Evaluation of City Resilience Based on the Perspective of Social Ecosystem

——Taking Chongqing as an Example

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Abstract

In order to quantitatively evaluate the urban resilience, this paper combines the realistic background and based on the perspective of social-ecosystem, selects 22 third-layer indicators for the ecological environment, municipal facilities, economic and social development in Chongqing from 2008 to 2017. The indicator will be analyzed on the case. The total resilience of each second-layer indicator in 10 years was finally obtained by calculating 22 third-layer indicators by using the method of fully arranged polygon graphic indicator method and entropy weight method. According to the resilience grade diagram, it was divided into grades and analyzed in combination with the realistic background.

Keywords

Urban resilience; Social-ecosystem perspective; Indicator system; Fully arranged polygon graphic indicator method; Entropy weight method.

1. Introduction

The city is a more important material carrier in people's modern life and production, and its scale will have an impact on the city's internal composition and status[1]. With the continuous advancement of urban modernization, cities have gradually become the most complex social ecosystem, their internal scale has gradually expanded, and the subsystem components they contain have become more and more complex. When any subsystem in the city is destroyed by the outside world or the system cannot function normally due to its inability to adapt to these new changes, it may cause a serious risk of crisis in the entire city[2].

The city is an important place to breed risk events. In recent years, with the rapid development of China's economy and the continuous innovation of engineering construction, the internal system of cities has also become more complicated, the possibility of internal risks is also increasing, and the frequency of risk events has also increased, such as 2008 The May 12 Wenchuan earthquake caused huge property losses and casualties in Yingxiu Town; the heavy rainstorm incident in Beijing on July 21, 2012 paralyzed Beijing’s traffic and caused great losses to the local economy; October 7, 2013 in Zhejiang Yuyao suffered from typhoon intrusion, which severely paralyzed the traffic and water and electricity supply system in the main urban area of the city. Rescue became extremely difficult, causing huge losses to the local economy. These disaster risks severely affect the sustainable development of cities, so establishing a resilient city indicator system and exploring methods for assessing city resilience have far-reaching significance and social value[3]

In order to quantitatively assess urban risks, the concept of "resilience" was introduced. The emergence of resilience provides a new perspective for understanding the operation and sustainable development of the system, especially the system's response to risk disasters[4]. According to the domestic and foreign literature research results, this article also combines cities with resilience and quantitatively evaluates the resilience of the cities.

In previous studies on cities, most of them were based on a single analysis based on social, ecological and economic aspects. However, the influence of a single factor is only an assumption in an ideal state. In reality, urban risk is caused by the coupling of multiple factors. As a result, the social-ecological system is a complex giant system composed of people, nature, and society. In this system, the change of any element will have a chain reaction to other elements[5]. Therefore, this article will discuss the urban resilience index system and evaluation method based on the socio-ecological perspective, and use Chongqing as a case city for specific analysis.

2. The concept of resilience and its integration with cities

2.1 The concept of resilience

Resilience (also translated as "resilience") (resilience) was originally derived from the Latin word resilio, meaning "rebound"[6]. The initial resilience is used to define the speed at which the system recovers to its own equilibrium state, the ability to resist external risks and recover from itself, and the ability to adapt to the new environment[7]. Since the 1990s, the concept of resilience has been gradually applied to other scientific fields, and its connotation has been continuously enriched. For example, the ecologist Holling applied the concept of resilience to the field of ecology for the first time to characterize how much the system absorbs due to external interference. The ability to change[8]; The Earthquake Engineering Comprehensive Research Center (MCEER) combines Resilience with earthquake disasters, and defines it as the possibility that the system reduces the possibility of vibration frequency when an earthquake occurs and can absorb the vibration and recover itself after the earthquake. Capacity[9]; Bruneau et al. proposed the definition of community resilience on the basis of research on seismic Resilience, that is, the community's ability to absorb damage and recover quickly[10]. By summarizing the resilience of various fields, Francis and Bekera proposed three characteristics of resilience, namely "outside resistance, ability to absorb outside risks, and self-recovery"[11]. Therefore, the general concept of resilience can be summarized as the ability of the system to maintain and restore the original state under the disturbance of the outside world, as well as the internal continuous learning and adaptation through self-organization.

2.2 Resilience combined with city

"Resilience" in the field of urban planning refers to the ability of the city as an independent system to be able to resist, absorb, gradually adapt and recover when it is disturbed by different types of external disasters, while keeping its own impact to a minimum[12]. In the 1990s, the research on resilience continued to deepen, and researchers began to combine resilience with urban public space, using resilience to characterize its resistance to external risks and damage to the risk of rapid response and timely recovery to achieve continuous operation. Ability[13]. At the same time, the system itself can continuously improve the ability to respond to risks through learning of existing risk cases. Research in the field of disasters has also continuously transformed from vulnerability research to resilience research paradigm[14]. For example, Younus[15] discusses climate change based on social resilience. Rose[16] measures the post-disaster economic situation through economic resilience and characterizes the degree of disaster impact ,, and Zhang Hui[17] used the literatures related to community disaster resilience in the SSCI database as analysis samples, and used Citespace software to summarize the literature on community disaster resilience research. Therefore, "urban resilience" can be defined as the city's ability to resist external disturbances under the disturbance of natural disasters, social risks and other external factors, and to restore its own operations within a certain period of time and its ability to adapt to external factors after an event[18].

