-ecological-economic system, such as nonlinear, feedback loops and multi-dimensional space-time scales (Sun et al. 2007), using quantitative models to assess resilience is still lacking; despite the fact that many researchers have tried to combine applicable factors from dynamics, economics, ecology, geography, and other disciplines to build a series of resilience models.

The purpose this study is to promote the healthy and sustainable development of RBCs (Liu et al. 2011) by evaluating and potentially improving RBCs resilience. Therefore, we chose Panzhihua, a typical RBC, as the study object, built a resilience evaluation system, and explored the evolutionary trend and key influencing factors before and after urban transformation. We believe the results of our study can help decision makers improve the RBCs' ability to resist, recover, and adapt to shocks and disturbances; reduce the social-economic-ecosystem vulnerability, and ultimately improve RBCs sustainable development.

METHOD

Study area

Justification for the study area selection
Panzhihua, a grown-up RBC, is the study object, from the years 2000 to 2016. It was selected based on the following criteria:

1. Characteristics of a typical RBC: Panzhihua has the topographic characteristics of a mountain environment, and resource exploitation serves as the leading industry. Thus, it has the dual attributes of a mountain city and resource-based city.
2. Adequate development maturity: Panzhihua has been developing as an RBC since 1965. As a typical, mature RBC, it has experienced development and growth periods, and thereby exemplifies development maturity. Furthermore, it has achieved good results in urban transformation. Although development has taken place over a reasonably long period, we chose 2000 to 2016 as the study period, which covers a relatively complete pre-transformation, in-transformation, and post-transformation process from recession-transformation-new development. Therefore, it is appropriate to study the urban resilience in the transformation period.
3. Successful urban transformation implementation: Panzhihua attempts to implement urban transformation by increasing scientific and technological investments, carrying out comprehensive resource exploitation and utilization, and adjusting the industrial structure. Furthermore, it has achieved good results in comprehensive resource utilization and ecological protection, and therefore represents the successful application of the RBC transformation model.
4. Clarity of research time point: in 2004, Panzhihua became one of China's top 10 cities with heavy pollution because of the extensive use of resources without paying attention to the protection the environment. Since then, the urban transformation of Panzhihua has become a hot topic of discussion. By 2016, the air quality of Panzhihua was good all year round. Thus, 2004 and 2016 can be treated as the specific time points of transformation, and for the convenience of comparison before and after transformation, we extended the study period to 2000. Thus, we finally determined the study period to be from 2000 to 2016.

Study area characteristics
Panzhihua is located in the southern Sichuan province of southwestern China (Fig. 2) and is characterized by a dry, sub-south subtropical climate that grades into a northern temperate climate, consisting of heavy and concentrated rainfall, and a high evaporation rate. The city contains copious hydropower resources as well as a wide variety of wildlife and is rich in important mineral resources, which provide iron for steel, and vanadium and titanium for the energy industry. As mentioned above, Panzhihua has the dual characteristics of an RBC and a mountainous city.

Panzhihua's large-scale construction began in 1965 and was subsidized by its rich mineral resources. Developing in accordance with the philosophy, "production first, live second," after more than 50 years of construction, Panzhihua has grown into an important new industrial city and energy base. In 2018, Panzhihua consisted of three districts and two counties with a total land area covering 7440 km². The total population was 1.0834 million, the urbanization rate was 66.59%, and urban residents' per capita disposable income increased each year. By the end of 2018, the city's GDP reached 117.352 billion yuan (Fig. 3). However, developing the economy also resulted in poorly designed industrial structures, inadequate infrastructure, and destruction of the environment; all of which had a negative impact on attempts at sustainable development. To resolve existing urban development complications and promote sustainable development of RBCs, in 2004, the government enacted a variety of measures to modify single industrial structures, promote renovation and modernization of traditional industries, and implement ecological restoration and environmental improvement. In addition, a new "health care and tourism" industry was developed, which relies on the strong, local sunlight resource. In 2017, Panzhihua achieved a 15.1% revenue increase in tourism compared to the year before and was named National Garden City and National Forest City by the government of China. Thus, Panzhihua's urban transformation has accomplished some remarkable achievements.

Fig. 2. Location of Panzhihua in the Sichuan Province.

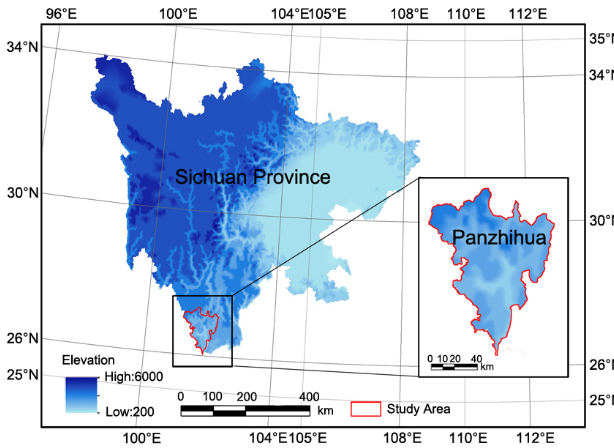
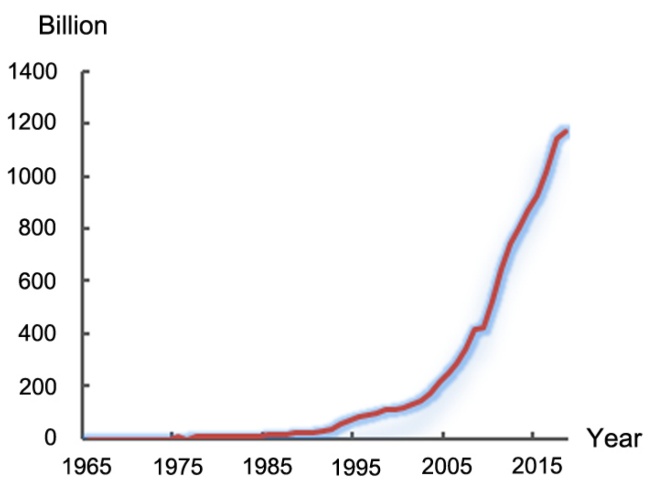


Fig. 3. Panzhihua' gross domestic product (GDP) from 1965-2015.



