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Research on Urban Resilience Evaluation of Ulaanbaatar City

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Abstract. As a complex social ecosystem, cities continue to suffer from various impacts and disturbances from the outside and themselves. In this context, the research on resilient cities becomes more and more necessary. This study takes Ulaanbaatar City as the research object, uses the TOPSIS-entropy weight method to measure and analyze the resilience level of Ulaanbaatar City from 2017 to 2021, and puts forward strategies to improve urban resilience according to the measurement results. The results show that: (1) the index ranges of economic resilience, social resilience, ecological resilience, infrastructure resilience and urban resilience of Ulaanbaatar are 0.097-0.901, 0.237-0.893, 0.465-0.622, 0.368-0.631 and 0.036-0.789, respectively. (2) The economic resilience index increased most significantly among the four resilience dimensions, with an increase of 828.86%. The social resilience index showed a trend of first increase and then decrease, but the overall increase was 0.387. The ecological resilience showed a wave-like downward trend, while the infrastructure resilience index showed a steady upward trend compared with the development fluctuations of other dimensions. (3) Under the joint action of the four dimensions, the urban resilience index showed a trend of first increasing and then decrease, with an increase of 0.644 compared with 2017. This study is of practical significance for clarifying the current situation of urban resilience development in Ulaanbaatar and improving the level of urban resilience in Ulaanbaatar.

Keywords: resilient city; Resilience evaluation; Topsis-entropy weight method; Strategy research

0. Introduction

On 31 October 2020, UN-Habitat (UN-Habitat) released its World Cities Report 2020 - The Value of Sustainable Urbanisation, which states that the share of the global population living in cities will increase to 60.4% by 2030. Urban development is becoming larger and more complex[1]. As cities are constantly subjected to various shocks and disturbances from the outside and within themselves, they are required to continuously improve their resilience level to cope with these risks. A resilient city refers to a city that can withstand disasters, mitigate disaster losses, and reasonably deploy resources to quickly recover from disasters. The core of building a resilient city is to improve the city's ability to respond quickly, adapt to and recover from risks.

The English word of resilience is "resilience", which is usually translated as "resilience", "resilience" and so on. The concept of resilience first comes from the field of physics to describe the ability of materials to absorb external impact forces. Studies have shown that the term [2] resilience appeared in ancient texts as early as the 17th century. After the 1950s, related concepts began to expand from "engineering resilience" and "ecological resilience" to "urban resilience". Zhou Limin and Yuan Weiqi measure [3] urban resilience from disaster protection, economy, community, organization, infrastructure and other aspects. Sun Yang et al. built an index system [4] to evaluate urban disaster resilience from the dimensions of economy, social environment, community, infrastructure and organization based on the baseline resilience model. Liu Yanping constructed an index system from the four dimensions of urban cultural resilience, economic resilience, social resilience and environmental resilience to evaluate [5] urban resilience.

Ulaanbaatar is not only the capital of Mongolia but also the political, economic, technological, cultural and transportation center of Mongolia. Compared with some international cities in the construction of resilient cities, Ulaanbaatar has the characteristics of the late start of resilient city construction, weak experience accumulation and imperfect construction measures. This study takes Ulaanbaatar City as the research object, constructs the resilience measurement index system of Ulaanbaatar City, and uses the TOPSIS-entropy weight method to measure and analyze the resilience level of Ulaanbaatar City from 2017 to 2021 from the four dimensions of economic resilience, social resilience, ecological resilience and infrastructure resilience. Based on the measurement results, urban resilience improvement strategies were proposed, to clarify the current development status of Ulaanbaatar's resilient city and provide data support and a decision-making basis for the formulation of urban resilience construction measures.

1. General situation and research methods of the study area

1.1. Research area overview

Ulaanbaatar is located in the central part of the Mongolian Plateau, with an altitude of 1,351m and an area of about 4,704.4 square kilometres. It is 718 kilometers from the Chinese border and 542 kilometers from the Russian border. At present, Ulaanbaatar city has 9 main districts (Baganoor District, Bayanhangai District, Bayangrad District, etc.), which contain 121 subdistricts. The urban population of Ulaanbaatar has seen a large increase since 2010, and its urban population accounts for 44% of Mongolia. The per capita GDP of Ulaanbaatar is more than three times the average level of Mongolia. The top two industries that account for the highest proportion of GDP are service industry and industry, while agriculture only accounts for 0.1% of GDP. The unreasonable economic development structure also brings a series of social problems, such as traffic congestion, environmental pollution, wealth gap and so on.