3. System Construction of Influencing Factors of Urban Resilience Based on Social Ecosystem Perspective

As a complex giant system, the city contains a variety of subsystems with different functions. To study its toughness, it is necessary to consider the toughness of its internal subsystems and summarize them to highlight the degree of urban resilience. Different subsystems have different capabilities to deal with external risk disasters, and comprehensive analysis should be conducted in conjunction with urban ecological, engineering, and economic and social development issues. In order to make the resilience research have significant characteristics, this paper selects the disaster factors that have a significant impact on it as a model for related research, such as the comprehensive assessment model of flood disasters established by Zhou Chenghu[19], the comprehensive assessment model of natural disaster risk established by Ge Quansheng[20], He Baoyin established the flood risk evaluation model[21], and integrated the existing research results[22] [23] [24], and then gave the city resilience index factor weight, combined with the standard model to evaluate it. The constructed resilient city equation is expressed as: R (urban resilience) = F (ecological environment factor, municipal facility factor, economic development factor, social development factor).

Based on the 2014 Rockefeller Foundation Resilience City Index System[25], Liu Jiangyan[26] and other tenacity city evaluation systems, combined with urban sustainable development related indicators, a city resilience composite index system was established.

Table 1 Evaluation index of urban resilience based on social ecological perspective

Secondary indicators	Third-level indicators
Ecosystem	Green area ratio of urban built-up area
	Park area per capita
	Urban domestic sewage discharge
	Urban sewage treatment capacity
	Municipal solid waste removal volume
	Comprehensive utilization rate of industrial solid waste
Municipal facilities	Length of roads in cities
	Built-up area
	Internet penetration
	Drainage pipe length
	Gas penetration rate
Economic development	Tertiary industry income
	Savings deposit balance of urban and rural residents
	GDP per capita
	Urban residents' income level
	Actual foreign direct investment
Social development	City Engel Coefficient
	Number of beds in urban health institutions
	Number of students in ordinary colleges and universities
	Number of people enrolled in basic medical insurance
	Urban population
	Housing area per capita

4. City resilience assessment method

At present, the research on urban resilience at home and abroad is at the initial stage, mainly focusing on its concepts and definitions[27]. It has always been a question for academics to quantify and evaluate it. There are still a few scholars who have obtained some results on their quantitative assessment methods. For example, Bruneau[28] proposed that the toughness can be expressed by the change curve of the internal function of the infrastructure system with time in the study of community seismic toughness and listed Correlation function equations were implemented to achieve a quantitative assessment of community seismic toughness; Ouyang[29] used a curve model of the functional response process of infrastructure in the face of risk disasters to construct a framework system mainly used to assess the toughness of infrastructure ; Attoh-Okine[30], etc. will use the urban infrastructure resilience index system built on the basis of the reliability function framework for the assessment of the resilience of the highway network; Omer[31], etc. combine the concept of urban resilience with the city Combining the resilience of telecommunications networks, on the basis of network topology, redefine the toughness of urban telecommunications networks and evaluate their resilience; Todini[32] believes that urban water supply systems, as part of urban infrastructure, also have their own quantifiable resilience. The assessment of toughness is regarded as the optimization of the two objective functions of the toughness and cost of the water supply system, so that a Pareto optimal solution set is formed between the two.

Regarding the study of urban resilience, the academic community has gradually begun to transform from definitions and concepts, based on specific mathematical calculations, function equations and model calculations and simulations, to achieve quantitative assessment of urban resilience. This article will measure the city's resilience based on the perspective of social ecology, combined with the fully arranged polygon graphical index method and the entropy weight method.

4.1 Fully arranged polygon graphic index method

The fully arranged polygon graphic index method is a mathematical calculation method. It is currently mainly used for evaluation of urban ecology, land utilization and green ecological service capabilities. It has not been combined with urban resilience. This article will use historical objective data, For the first time, the city's toughness was measured using the fully arranged polygon icon method.Combined with relevant literature, define the fully arranged polygon graph index method: before the definition, the data needs to be standardized, and assuming that the research object has n indexes, then the upper limit of the n indexes (that is, the maximum value)) As a radius, construct a center regular n-polygon with a radius as the upper limit, and then connect the standard values of the data corresponding to the n indicators, and an irregular center n-polygon can be obtained within it. The n vertices are a total arrangement of n indicators connected end to end. There are $(n-1)!/2$ irregular center n polygons with different shapes. The calculation of each single index is the ratio of the area of the irregular center n polygon to the center positive n polygon.