Establishment of the evaluation system

Variable selection
Although there are numerous assessment frameworks for measuring urban resilience (Resilience Alliance 2007, Cutter et al. 2008, Jha et al. 2013, RF and ARUP 2014, Abdrabo and Hassaan 2015), most of them are designed based on the characteristics of specific regions, either the general city type, particular city type, or the subsystem within a city. Because of the challenges associated with meeting China's urban development needs in general, and that of RBCs in particular, we attempted to establish an urban resilience assessment framework by using the Rockefeller Foundation's resilient city index as a base (Table 4). Thus, we constructed the following urban resilience indicator system by highlighting the characteristics of RBCs resilience with available and accessible data.

Description of categories
Health and well-being: this category primarily measures resilience changes during urban transformation, based on the residents' perceptions, and includes three indicators and nine sub-indicators. Among them, the residents' vulnerability index reflects improvement in their socioeconomic status and living environment. In general, higher resident living standards are positively correlated with their ability to cope with disturbances and changes because of urban transformation. Livelihood vulnerability reflects the improvement of residents' livelihood levels in response to urban transformation. By lowering the employment rate and increasing social security status, the RBCs' exposure and vulnerability decreased. Food production, medical care, and other indicators that reflect the residents' health, safety, and quality of life were used to measure health and well-being during urban transformation.

Infrastructure and environment: traditionally, RBCs have promoted industrial development at the expense of adequate infrastructure and environmental pollution prevention. Thus, during urban transformation, RBCs should invest more heavily in construction of adequate infrastructure and environmental protection. This category is measured using 3 indicators (1) transportation and communication, (2) ecological services, and (3) environmental management, which are further divided into 10 sub-indicators. Transportation and communication reflect the improvement of urban infrastructure to enhance the emergency response capacity. Ecological services and environmental management signify the intensity of investment in energy conservation and environmental governance, as well as the effectiveness of measures implemented to mitigate the serious environmental problems originating from before urban transformation.

Economy and society: the economic indicators are used to evaluate the RBCs' current state of economic development and future potential for expansion; whereas the social indicators reflect the social support provided by the urban government for the purpose of improving the urban residents' quality of life. This category includes three indicators and nine sub-indicators. With respect to the economy, indicators, such as total industrial output value and total tourism income, are used to assess the RBCs' economic condition and structure. The stronger the economy is, the stronger the city's capacity to adapt to change (Wang et al. 2016). Moreover, adjustments to the economic structure serve as an important measure of the RBC's functionality during transformation. The total tourism income reflects how effectively the RBC is using local natural resources to develop tourism, while actively undergoing transformation. In terms of society, the indicators signify any reduction in urban exposure and vulnerability by ensuring basic necessities for vulnerable groups, such as the elderly and low-income groups, as well as the degree of social stability during transformation.

Government management capacity: a successful urban transformation is almost completely dependent on the government's management capability. Thus, this category mainly includes three indicators, consisting of government financial capacity, educational development capacity, and social development capacity, which are further divided into eight sub-

Table 4. Evaluation system of resource-based cities' (RBCs) urban resilience.

Categories	Weight	Indicators	Weight	Sub-indicators	Weight
Health and well-being	0.2394	Resident vulnerability	0.0678	Water use	0.0224
				Total electricity consumption	0.0232
				† Engel coefficient of urban residents	0.0131
				Per capita living area	0.0091
		Livelihood vulnerability	0.1082	† Unemployment rate	0.0183
				Per capita disposable income of urban residents	0.0394
				Annual social security expenditure	0.0505
		Safeguards to human life and health	0.0634	Number of beds per thousand	0.0301
				Proportion of health care expenditure	0.0259
				Total grain output	0.0073
Infrastructure and environment	0.2650	Transportation and communication	0.0628	Highway mileage	0.0144
				Broadcast coverage	0.0215
				Telephone coverage	0.0270
		Ecological services	0.0440	Rate of good air quality	0.0235
				Per capita public green space	0.0057
				Forest coverage	0.0147
		Environmental management	0.1582	Energy conservation and environmental protection account by GDP expenditure	0.0347
				Afforestation area	0.0316
				City sewage treatment	0.0437
				Urban rubbish treated without causing pollution	0.0331
				† Integrated energy consumption	0.0152
Economy and society	0.3440	Social security status	0.0439	Basic pension insurance coverage	0.0272
				The number of guaranteed subsistence allowances for urban residents	0.0167
		Social stability and security	0.1187	† The number of criminal cases filed	0.0444
				† Traffic accident losses	0.0259
				† Fire losses	0.0484
		Economic coping capacity	0.1814	Total tourism income	0.0560
				Total industrial output value	0.0310
				Per capita gross regional product	0.0329
				Total retail sales of consumer goods	0.0242
				Proportion of the tertiary industry	0.0373
Government management capacity	0.1516	Government financial capacity	0.0818	Total financial revenue of local government	0.0301
				Total foreign trade volume	0.0150
				Total fixed assets investment	0.0368
		Educational development capacity	0.0413	Proportion of the education expenditure	0.0247
				Number of college students per 10,000 people	0.0166
		Social development capacity	0.0284	Urbanization rate	0.0284