1.2. Research methods

The TOPSis-entropy weight model was adopted in this study. Topsis (Technique for Order Preference by Similarity to Ideal Solution) is a multi-attribute decision-making method, which is often used to evaluate the advantages and disadvantages of multiple alternatives. Topsis avoids the subjectivity of data, can better describe the comprehensive influence of multiple influence indicators, and has no strict restrictions on data distribution, sample size and the number of indicators, so it is suitable for large systems with multiple evaluation units and indicators. The entropy weight method is a weight determination method based on information entropy, which can consider the mutual influence and importance of various indicators, and give reasonable weights to indicators. Combining Topsis and entropy weight method, the TOPSIS-entropy weight method can fully consider the correlation and importance among indicators in multi-attribute decision-making, and help make more scientific and reasonable decisions through scientific determination of index weights and comprehensive evaluation of scheme ranking.

1.2.1. Entropy weight method

In the data preprocessing stage, the data is standardized according to the initial evaluation table, as shown in formula (1) :

$$Y_{ij} = \frac{X_{ij} - min(X_i)}{max(X_i) - min(X_i)} \tag{1}$$

Find the proportion of the first indicator in the first scheme, as shown in formula (2) :

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}}, i = 1, \cdots, j = 1, \cdots m \tag{2}$$

Calculate the information entropy of the JTH index, as shown in formula (3) :

$$E_j = -\ln(n)^{-1} \sum_{i=1}^{n} P_{ij} \ln P_{ij} \tag{3}$$

Find the weight of the JTH indicator, as shown in formula (4) :

$$W_j = \frac{1 - E_j}{k - \sum E_j} (j = 1, 2, \cdots, m) \tag{4}$$

i,e,k Refers to the number of indicators, i.e.$k = m$

1.2.2. Topsis model

Carry out the data preprocessing stage. Due to the differences in the types of urban resilience indicators, it is necessary to convert different types of indicators into the same type of indicators for comparison. For the non-extremely large indicators, the positive processing is carried out, and for the extremely small indicators, the positive processing is shown in formula (5) :

$$x'_i = x_{max} - x_i \tag{5}$$

Where, is the data after forward processing, is the initial data, and is the maximum value of the indicator data? $x'_i x_i x_{max}$

All the data after the forward processing are listed as a forward matrix:

$$\begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix} \tag{6}$$

Carry out the standardized treatment stage. nConstitutes the positive matrix, is the number of evaluation years, is the number of indicators.m

In order to eliminate the impact of dimension on model results, data standardization is carried out, as shown in formula (7) :

$$Z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{7}$$

Where, is the data after standardization, is the data in the forward matrix, and is the sum of squares of the index data $Z_{ij} X_{ij} \sum_{i=1}^{n} x_{ij}^2 \, j$

The optimal solution for relative distance calculation is the maximum value existing for each parameter, and the worst solution is the minimum value existing for each parameter, which is calculated as shown in formulas (8) and (9) :

$$Z^+ = (Z_1^+, Z_2^+, \cdots, Z_m^+) = (max\{Z_{11}\}, max\{Z_{21}\}, \cdots, max\{Z_{n1}\}) \tag{8}$$

$$Z^- = (Z_1^-, Z_2^-, \cdots, Z_m^-) = (min\{Z_{11}\}, min\{Z_{21}\}, \cdots, min\{Z_{n1}\}) \tag{9}$$

Where, is the vector composed of the maximum value of each indicator and the vector composed of the minimum value of each indicator? $Z^+ Z^-$

The Euclidean distance is used to calculate the optimal distance and the worst distance of each scheme under various factors:

$$D_i^+ = \sqrt{\mathrm{W_j} \sum_{j=1}^{m} \left(Z_j^+ - Z_{ij}\right)^2} \tag{10}$$

$$D_i^- = \sqrt{\mathrm{W_j} \sum_{j=1}^{m} \left(Z_j^- - Z_{ij}\right)^2} \tag{11}$$

Where is the optimal distance and the worst distance? $D_i^+ D_i^-$

The Topsis model index measures the toughness value, as shown in formula (12) :

$$S = \frac{D_i^-}{D_i^- + D_i^+} \tag{12}$$

2. Data source and index system construction

2.1. Research data sources

This paper takes Ulaanbaatar City as the research object to carry out urban resilience evaluation research. The data used in this research mainly came from (1) Mongolia Statistical Yearbook from 2018 to 2022, (2) Ulaanbaatar Statistical Yearbook from 2018 to 2022, (2) Ulaanbaatar Annual Environmental Statistical Report from 2017 to 2021, (4) Mongolian Bureau of Environment and Economy, and (5) EPSDATA Databank.