Use the following standardized functions to standardize the indicators[33]:

$$F(x)=\frac{a(x+b)}{x+c}, a\neq 0, x\geq 0$$

$F(x)$ satisfies the following conditions:

$$F(L)=-1, F(T)=0, F(U)=1$$

Among them, L is the lower limit of the indicator, T is the critical threshold of the indicator, and U is the upper limit of the indicator.

Solve the following three formulas:

$$\frac{a(L+b)}{L+c}=-1$$

$$\frac{a(T+b)}{T+c}=0$$

$$\frac{a(T+b)}{T+c}=1$$

Get the expression of a, b, c:

$$a=\frac{U-L}{U+L-2T},\quad b=-T,\quad c=\frac{(L+U)T-2UL}{L+U-2T}$$

Substitute a, b, c into the standardized function to obtain the standardized calculation formula of the index value:

$$F(x)=\frac{(U-L)(x-T)}{(U+L-2T)x+UT+LT-2UL},\quad x\in[L,U]$$

Use the standardized function $F(x)$ to map the index value on $[L,U]$ to the [-1,1] interval, and change the growth rate of the index through the standardized method. When the index value is greater than the critical threshold, the normalized index growth rate gradually accelerates; otherwise, its growth rate gradually slows down.

According to the above formula, the standardized function of the i-th indicator can be obtained:

$$S_i = \frac{(U_i - L_i)(X_i - T_i)}{(U_i + L_i - 2T_i)X_i + U_i T_i + L_i T_i - 2U_i L_i}$$

The schematic diagram of the index method of fully arranged polygons is shown in Figure 1.

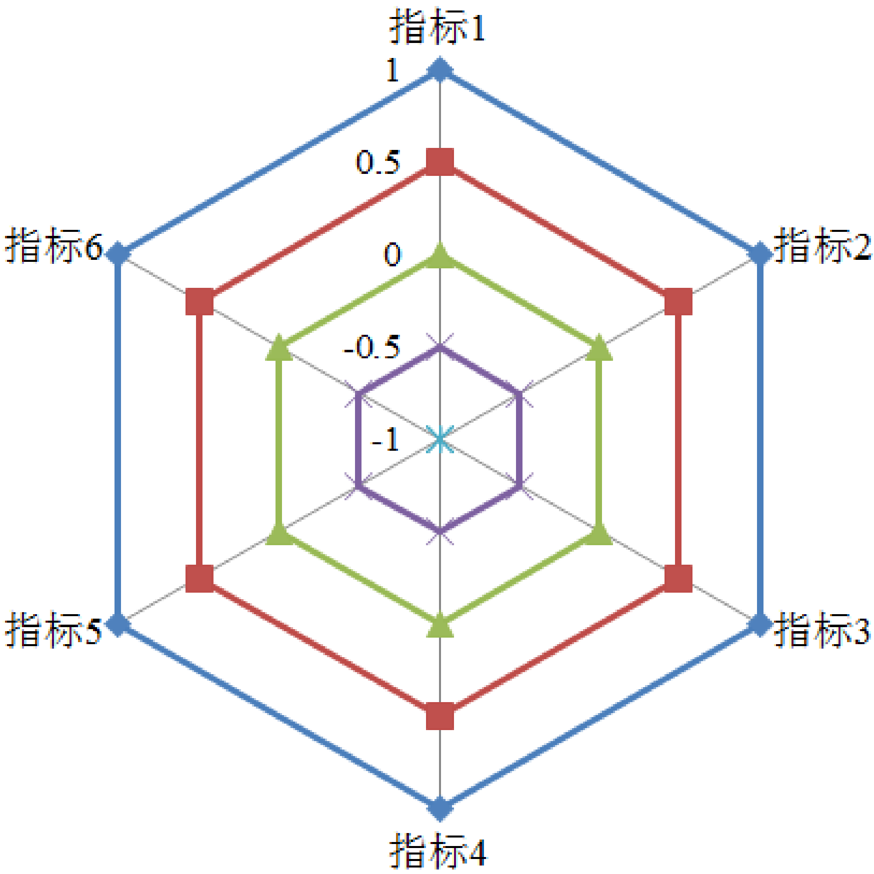

Fig. 1 Schematic diagram of the index method of fully arranged polygon icons

In order to make it easy to distinguish the calculated toughness, this article classifies the results. The results are shown in Table 2.

Table 2 Urban resilience grading standard

Grade	Index number	Resilience
I	＞0.75	Excellent
II	0.5~0.75	Better
III	0.25~0.5	General
Ⅳ	＜0.25	Poor

On the basis of calculating each index, the calculation formula of the comprehensive index of the fully arranged polygon can be obtained as follows：

$$S = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}(S_i + 1)(S_j + 1)}{2n(n-1)}, \quad i \neq j$$

Among them, S_i and S_j represent the standardized values of the i-th and j-th indicators, respectively, and S represents the value of the comprehensive indicator.

Compared with the traditional weighting method, the fully arranged polygon graphic index method is more convincing, reduces subjective judgment, the data source is more objective[34], the upper and lower limits of the index and their critical thresholds are based on local statistical data, and can also be based on The goal is to adjust it appropriately, to be more precise and flexible. Overall, the assessment of urban resilience using this method is relatively accurate and objective.