† indicates a negative index. Data sources: the Panzhihua Statistics Yearbook (2001-2017), Panzhihua Statistical Bulletin for National Economic and Social Development (2000-2016), Panzhihua Environment Statistical Bulletin (2013-2016), Sichuan Province Statistical Yearbook (2001-2017).

indicators. Government financial capacity reflects the local government's economic strength. Educational development capacity signifies the local government's support for education to enhance urban resilience; the higher the general level of education, the higher the response capacity (Wang et al. 2016). Social development capacity implies the degree of urban development in response to government management.

Data sources

Data used in this work primarily came from the following sources: Panzhihua "13th five-year" Disaster Prevention and Reduction Plan, Panzhihua 2018 Geological Disaster Prevention and Control Plan, Panzhihua General Urban Plan (2011-2030; 2017 edition), Panzhihua Public Information Network (open information), Panzhihua Planning and Construction Network, Panzhihua Panxi National Strategic Resources Innovation and

Development Pilot Zone Construction Implementation Plan, Panzhihua National Garden City Construction planning (2013~2017), and the Panzhihua General Urban Plan (2011-2030). The administrative boundaries data were retrieved from the National Geographic Foundation database.

Data analysis

The influence of each indicator on urban resilience can be either positive or negative, and the influence on the system is uncertain. Therefore, the resilience measure is essentially an analytical process that combines deterministic evaluation criteria with uncertainty evaluation factors and their content changes. The data processing method used in this work is as follows:

(1) Data reliability analysis: the reliability test was employed to determine results consistency when the same method was used to repeatedly measure the same object. Values > 0.7 are considered reliable. Data used in this study produced a Cronbach's alpha coefficient of 0.782 that is reliable.

(2) Data standardization: because the indicators' units must allow for comparability of the data, herein, the 0-1 standardization was adopted. The formula is as follows:

$$X = (x - \min) / (\max - \min) \quad (1)$$

where, max and min represent the maximum and minimum values of the same index, respectively, x is the original value of a certain index, and X is the standardized value of this index.

(3) Index weight determinations: to avoid the deviation of subjective factors on the evaluation results, the entropy method was used to determine the index weights. The formula is as follows:

$$W_j = \frac{H_j}{\sum_{j=1}^{m} H_j} (1 \le j \le m) \quad (2)$$

where Wj and Hj are the weight and utility values of j, respectively; and H is the difference between the entropy of 1 and the entropy of j.

(4) Composite score calculations: the comprehensive index method was used to calculate the urban resilience comprehensive score. Through data standardization and weight calculation, the standardized value of each index in the mountain town system was multiplied by its weight and then summed up to obtain the resilience index of each subsystem in Panzhihua. Subsequently, Panzhihua's annual resilience index was obtained. The formula is as follows:

$$URI_s = \sum_{j=1}^{n} X_i W_i \quad (3)$$

$$URI = \sum_{j=1}^{m} (URI_s)_j W_j \quad (4)$$

where URI_S is the resilience index of different categories, URI is the urban resilience index, Xi is the standardized index, Wi is the weight of the index, Wj is the weight of different categories, m is the number of categories, and n is the number of indexes contained in different types.

(5) Grey relational analysis: the urban resilience influencing factors are complex and variable. The factors affecting urban resilience are directly reflected in each index, and the grey correlation analysis can correctly rank the impact of each index. Thus, the grey relational analysis was applied to rank the impact of 12 indicators on urban resilience. Detailed calculation steps can be found in Sun (2014) and Zhang and Zhang (1996).

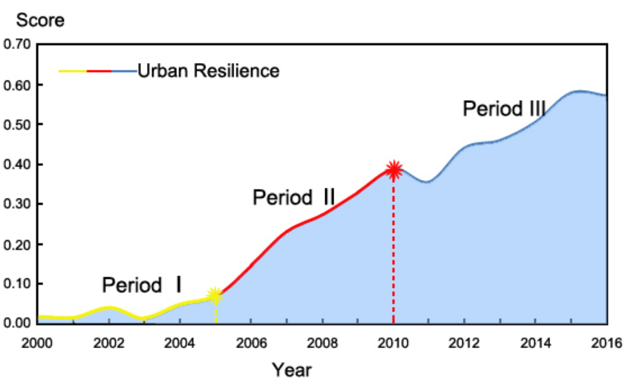
RESULTS

Comprehensive analysis of Panzhihua's urban resilience

General evolution trend

From 2000 to 2016, Panzhihua's urban resilience showed an overall upward trend (Fig. 4). According to the annual rate of growth, from 2000-2005, average growth rate was 0.0176, from 2006-2010, average growth rate was 0.0589, by 2011, the annual growth rate was in decline, and the average growth rate was 0.0275 from 2011-2016. Therefore, it can be divided into three periods:

Fig. 4. Panzhihua's urban resilience trend.



(1) Slow rising period (2000-2005): as a typical RBC, at the beginning of its development, Panzhihua grew rapidly by relying on its rich resources. However, under the influence of unsustainable resource utilization, inappropriate industrial structure, special development requirements, and gradual deterioration of the natural environment, among other negative factors, Panzhihua entered a depletion period as a grown-up RBC. Thus, a series of social, economic, and environmental problems followed. While the development pace slowed down, Panzhihua's urban resilience slowly rose. In 2004, Panzhihua had become one of the country's top 10 cities with terrible air pollutions; the rate of good air quality was only 16%.