For individual missing data, the processing methods adopted include interpolation method, autoregressive fitting method, mean value method of adjacent years, and contacting relevant departments to seek missing data (email, telephone, official website consultation).

2.2. Construction of urban resilience index system

Toughness city in accordance with the safety evaluation guide "(GB/T 40947-2021), in London to manage risk and enhance toughness, the Rockefeller foundation toughness cities 100 projects proposed toughness index system (https://www.cityresilienceindex.org/#/), On the basis of referring to relevant literature and existing research results[4-11], combined with the actual situation of Ulaanbaatar City, and based on the principles of scientificity, wholeness, representativeness, comprehensiveness, orientation and operability, four dimensions of Ulaanbaatar City resilience evaluation were established, namely, social resilience dimension, economic resilience dimension, ecological resilience dimension and infrastructure resilience dimension. These four dimensions contain a total of 20 resilience evaluation indicators, thus constructing the urban resilience index system of Ulaanbaatar City, as shown in Table 2.1.

Table 2.1: Urban resilience measurement index system of Ulaanbaatar City

Target Layer	Guideline layer	Guideline layer	Units	Indicator properties
Measure of urban resilience of Ulaanbaatar City	**Economic Resilience**	GDP per capita	Vantuglak	+
		Labour force per thousand people	people	+
		Average monthly income level of urban residents	Vantuglak	+
		Average monthly household expenditure	Vantuglak	+
		Proportion of government spending on environmental	%	+

Target Layer	Guideline layer	Guideline layer	Units	Indicator properties
		protection		
	Social resilience	Population density	People /km²	+
		Death rate per 1,000 people	people	-
		Number of students enrolled in regular institutions of higher learning	Thousand people	+
		Per capita park green space	m²	+
		Number of beds in health institutions per 10,000 people	zhang	+
	Ecological resilience	Annual frequency of dust storms	time	-
		Earthquake magnitude 3.5 or more times	time	-
		Arable land area	m²	+
		Average annual PM2.5 particle content	mg/m³	-
		Land technical reclamation area	ga	+
		Afforestation area	ga	+
	Infrastructure resilience	Electricity consumption of the whole society	Kilowatts	+
		Per capita road area	m²	+
		Number of mobile phone users	a	+
		Number of Internet users	people	+

2.2.1. Economic resilience

Industry in Ulaanbaatar accounts for 35.5% of GDP, while agriculture accounts for only 0.1% of GDP. Ulaanbaatar is the least developed agricultural region in Mongolia, with an unbalanced economic structure. Urban economic resilience refers to the ability of the urban economic system to predict, resist and recover in the face of economic crisis, disaster and threat, which has become one of the important indicators to evaluate the stable development of the urban economy. The per capita GDP index is used to measure the economic capacity of a city, and it has a characteristic role in the speed and quality of recovery after disasters. Economic resilience is used to measure a city's economic ability to cope with shocks, in which the average monthly income level of urban residents and the average monthly household expenditure are two important indicators. In addition, the impact of economic development on the environment can be measured by the proportion of fiscal expenditure on environmental protection. Economic development potential can be measured by the number of workers per 1,000 people, which reflects a city's future economic development potential.

2.2.2. Social resilience

With the development of economy, social problems in Ulaanbaatar have become increasingly prominent, such as traffic congestion and the deepening gap between the rich and the poor. Urban social resilience is one of the important dimensions to evaluate urban resilience, which represents the ability of urban social system in defense, adaptation and recovery in the face of social hazards, disasters and threats. Urban social status refers to whether the current social environment of a city is compatible with social productivity, usually measured by population density and mortality rate per 1,000 people. The ability of urban social security is crucial to every city, and if the ability of urban social security cannot keep up with the development of the city, it may lead to the collapse of the entire urban society when it encounters a huge shock. The capacity of social security can be measured by the number of beds in health institutions per 10,000 people and the area of green park space per capita. Social development potential, which represents a city's future development potential, can usually be measured by the number of students enrolled in ordinary institutions of higher learning.

2.2.3. Ecological resilience

Due to the developed industrial economy, Ulaanbaatar city has relatively serious air pollution, and its AQI often exceeds 500 and even reaches more than 1000. Urban ecological resilience refers to the adaptive ability and self-repair ability of urban ecosystems in the face of ecological hazards and is one of the key criteria for assessing resilient cities. The urban ecological status is mainly measured by the indicator of cultivated land area. The ability to improve ecological status refers to the ability of human beings to take improvement measures to deal with the destruction of the ecosystem and the degree of pollution, which is usually measured by the two indicators of land technical reclamation area and afforestation area. The average annual frequency of sandstorms, the number of earthquakes with a magnitude above 3.5 and the average annual content of PM2.5 particulate matter reflect the degree of pressure on urban ecology.