4.2 Entropy weight method

Entropy was first introduced into information theory by Shannon[35] to characterize the degree of chaos in system systems, and has been widely used in engineering technology, social economy and other fields. The basic idea of the entropy weight method is to determine the objective weight according to the index variability. The weighting steps are as follows:

(1) Data standardization

(2) Find the information entropy of each index

(3) Determine the weight of each indicator

In general, it is assumed that the smaller the information entropy E_j of a certain index, the greater the degree of variation of the index value, the more information is provided, the role played in the comprehensive evaluation is also relatively large, and the greater the weight Assuming that the greater the information entropy E_j of a certain index, the smaller the degree of variation of the index value and the less information provided, the role played in the comprehensive evaluation is relatively small, and the weight is smaller[36]. Information entropy is an effective scientific method for calculating the weight of each index. In this paper, the entropy weight method will be used to perform related calculations on the basis of the fully arranged polygon graphic index method.

5. Case urban resilience assessment

As the only municipality directly under the Central Government in central and western China, Chongqing is a central city of finance, science and technology, shipping, and trade and logistics centers. It is an important strategic fulcrum for the development of the western region, an important connection point of the “Belt and Road” and the Yangtze River Economic Belt, and an open highland inland. It has a significant impact on driving the economic development of the western region and promoting the steady and healthy development of the country. Therefore, how to maintain Chongqing’s ability to resist and adapt to external risks and restore its self-operation function within a short time after the disaster, that is, the resilience of Chongqing, is What this article will study. Aiming at the quantitative research of Chongqing's resilience, this paper combines the fully arranged polygon icon method and the entropy weight method to calculate the resilience of Chongqing.

5.1 Data Sources

The time span of relevant data used in this article is ten years, that is, from 2008 to 2017, Chongqing's data indicators are mainly derived from "Chongqing Statistical Yearbook", "China Statistical Yearbook", and partly from "Chongqing Environmental Bulletin", "China Urban Construction" Statistical Yearbook, "Statistical Report on the Development of China's Internet Network".

5.2 Chongqing Resilience Assessment

5.2.1 Chongqing Resilience Index Data Source

The time span of relevant data used in this article is ten years, that is, from 2008 to 2017, Chongqing's data indicators are mainly derived from "Chongqing Statistical Yearbook", "China Statistical Yearbook", and partly from "Chongqing Environmental Bulletin", "China Urban Construction" "Statistical Yearbook" and "Statistical Report on the Development of China's Internet Network" summarize the three-level indicators of the four indicators of Chongqing's ecological environment, municipal facilities, economic development and social development as follows:

Table 3 Data of eco-environment of Chongqing

	Urban green area ratio (%)	Park green area per capita (m2)	Urban sewage daily treatment capacity (10,000 cubic meters)	Urban domestic sewage discharge (10,000 tons)	Urban domestic garbage removal and transportation (10,000 tons)	Comprehensive utilization rate of industrial solid waste (%)
2008	30.93	8.91	53261	78086	225.2	79.1
2009	33.44	10.57	62027	81385	224.3	79.8
2010	36.19	12.72	69753	82933.3	256.7	80.4
2011	37.25	17.01	77208	97355.6	281.6	76.86
2012	39.12	17.41	80440	101676.69	335.29	81.6
2013	37.96	17.10	90699	106936.73	349.8	84
2014	37.39	16.54	97389	110705.2	399.37	84.2
2015	37.02	16.10	101176	114117.59	440	84.5
2016	37.87	16.18	107904	176020.84	494.1	76.9
2017	37.60	16.43	112096	181252.34	529.7	69.8

Table 4 Data of municipal facility of Chongqing

	Urban road length (km)	Built-up area (km^2)	Internet penetration rate(%)	Drainage pipe length (km)	Gas penetration rate(%)
2008	5937	933.04	33.6	7899	86.8
2009	6335	1026.84	34.3	9033	88.56
2010	6733	1136.53	34.6	9663	90.03
2011	7158	1325.44	37	11212	91.26
2012	7660	1324.94	40.9	12061	92.54
2013	8008	1395.86	43.9	13005	92.53
2014	8531	1470.12	45.7	14135	93.73
2015	9095	1529.15	48.3	15502	94.64
2016	9600	1494.47	51.6	17522	95.73
2017	10427	1573.02	53	19575	96.06

Table 5 Data of economic development of Chongqing

	Tertiary industry revenue (100 million yuan)	Balance of savings deposits of urban and rural residents (100 million yuan)	GDP per capita (yuan)	Urban residents' income level (yuan)	Actual foreign direct investment (ten thousand US dollars)
2008	2641.16	3988.96	20490	15709	245196
2009	2996.83	4908.68	22920	17191	337577
2010	3724.33	5839.66	27596	19100	304264
2011	4723.93	6990.25	34500	21955	582575
2012	5319.79	8361.64	38914	22968	352418
2013	5991.52	9622.31	42795	25216	414353
2014	6694.92	10774.12	47850	25147	423348
2015	7527.08	12207.28	52321	27239	377183
2016	8538.43	13399.44	58502	29610	279037
2017	9564.04	14367.38	63689	32193	222004