(2) Rapid rising period (2006-2010): after 2004, Panzhihua implemented numerous mitigation measures to abate environmental pollution, modify the industrial structure, and promote urban transformation (Table 5). The government changed the city's primary income from the mineral industry to the health care and tourism industry, thereby harvesting the city's natural solar resource. Panzhihua quickly developed from a polluted, industrial city to a modern, residential city with distinctive industrial characteristics and diversified industrial development. During this period, the government actively improved urban supporting facilities and services and introduced a series of policies that created a favorable environment for

Table 5. Some relevant policies introduced by the government to promote urban transformation from 2006-2010.

Date		Policies and Main Content
2006.04.25	Policy	The government deliberated and approved the "Economic Transformation Strategy of Panzhihua Resource-based City" project proposal.
	Content	This project put forward some measures and suggestions for economic transformation based on the current situation, existing policies, and system policies of Panzhihua’s resource-based economy.
2008.03.31	Policy	Suggestions from Panzhihua’s Government on accelerating development of the forestry industry.
	Content	With increasing agricultural income based on forest resource cultivation, the government would actively promote the forestry industrialization process and meet the varied demands of economic and social development for forest products and ecological services to the greatest extent.
2008.10.15	Policy	Implementation of suggestions by Panzhihua’s Government on establishing a new mode of important mineral resources exploitation.
	Content	Promote win-win development, rational utilization, and scientific development of important mineral resources; and establish a new pattern for development of important mineral resources.
2009.09.18	Policy	Suggestion for promoting the construction of a demonstration base for the comprehensive development of Vanadium-Titanium.
	Content	To constantly improve comprehensive resource utilization, and the core level of industry, requires that Panzhihua expanded by continuously extending industrial chains and industry clusters; thereby making Panzhihua a world-class leading Vanadium-Titanium comprehensive resource development demonstration base.
2010.07.12	Policy	Panzhihua’s Ecological City Construction Implementation Plan
	Content	Set the construction goals of various counties throughout the city for building an ecological economic system, natural resources guarantee system, ecological environment system, ecological human settlement system, ecological culture system, and ecological capacity support system to improve the ecological environment and foster ecological culture.

industrial development and residential living space. Because of continuous promotion of these effective measures and policies, Panzhihua’s industry, infrastructure, and ecological environment have continued to improve, thus enhancing the residents’ quality of life. In addition, the economy became more stable than ever, and in response, urban resilience rapidly rose throughout this period.

(3) Fluctuating development period (2011-2016): after several years of comprehensive environmental and industrial renovation, which resulted in significant development, Panzhihua gradually entered the period in which development was subject to regular fluctuation, but overall, maintained its upward trend. During this period, Panzhihua’s economy remained stable and rising, a consequence of reinforcing urban infrastructure, supporting urban functional structure, emphasizing the importance of maintaining a clean and aesthetic urban ecological environment and landscape, and promoting energy-saving methods and emission reduction. In fact, Panzhihua’s air quality increased from an abysmal 16% in 2004 to a perfect 100% in 2016. Thus, Panzhihua served as a model city for national health and provincial environmental protection.

Trend fluctuation characteristics

In term of evident fluctuation points, peaks and troughs throughout Panzhihua’s urban resilience trend correspond with key years in the city’s development and transformation. For example, the peak at 2004 reflects the beginning of urban transformation and that at 2010 marks the initial success of the project. In other years, urban resilience closely paralleled normal social development and depicted a steady rise, indicating expansion of the urban system’s resilience-bearing threshold. Prior to 2005, urban resilience was low. Urban development was deteriorating under slow and long-term pressure from extensive industrial development, unsustainable resource use, and destruction of the ecological environment. However, with the continuous improvement due to urban transformation and ecological construction, the long-term pressure on urban development has diminished, urban resilience has significantly improved, and resilience of the collective residential, industrial, urban, and environmental systems was substantially enhanced.