2.2.4. Infrastructure resilience

Due to unreasonable urban planning, the infrastructure construction of Ulaanbaatar lags behind, such as uneven road repair, which affects People's Daily life. Urban infrastructure is the lifeline project that supports the normal operation and sustainable development of the whole city, so improving the resilience of urban facilities is the key to achieve efficient urban operation. As a dimension of evaluating resilient cities, the resilience of basic urban infrastructure refers to the ability of urban infrastructure system to respond to emergencies, disasters and threats and reduce negative impacts. It is also one of the important indicators to evaluate the efficient operation of urban infrastructure. The communication capacity of infrastructure is measured by the number of mobile phone users and the number of Internet users; And the capacity of urban infrastructure evacuation and resettlement can be measured by the per capita road area. In addition, the capacity of urban energy supply can be measured by the electricity consumption of the whole society.

3. Evaluation and analysis of urban resilience in Ulaanbaatar

3.1. Evaluation of resilience index of Ulaanbaatar City

Based on the data obtained from Mongolia Statistical Yearbook, Ulaanbaatar Statistical Yearbook and Ulaanbaatar Annual Environmental Statistical Report, the urban resilience level of Ulaanbaatar City from 2017 to 2021 was measured from four dimensions of economic resilience, social resilience, ecological resilience and infrastructure resilience by TOPSIS-entropy weight method. The measurement results are shown in Table 3.1.

Table 3.1: Urban resilience measurement results of Ulaanbaatar City

Year \ Dimension	Urban resilience	Economic resilience	Social resilience	Ecological resilience	Infrastructure resilience
2017	0.036	0.097	0.237	0.495	0.368
2018	0.186	0.352	0.279	0.530	0.369
2019	0.385	0.621	0.310	0.622	0.514
2020	0.789	0.774	0.893	0.465	0.526
2021	0.680	0.901	0.624	0.467	0.631

3.2. Analysis of resilience evolution characteristics of Ulaanbaatar City

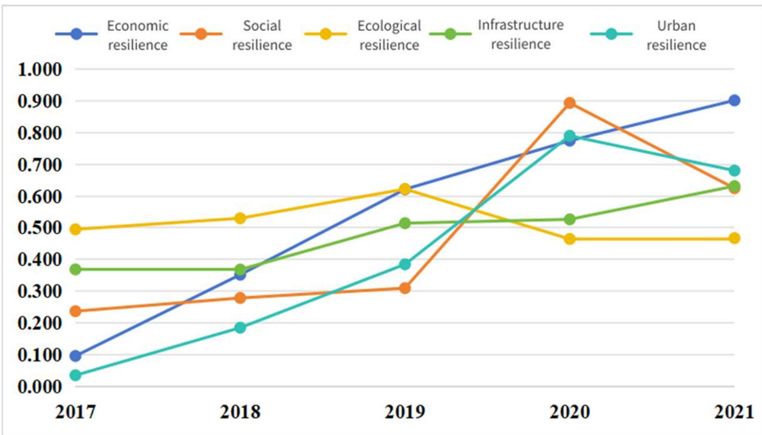

Figure 3.1: Urban resilience evolution process of Ulaanbaatar City from 2017 to 2021

As can be seen from Figure 3.1, in addition to ecological resilience, other dimensions of resilience generally show an upward trend. From 2017 to 2021, the economic resilience index ranges from 0.097 to 0.901, the social resilience index ranges from 0.237 to 0.893, the ecological resilience index ranges from 0.465 to 0.622, and the infrastructure resilience index ranges from 0.368-0.631. The urban resilience index ranges from 0.036 to 0.789.

Among the four dimensions of resilience, the economic resilience index rose the most significantly, with an increase of 828.86%, mainly due to the improvement of the average monthly income of urban residents, which continued to rise from 11,179,921 million tugerlak in 2017 to 1,17,382 million tugerlak in 2021, and the average monthly household expenditure also increased significantly. From 10,92384 million tuglerak in 2017 to 1,4991.8 million tuglerak in 2021, the rise of the two indicators fully promoted the economic flow of Ulaanbaatar city, and it's per capita GDP also increased with the increase, the increase reached 47.69.

After a sharp rise in 2019, the social resilience index decreased in 2020, but compared with 2017, the social resilience index increased by 0.387 in 2021. During the height of the pandemic, Ulaanbaatar's mortality rate rose from 4.6 to 5.9 per 1,000 people, while a reduction in the number of beds per 10,000 people in health facilities led to a decline in its social resilience index, which decreased by 0.269 between 2020 and 2021.