Table 6 Data of social development of Chongqing

	City Engel Coefficient (%)	Number of beds in urban health institutions	Number of students in ordinary colleges and universities	Number of people enrolled in basic medical insurance (10,000 people)	Urban population (ten thousand people)	Housing area per capita (m^2)
2008	39.1	81950	485013	326.15	1419.09	29.68
2009	37.2	92689	523279	362.43	1474.92	31.42
2010	37.5	103624	565868	406.21	1529.55	31.69
2011	38.5	115627	613026	458.48	1605.96	31.77
2012	41.5	130813	670174	496.48	1678.11	32.17
2013	35	147436	707610	539.53	1732.76	35.1
2014	34.5	160446	740534	575.77	1783.01	35.63
2015	33.6	176674	767114	588.46	1838.41	35.16
2016	32.7	190850	784631	604.76	1908.45	34
2017	32.1	206080	805208	640.28	1970.68	35.28

5.2.2 Calculation method of Chongqing resilience index

(1) Calculation result of fully arranged polygon graphic index method

According to the steps of the fully arranged polygon graphic index method, the collected data is substituted to obtain the standardized value of each index, and then the standardized value is calculated for the comprehensive index, and finally the total value of the ten-year toughness of each third-level index can be obtained (The mapping interval is [0,1]), as shown in Table 7 to 10.

Table 7 Result of standardization and resilience calculation of Chongqing ecological environment data

	Green area ratio of urban built-up area	Park area per capita	Urban sewage treatment capacity	Urban domestic sewage discharge	Municipal solid waste removal volume	Comprehensive utilization rate of industrial solid waste
2008	-1	-1	-1	-1	-0.9920	-0.0924
2009	-0.6521	-0.8151	-0.7429	-0.880	-1	0.0131
2010	-0.0779	-0.4914	-0.5059	-0.8259	-0.7217	0.1100
2011	0.2338	0.7895	-0.2673	-0.3849	-0.5215	-0.3833
2012	1	1	-0.1606	-0.2712	-0.1252	0.3250
2013	0.4855	0.8346	0.1916	-0.0959	-0.0256	0.8640
2014	0.2804	0.5728	0.4330	-0.0559	0.2931	0.9172
2015	0.1603	0.3946	0.5741	0.0186	0.5321	1
2016	0.4514	0.4254	0.8331	0.9462	0.8233	-0.3786
2017	0.3529	0.5262	1	1	1	-1
Resilience Value	0.6144	0.7227	0.5131	0.3330	0.4024	0.6258

Table 8 Result of chongqing municipal facilities data standardization and resilience calculation

	Length of roads in cities	Built-up area	Internet penetration	Drainage pipe length	Gas penetration rate
2008	-1	-1	-1	-1	-1
2009	-0.7859	-0.7992	-0.9118	-0.7535	-0.7114
2010	-0.5804	-0.5350	-0.8744	-0.6226	-0.4441
2011	-0.3696	0.0148	-0.5849	-0.3178	-0.1992
2012	-0.1316	0.0131	-0.1471	-0.1602	0.0791
2013	0.0268	0.2586	0.1649	0.0077	0.0769
2014	0.2554	0.5446	0.3427	0.1993	0.3625
2015	0.4900	0.7965	0.5880	0.4185	0.5974
2016	0.6903	0.6457	0.8813	0.7193	0.9022
2017	1	1	1	1	1
Resilience Value	0.4388	0.5747	0.4185	0.4293	0.5462

Table 9 Results of chongqing economic development data standardization and resilience calculation

	Tertiary industry income	Savings deposit balance of urban and rural residents	GDP per capita	Urban residents' income level	Actual foreign direct investment
2008	-1	-1	-1	-1	-0.7868
2009	-0.8769	-0.8144	-0.8758	-0.8071	-0.0996
2010	-0.6331	-0.6282	-0.6412	-0.5628	-0.3218
2011	-0.3148	-0.4005	-0.3046	-0.2055	1
2012	-0.1336	-0.1324	-0.0954	-0.0810	-0.0083
2013	0.0636	0.1108	0.0849	0.1910	0.3300
2014	0.2623	0.3304	0.3147	0.1827	0.3740
2015	0.4878	0.6003	0.5133	0.4309	0.1348
2016	0.7489	0.8219	0.7812	0.7065	-0.5081
2017	1	1	1	1	-1
Resilience Value	0.4382	0.4645	0.4543	0.4646	0.3977

Table 10 Result of standardization and resilience calculation of social development data in Chongqing