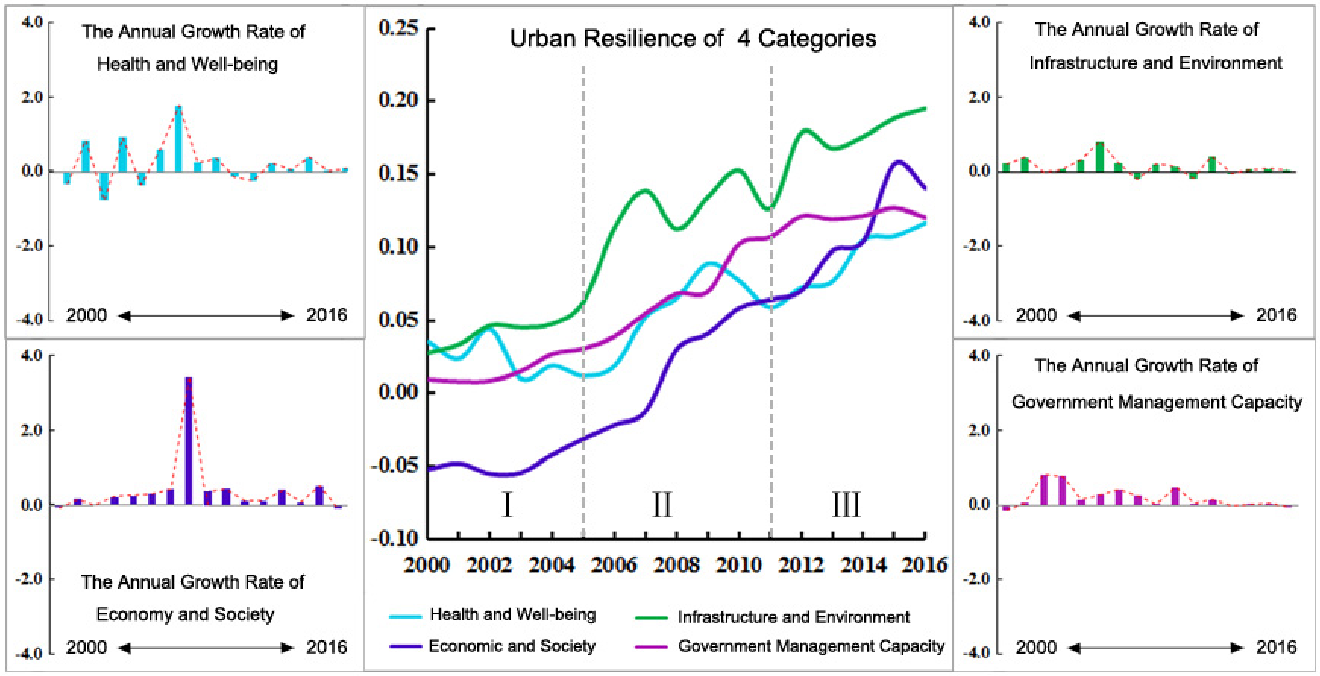
Analysis of the urban system’s adaptive cycle

The adaptive cycle theory asserts that the social-ecological system will experience reorganization (α), exploitation (r), conservation (K), and release (Ω) phases. The adaptive cycle can be used to explain the fluctuation characteristics in the resilience trend during the different stages (Holling 2001). As a result of extensive exploitation and utilization of a single resource, urban development momentum abated. Prior to 2004, Panzhihua was in the release phase (Ω). After entering the period of urban transformation, Panzhihua transitioned to the reorganization phase (α) in response to industrial structure modification, comprehensive utilization of resources, and increased investment in ecological and environmental protection. During this period, economic and social development, as well as the ecological environment, underwent significant improvements, resulting in enhanced system resilience. Subsequently, at around 2010, the system gradually transitioned from the reorganization (α) to the exploitation (r) phase, in which both development and environmental protection were maintained, allowing for economic and social stability.

Impacts of the four categories on urban resilience

With the development of social, economic, and ecological stability, in general, urban resilience in all four categories improved to various degrees; as evidenced by their gradual upward trend (Fig. 5). Among them, infrastructure and environment exhibited the largest variation, the economy and society category demonstrated the next largest degree of change. Finally, although health and well-being and government management capacity showed relatively small variations, both of

Fig. 5. Panzhihua's urban resilience trends by category.

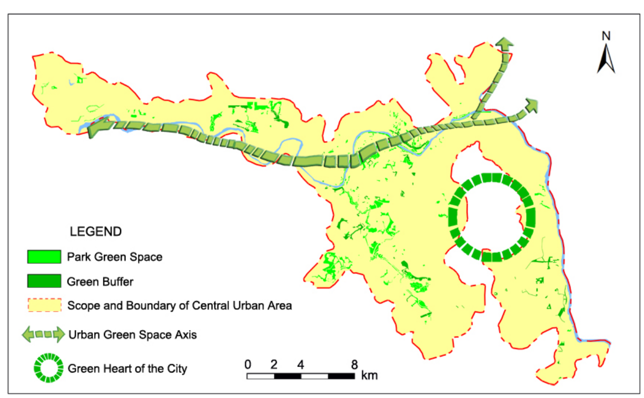


them exhibited an upward trend, guaranteeing improvement in urban resilience.

Health and well-being category
During the study period, the health and well-being category showed less fluctuation relative to the other three. From the beginning of the study period, this category's resilience exhibited a high level of stability. However, because urban transformation primarily focused on other areas, the growth was slow but continuous. From 2003-2008, the growth of social security and employment expenditure was relatively slow compared with the growth of other indicators. Eventually, social security and employment expenditure decreased compared with the growth of other indicators.

Infrastructure and environment category
Compared with other categories, the infrastructure and environment category grew the most rapidly. Prior to 2005, there was a mild, but steady increase and the few observable fluctuations were of a very small amplitude. After 2005, this category showed a rapid rise that was prone to large fluctuations. Because of the country's high demand for resources, the development of iron and steel resources, and heavy industry drove Panzhihua to rapidly develop. However, the lack of comprehensive planning, inappropriate city layout, and limited investment in infrastructure were unable to meet the residents' requirements for living and environmental improvement. Since the city began to apply urban transformation in 2005, Panzhihua implemented measures to improve the residential environment by promoting investment in environmental protection and infrastructure construction. Therefore, the infrastructure and environmental category varied over a longer time and with more intensity compared to the other categories. In the urban planning of Panzhihua (2011-2030), the land allocated for green space areas and public service facilities increased significantly, which further improved Panzhihua's environmental quality and service functions. In the National Garden City construction plan issued in 2013, the basic green space structure of "blue corridor and green lung, group isolation, forest network, and multi-island radiation" was established to improve the framework and quality of urban landscaping systems (Fig. 6).

Fig. 6. Central urban green space system layout plan for Panzhihua (2011-2030).