The ecological resilience index showed a wavy downward trend, with the index falling to 0.467 in 2021 from 0.495 in 2017. Compared with 2020, the area of cultivated land in 2021 will decrease by 8.39%, the area of technical land reclamation will decrease by 29.77%, and the area of afforestation will decrease by 25%.

The infrastructure resilience index showed a steady upward trend. The infrastructure resilience index rose steadily from 0.368 in 2017 to 0.631 in 2021 due to steady growth in electricity consumption, per capita road area and the number of mobile phone users in the whole society.

The four dimensions of economic resilience, social resilience, ecological resilience and infrastructure jointly assess the level of urban resilience. With the four dimensions showing an upward trend from 2017 to 2019, the growth rate of the urban resilience index increased and showed an upward trend. Between 2019 and 2020, the ecological resilience index continued to decline, but the social resilience index rose sharply, leading the urban resilience growth rate to further increase. Between 2020 and 2021, as the social resilience index declined significantly, so did the urban resilience index.

4. Conclusions and strategies for improving urban resilience

4.1. Conclusions

As a complex social ecosystem, cities continue to suffer from various impacts and disturbances [6] from the outside and from themselves. In this context, the importance of resilient cities is becoming more and more prominent, and its research has attracted more and more scholars' attention. Based on this, the main conclusions of the urban resilience evaluation of Ulaanbaatar city by TOPSIS-entropy weight method are as follows:

In addition to the ecological resilience, the other resilience dimensions of Ulaanbaatar showed an upward trend on the whole. The index ranges of economic resilience, social resilience, ecological resilience, infrastructure resilience and urban resilience are 0.097-0.901, 0.237-0.893, 0.4655-0.622, 0.368-0.631 and 0.036-0.789, respectively.

The economic resilience index rose the most among the four resilience dimensions, reaching 828.86%. After a sharp rise in 2019, the social resilience index declined in 2020, but compared to 2017, the social resilience index increased by 0.387 in 2021. Ecological resilience is the only one of the four resilience dimensions to show a wavy decline, with the index falling from 0.495 in 2017 to 0.467 in 2021. Compared with the development fluctuations of other dimensions, the infrastructure resilience index showed a steady upward trend.

Under the joint action of the four dimensions, the urban resilience index showed a trend of first increase and then decrease. Between 2019 and 2020, the ecological resilience index continued to decline, but the social resilience index rose sharply, leading the growth rate of urban resilience to further increase. In the period from 2020 to 2021, as the social resilience index decreased significantly, the urban resilience index also decreased, but increased by 0.644 compared with 2017.

4.2. Strategies for improving urban resilience

Based on the current development status and research results of Ulaanbaatar's resilient city, the following strategies for improving urban resilience are proposed:

First, Combined with the actual situation of Ulaanbaatar city, continues to deepen the basic connotation and understanding of a resilient city. Compared with some foreign cities in the construction of resilient cities, Ulaanbaatar has the characteristics of the late start of resilient city construction, weak experience accumulation and imperfect construction measures. Therefore, Ulaanbaatar should continue to deepen the basic connotation and understanding of a resilient city in combination with the city's situation, evaluate the city's resilient development from multiple dimensions, and formulate resilient city construction measures according to local conditions.

Second, Maintain the development momentum of economic resilience and infrastructure resilience, optimize the development trend of social resilience, and promote the upward development of ecological resilience. According to the analysis of the research results, both economic resilience and infrastructure resilience have a growing trend over time, while social resilience shows a trend of first increasing and then decreasing, while ecological resilience is a dimension showing a wavy downward trend, so different development strategies should be formulated according to the development trends of these different dimensions.

Third, Driving economic resilience as a leader in the development of resilience, and driving other dimensions of coordinated development.

Among the four dimensions of resilience, the index of economic resilience has risen the most, reaching an increase of 828.86%. We should give full play to the leading role of economic resilience in resilient development, and make good use of product resources brought about by resilient development to drive growth in other dimensions of resilience.

Fourth, We should strengthen the driving force of digital technology and integrate artificial intelligence into the development of resilience. With the development of intelligent technology, digitalization is everywhere in human life. We should make good use of digital technologies such as big data, Internet, AI intelligence and cloud computing to build a city perception system in Ulaanbaatar city, monitor risks in real-time, realize intensive overall construction, sub-construction sharing and effective management of sensing equipment, and realize resource sharing and interconnection [14]. To deepen the integration of resilience development and digital technology, break through the prison of resilience information congestion and information fragmentation, so as to provide a decision-making basis for the construction of a resilient city in Ulaanbaatar, and further improve the resilience level of Ulaanbaatar City.

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