	City Engel Coefficient	Number of beds in urban health institutions	Number of students in ordinary colleges and universities	Number of people enrolled in basic medical insurance	Urban population	Housing area per capita
2008	0.5850	-1	-1	-1	-1	-1
2009	0.2167	-0.8089	-0.8115	-0.8089	-0.7965	-0.5536
2010	0.2774	-0.6181	--0.5885	-0.5668	-0.5976	-0.4764
2011	0.4728	-0.4130	-0.3239	-0.2591	-0.3199	-0.4531
2012	1	-0.1599	0.0251	-0.0217	-0.0580	-0.3331
2013	-0.2624	0.1095	0.2724	0.2626	0.1401	0.7534
2014	-0.3803	0.3149	0.5036	0.5155	0.3221	1
2015	-0.6017	0.5647	0.7005	0.6072	0.5225	0.7803
2016	-0.8361	0.7772	0.8356	0.7275	0.7755	0.2964
2017	-1	1	1	1	1	0.8350
Resilience Value	0.4267	0.4533	0.5377	0.5230	0.4761	0.5622

(1) Result of calculation of entropy weight method

The weighting step according to the entropy weight method can obtain the weight ratio of each third-level index in the second-level index, and the sum of the product of the weight value of each third-level index and its own toughness value can obtain the toughness of each second-level index Values and summarize them in Table 11.

Table 11 Calculation result of resilience value of Chongqing secondary index

	Ecosystem	Municipal facilities	Economic development	Social development
Resilience Value	0.5329	0.4810	0.4437	0.4961

5.3 Calculation result analysis

According to the calculated standardization results of each index data, the changes of each secondary index every year can be obtained, as shown in Figure 2 to 5.

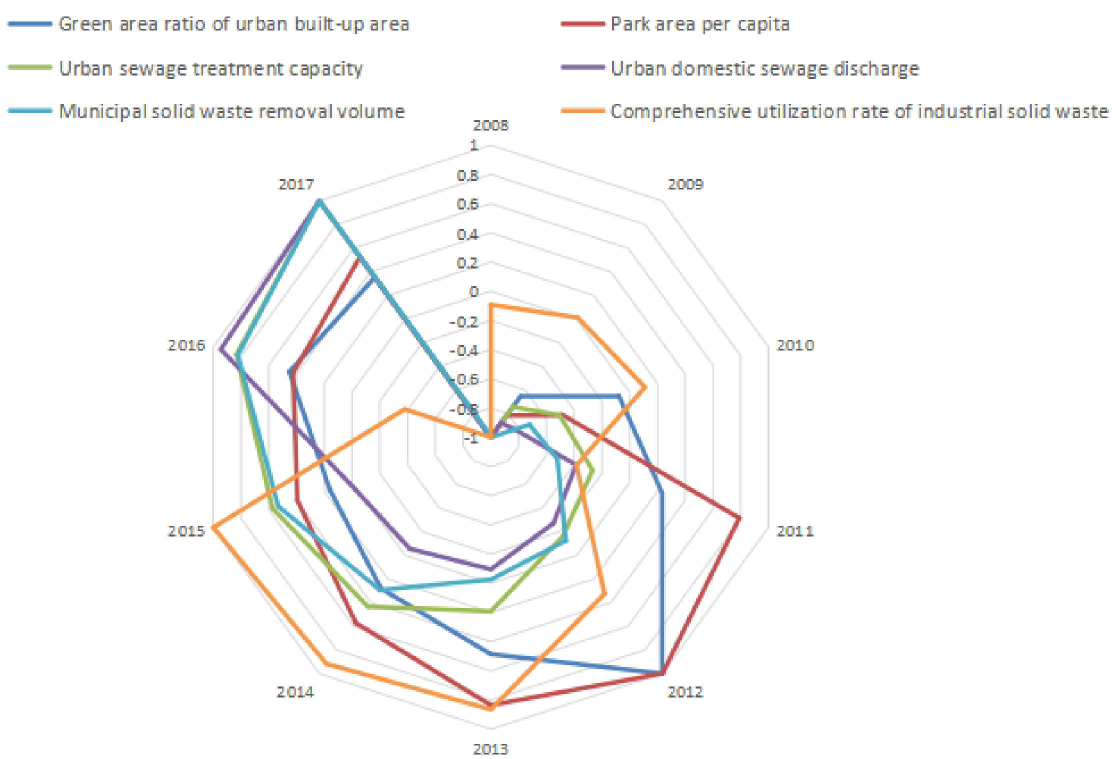

Fig.2 Polygonal diagram of all indicators of Chongqing ecological environment from 2008 to 2017