Economy and society category
Panzhihua thrives on the use of resources. In the early stage of development, resource utilization played a very important role in promoting urban economic development. However, over time, the

influence of resources on economic and social development decreased, the speed of urban economic and social development slowed down, and Panzhihua slowly became more vulnerable. Prior to 2007, the development pace was relatively slow; after 2007, a significant acceleration was observed. Correlating these results with reality shows that after the RBC entered the mature period, the city lacked new development vitality. However, after the implementation of urban transformation in 2005, the urban development model was transformed. Urban transformation brought new development opportunities to Panzhihua's economy. The city designed and implemented a comprehensive development and sunshine resource utilization plan, in which they leveraged sunshine resources to develop a health and wellness industry, which ultimately spawned a major tourism industry. The urban economy benefited from new development opportunities as investments were poured into ecological maintenance, the health and wellness industry, and constructing a city that was attractive to tourists. Furthermore, Panzhihua's infrastructure facilities were improving remarkably and a stable social infrastructure was steadily developing. Although the urban transformation began in 2005, due to the effect of time lag, the level of economic and social development in Panzhihua began to show an obvious rise in 2007. Because the city's economy and society gained new development impetus, the urban system evolved to a more prosperous stage, and resilience has greatly improved.

Government management capacity

Active promotion of urban transformation is a direct reflection of the government's management capacity. Education development ability is a product of the local government's emphasis on education and the potential for long-term sustainable development of the regional economy and society, whereas the urbanization rate exemplifies governing capacity. Panzhihua has a large urban population and has made remarkable progress in various social undertakings, e.g., the education and economic development level is continuously improving. Thus, the government management capacity category shows a stable growth trend.

Impacts of the influencing factors on urban resilience

The correlation analysis results (Table 6) show that in Panzhihua:

(1) The degree of urban resilience is most closely related to the degree of transportation and communication, and that of social security. Due to the long-term development of heavy industry at the expense of solid infrastructure and social security, the most important factors restricting urban resilience, Panzhihua's resilience showed only limited improvement prior to beginning urban transformation. Since then, Panzhihua has enacted numerous measures, including a comprehensive development and resource use plan along with the development of a health and wellness industry that spawned a tourist city. All these positive features demanded higher requirements for the local infrastructure. Accordingly, Panzhihua's infrastructure and social security greatly improved over a short time.

(2) Education and social development ability are closely related to urban resilience. Education is the core of competition and the future development potential of a region. During the study period, Panzhihua's educational development capacity showed a step-like increasing trend. The proportion of the public budget expenditure allocated to education has increased each year, as has the number of college students. Relevant studies show that 10-14% of the fiscal budget should be apportioned to education but additional funding would require budget cuts in agriculture and other departments. However, from 2011 to 2016, Panzhihua spent > 16% of its fiscal budget on education and reached 20% at its peak, indicating that the government attributed major importance to education investment. Social development ability influences Panzhihua's development status and trend. By adjusting the industrial structure and promoting urban transformation, Panzhihua demonstrates a healthy, all-inclusive development trend and an increasing urbanization rate.

Table 6. Correlation degree of the urban resilience influencing factors.

Indicators	Correlation degree	Indicators	Correlation degree
Resident vulnerability	0.6744	Social security status	0.7898
Livelihood vulnerability	0.6137	Social stability and security	0.6550
Safeguards to human life and health	0.6818	Economic coping capacity	0.6721
Transportation and communication	0.8425	Government financial capacity	0.6338
Ecological services	0.6851	Educational development capacity	0.7613
Environmental management	0.6959	Social development capacity	0.7608

(3) Urban resilience is closely related to ecological services and environmental management. Ecological service indicates the natural support provided by the urban ecosystem for urban development and is the natural foundation of regional development. Urban economic competition and security depend on sustainable use of natural resources and ecosystem services (Maes and Jacobs 2017). To improve the natural environment, the city implemented a variety of policies and processes to establish and improve a long-term sustainable development mechanism, strengthen ecological environmental protection and governance, and enhance ecosystem services. All of these measures played an important role in improving the local ecological environment and enhancing urban resilience. As shown in Figure 7, the energy conservation and environmental protection expenditure in

Fig. 7. Proportion of energy conservation and environmental protection expenditures from Panzhihua's fiscal budget (2000-2016).