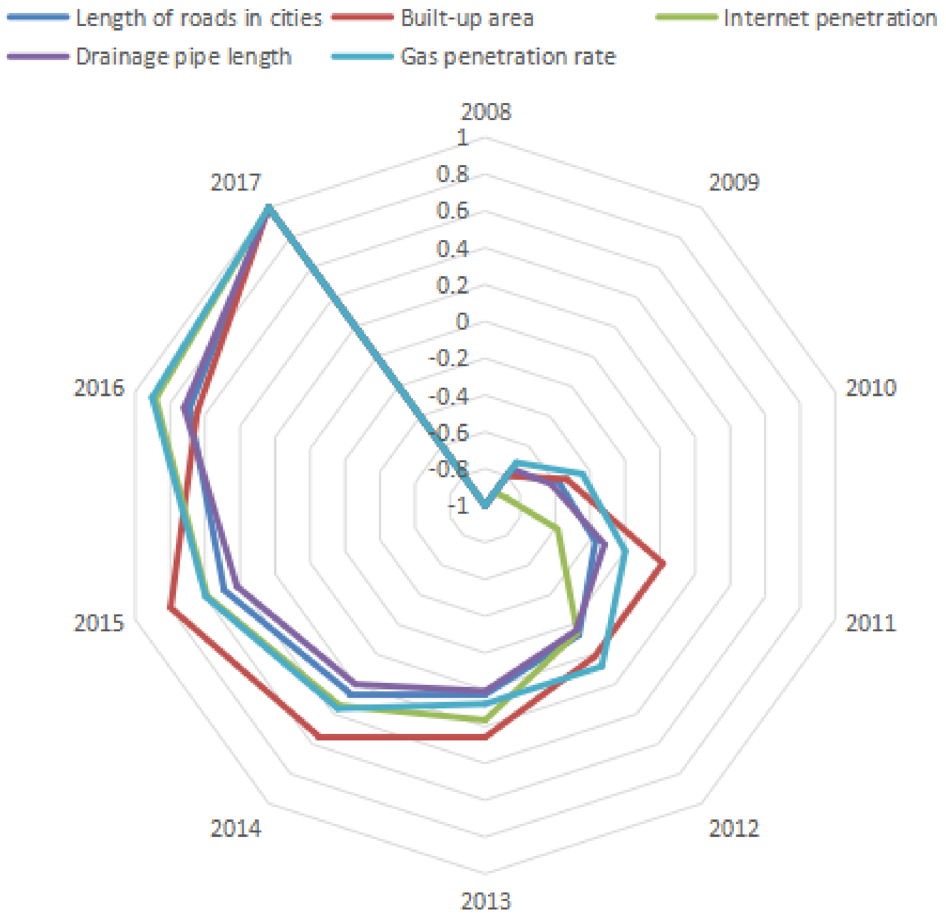

Fig.3 Polygon diagram of all indicators of Chongqing municipal facilities from 2008 to 2017

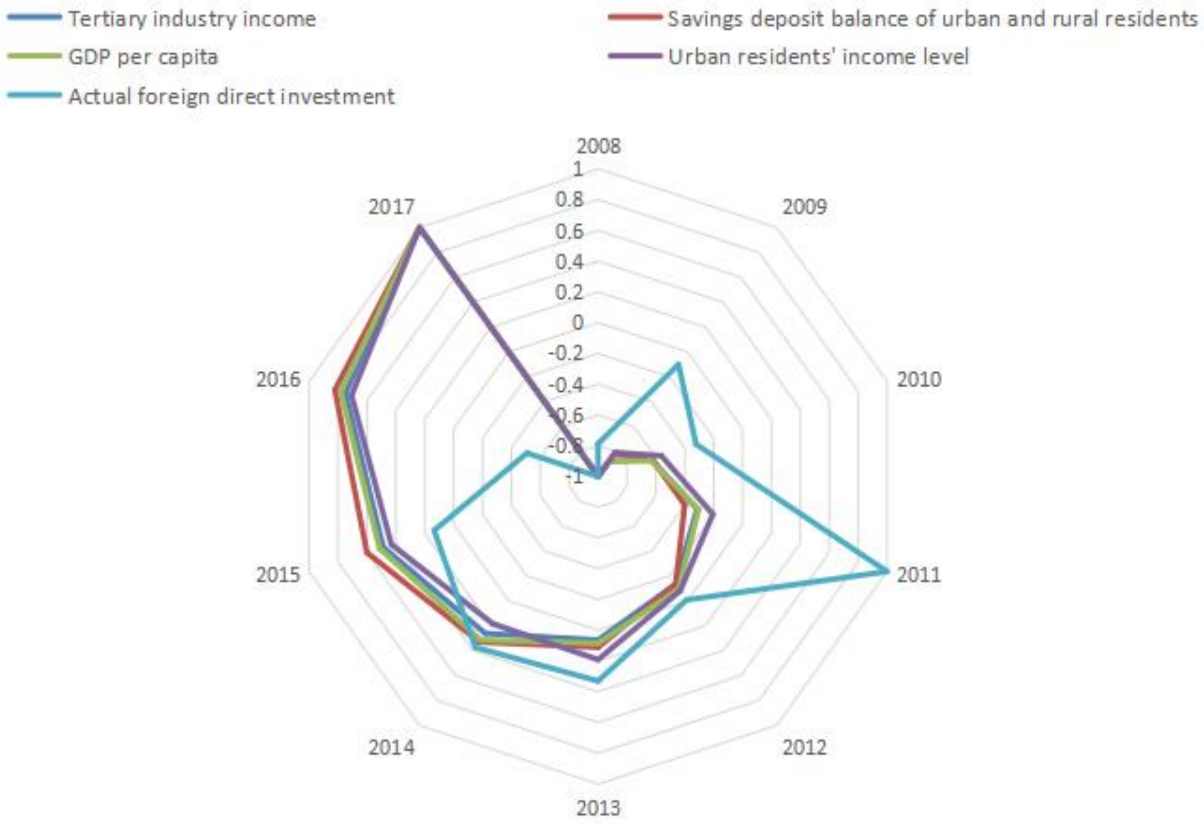

Fig.4 Polygonal diagram of all indicators of Chongqing's economic development from 2008 to 2017

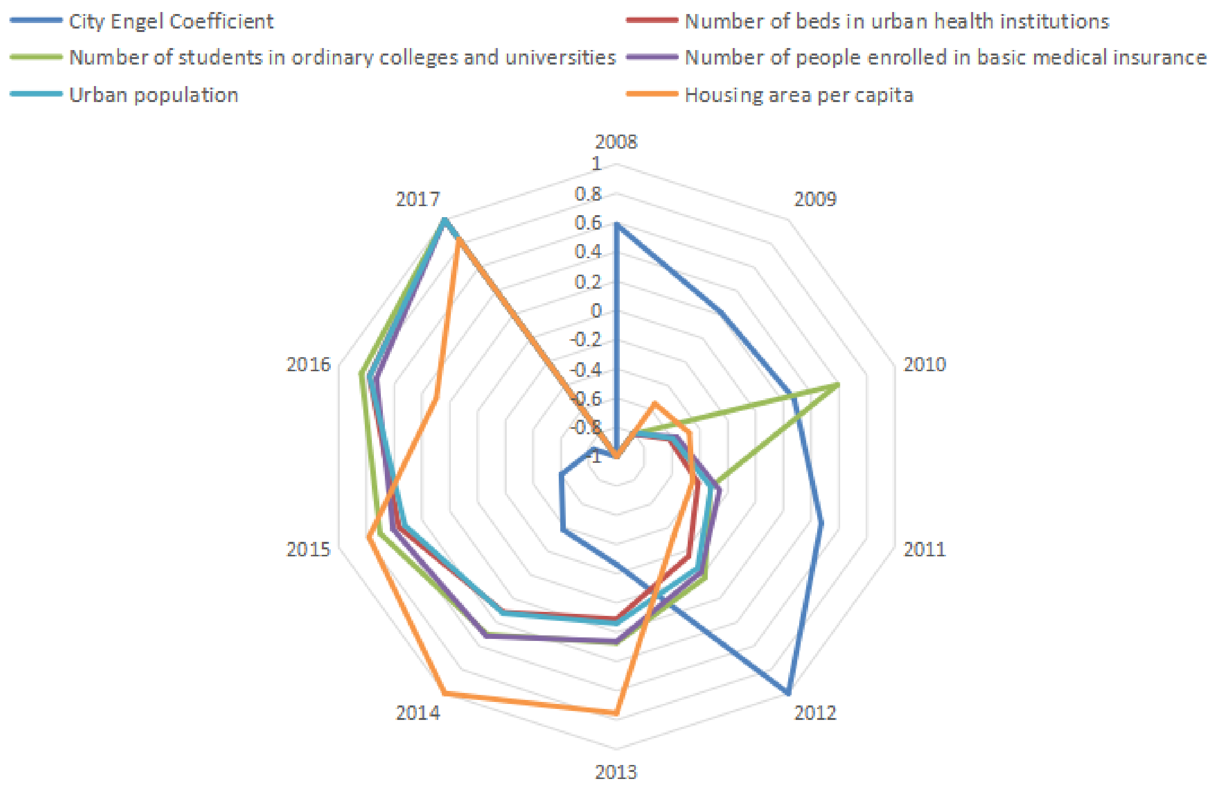

Fig.5 Polygonal diagram of all indicators of Chongqing's social development from 2008 to 2017

6. Conclusion

Quantitative research on urban resilience has always been one of the focuses of academic research. Through literature research, this paper builds a city resilience assessment system based on the perspective of social ecology. Using the fully arranged polygon graphical index method and entropy weight method, combined with the historical data collected, a quantitative assessment of the city's resilience in Chongqing has been conducted. The 10-year total toughness of the secondary indicators, combined with the calculation results, objectively evaluates them.

According to the calculation results, the toughness of each secondary index is ranked: ecological environment> social development> municipal facilities> economic development. It can be seen that Chongqing has the highest ecological environment resilience, indicating that the measures taken by the Chongqing municipal government to maintain the ecological environment and protect the natural environment are better than the other three aspects. In order to improve the overall urban resilience of Chongqing, it also needs to be improved Pay attention to social development, municipal facilities and economic development, increase investment and increase construction expenditure. Economic development is the basis for driving development in other fields, but Chongqing’s economic development has the lowest resilience, which means that its ability to resist external risks, respond to risks, and adapt to risks is very weak. When suffering major disasters and other events, economic losses will be relatively Increased, therefore, the resilience of economic development also needs the attention of the government and relevant departments.

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