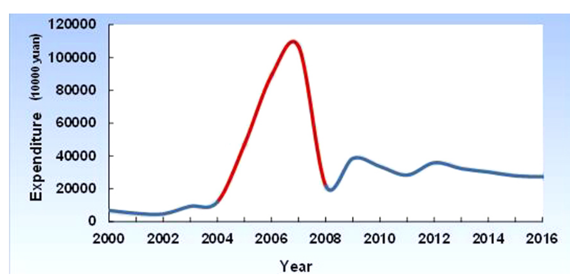
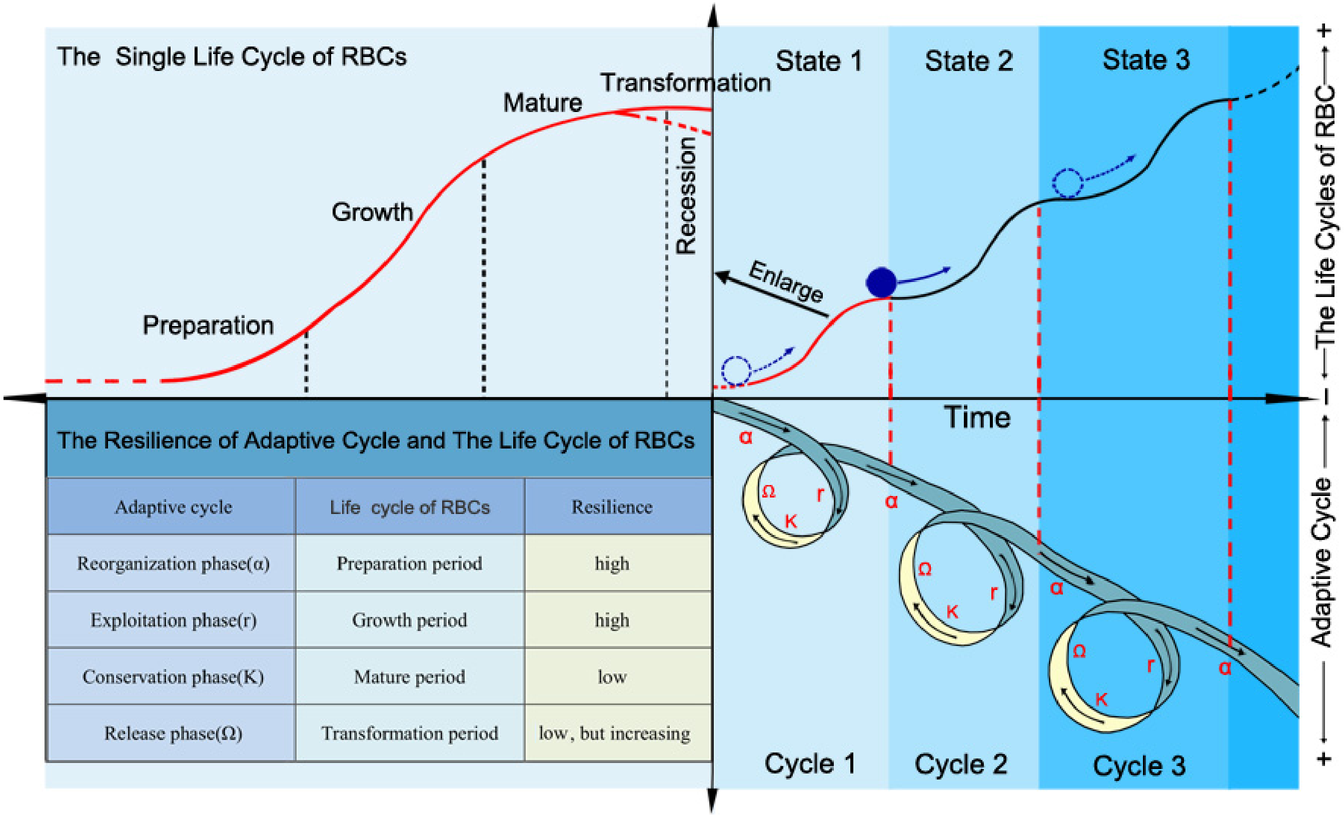


Fig. 8. High correlation between the resource-based cities' (RBCs) adaptive and life cycles.



Adaptive cycle	Life cycle of RBCs	Resilience
Reorganization phase(α)	Preparation period	high
Exploitation phase(r)	Growth period	high
Conservation phase(K)	Mature period	low
Release phase(Ω)	Transformation period	low, but increasing

Panzhihua was very low before 2004. Subsequently, it increased significantly from 2004 to 2008, then dropped to a sustainable, but reasonably high level, where it has remained afterward.

DISCUSSION

Resource-based cities' development has a natural resource exploitation life cycle

This life cycle enables RBCs' to be categorized based on different stages of resource development. Furthermore, the city's socioeconomic environment and economic structure also show obvious cyclical changes. Depending on the stage of development, RBCs will have significantly different degrees of economic development, subsystem connectivity, development potential, and urban resilience capability.

Resource-based cities' urban resilience fluctuates considerably in response to urban transformation

Prior to urban transformation, extensive exploitation, resource use, resource depletion, and ecological environment deterioration stagnated the RBCs' socioeconomic system. In the process of urban transformation, various internal and external measures were implemented to reinitiate urban system development. The revitalization process encountered significant fluctuations in resilience, but ultimately stabilized upon entering a new stage of development following a successful transformation. Urban transformation is the key point of RBCs' system change and resilience change.

The life cycle of RBCs is an upward spiral (Markusen 1996, Mao and He 2008). With exploitation and use of single resources, the RBCs will undergo a preparation, growth, and mature period. Subsequently, RBCs will enter a period of decline due to a severe reduction or exhaustion of resources. If transformation and comprehensive natural resource use can be carried out, the urban system will enter a new life cycle (State 1 to State 2). In the later stage of State 2, the urban system will face with a new potential transformation. Through comprehensive and coordinated development and resource use, it will enter the new life cycle at State 3.

Correlation between the RBCs' adaptive and life cycles

As a social-ecological system, RBCs' development will undergo reorganization (α), exploitation (r), conservation (K), and release (Ω) phases, which ultimately constitute an adaptive cycle (Holling 2001). A comparison of the RBCs' life cycle trend and the adaptive cycle periods shows that a high degree of correlation exists between the system characteristics and periods of resilience (Fig. 8).

During the preparation period, the RBCs enter a new development cycle (State 1). Because the discovery and preparation of new resources provide new impetus for urban development, the RBCs are about to undergo a rapid development stage from a long-term, low-level development stage, and the city's development potential and resilience will gradually increase. However, during this period, because of the underutilized or poorly utilized resources, the subsystem and individual element connectivity throughout the RBCs is low, and urban resilience is high. The preparation period corresponds to the reorganization phase (α) of adaptive cycle 1.

In the growth period, the RBCs enter a period of rapid development in response to massive resource exploitation, with huge potential and wide prospects for large-scale growth. The economic development level of RBCs has been greatly improved, and the economic subsystem development has driven the development of other subsystems. Finally, the RBCs' urban system exhibits a high resilience and increasingly closer connectivity among various subsystems. This growth period corresponds to the exploitation phase (r) of adaptive cycle 1.

After entering the mature period, the RBCs' development rate gradually slows down. Because of the urban subsystems' close connectivity and dependency, the development of the urban system depends too much on resources, while the development capacity of the urban system itself is insufficient. The whole urban system becomes inflexible and vulnerable to external interference. Once resources are exhausted, the development of RBCs will be threatened. At this time, the resilience of the system is reduced compared with the previous stage, and the trend is gradually decreasing. This mature period corresponds to the conservation phase (K) of adaptive cycle 1.

After entering the transitional period because of resource exhaustion or unreasonable resource development mode, the system is unable to provide stable impetus for the development of RBCs, but hinders the further development of RBCs. The urban system will experience disturbance as the city undergoes rapid collapse, urban decay, and attempts to revive (i.e., enter a new life cycle - state 2) by developing new industries. This transitional period corresponds to the release phase (Ω) of adaptive cycle 1. During the transitional period, the urban system is trying to reorganize and regenerate; urban resilience is low but increasing. Next, the urban system enters adaptive cycle 2. If the RBCs cannot make the transition successfully, they will gradually decline.

The established cycle of preparation → exploitation→ maturation → transition will then repeat.

In our research, there is a relatively good correspondence between the stages of RBCs development and the stages of adaptive cycle. This finding agreed well with other research evidence that the coupled cycles of change in resource exploitation, governance, and management will influence the development of social-ecological system (Holling and Meffe 1996, Beier et al. 2009). However it is difficult to define the position of the system in the adaptive cycle through quantitative methods (Castell and Schrenk 2020), the boundary between one and the other is blurred, therefore most of the studies are based on the qualitative analysis of metaphor and hypothesis (Burkhard et al. 2011, Pelling and Manuel-Navarrete 2011, Fath et al. 2015), and a small number of studies attempted to quantify them (Angeler et al. 2015, Castell and Schrenk 2020). Our research provides a possible quantitative method to define the position of RBCs' development in the adaptive cycle. Due to the numerous types of RBCs, although it is impossible to find a unified standard to define the position of all RBCs in the adaptive cycle, but for each type of RBCs, we can find a specific indicator to define its stage, evaluate the approximate time and distance of RBCs' system transformation threshold, move the adaptive cycle from a metaphor to a framework (Angeler et al. 2015), and finally provide a possible reference for resource exploitation, adaptive management, and sustainable development of RBCs.

CONCLUSION

(1) Panzhihua is an RBC that has undergone urban transformation. Its urban resilience shows an overall increasing trend, which can be divided into three stages based on the rate of increase: slow rising period (2000-2005), rapid rising period (2006-2010), and fluctuating development period (2011-2016). The resilience trend fluctuations are generally consistent with the goings-on during key years of the city's development and transformation, and reflect the urban system's resilience-bearing threshold at that point. Before 2005, Panzhihua's urban resilience was low, but significantly enhanced afterward. Later, the urban resilience significantly improved and the system resilience was enhanced.

(2) Because of their significant contribution to system resilience, all four categories that were assessed showed a gradual upward trend. Among them, the infrastructure and environment depicted the largest variation, followed by economy and society. Due to the lack of unified planning and adequate infrastructure in the early period of RBC development, the residents' needs were unable to be met. In the transition period, urban resilience can be enhanced by increasing investment in infrastructure and improving residents' living environment. Single resource use in the early period and comprehensive resource use in the later period have provided incentive for RBC economic and social development, before and after transformation, respectively. The health and well-being and government management capacity variation were relatively small. Based on 12 relevant indicators, the level of urban resilience in Panzhihua was most closely related to the degree of transportation and communication, as well as social security. All of these results can be used to guide resilience improvement in urban development.

(3) During urban transformation, RBCs' resilience significantly fluctuated, reflecting the instability brought on as the urban system transited from a previous state to a new state. There is a high degree of correlation between the RBC life cycle and adaptation cycle. As resource exploitation and use change, the degree of connectivity and resilience among various subsystems and elements with the urban systems are modified in parallel.

Resource-based city development and evolution are rooted in the region's natural conditions and characteristics. As such, resilience improvement must revolve around the region's geology, geography, weather, and natural resources. Once the complexity of the RBC's social and ecological dynamics are fully understood, a range of nature-based solutions can be implemented to optimize the synergy between nature, society, and the economy; ultimately reducing risk and vulnerability, and improving resilience to ensure a healthy response to challenges, such as climate change, health, and well-being.

This study has made some valuable findings, but there are still some shortcomings. First, because of the limitation of data availability, we considered some of the qualitative indexes such as policies and the attitudes (or emotion) of stakeholders less than we would have liked. Second, this research is based on a single case study, did not conduct a comparative study on urban resilience of different types of RBCs. Therefore, in the next research plan, quantitative research can be conducted on qualitative indices through mathematical methods, structured interviews, etc., which can enrich the evaluation system of RBCs' urban resilience. In terms of the external validity of the model, a comparative study can be made to find out whether there are some common rules or different characteristics in the stages of resilience evolution and adaptive cycles, combined with the diversity and complexity of characteristics of different types of RBCs.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12280

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Data Availability:

The data that support the findings of this study are available on request from the corresponding author, Yiping Fang. None of the data code are publicly available because they are collected by researchers from paper documents that are published by the Chinese Government Statistical Agency.

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