Comprehensive Evaluation of Urban Ecological Carrying Capacity ——A Case Study of Chongqing

Li Qiulin(✉)

Chongqing University, Chongqing, China
Lql_cqu@126.com

Abstract. In some cities, the economic development remains high, but the ecological environment deteriorates rapidly. This means that their economy has exceeded the limits of urban ecological carrying capacity. Based on the P-S-R model, the quantitative index system of urban ecological carrying capacity was constructed, and the evaluation model of urban ecological carrying capacity including ecological support model, ecological pressure model and ecological carrying capacity model was established. The ecosystem capacity of Chongqing from 2007 to 2016 was evaluated comprehensively by using the evaluation index system. According to the evaluation results, the paper puts forward targeted guidance for the construction of ecological civilization in Chongqing, provides reference for ecological construction and sustainable development in Chongqing, and provides reference for the study of ecological carrying capacity in other areas.

Keywords: Urban ecological carrying capacity · Sustainable development · Index system · Chongqing

1 Introduction

Cities play an increasingly important role in the development of national economy. With the increase of population and the deterioration of ecological environment, the sustainable development of urban ecology is hindered. Sustainable development of ecological environment and social economy is attracting worldwide attention. It is generally believed that urban economic development and human activities will have a significant impact on the development of the ecological environment. Today's society is pursuing the coordinated development of ecological environment and social economy. Therefore, in order to seek the balanced development of ecological environment and socio-economic development, urban ecological carrying capacity has become an important indicator to measure the sustainable development of regional economy, society and ecology [1]. Establishing a clear ecological carrying capacity evaluation model to provide decision-making basis for management is urgently needed by the relevant government and institutions.

Sustainable development has shifted from conceptual and qualitative research to quantitative research. The evaluation of urban ecological carrying capacity has become

F. Long et al. (Eds.): CRIOCM 2018, *Proceedings of the 23rd International Symposium on Advancement of Construction Management and Real Estate*, pp. 854–868, 2021.
https://doi.org/10.1007/978-981-15-3977-0_65

an important part of the quantitative evaluation of sustainable development [2]. In the past, only one factor has been emphasized, that is, the carrying capacity of resources and environment, and the overall effect of ecosystem has been neglected [3, 4]. As we all know, urban ecosystem is a social-economic-natural complex system composed of human beings and their surrounding environment [5]. Therefore, scholars have studied the coordinated development of economic growth, ecological environment and ecological economy [6]. Indicators such as ecological footprint, energy/exergy, human development index, and environmental vulnerability index are used to evaluate the sustainability index of city [7]. On the basis of studying the relationship between environmental quality, ecological quality and social economy, Wang Jiayang et al. established the evaluation model of carrying capacity of regional ecological environment to social and economic development [8]. Mo Zhang et al. discussed the new meaning of urban resources and environment carrying capacity from water carrying capacity, land carrying capacity, atmospheric environment carrying capacity, energy carrying capacity, environmental carrying capacity and other aspects by constructing an evaluation index system containing 18 indicators [9]. Wei Fang et al. established a dynamic model of urban ecosystem including three subsystems: population subsystem, economic subsystem and resource and environment subsystem, and measured the urban ecological carrying capacity [10]. Jian Peng et al. constructed the index system of ecological carrying capacity from the aspects of ecosystem vitality, carrying capacity of resources and environment, and social development capacity [11]. Ying Li et al. constructed an evaluation model of ecological carrying capacity in shallow mountainous areas based on the evaluation index of urban ecological carrying capacity and pressure [12]. Furthermore, Linyu Xue and Xiaodong Xie believe that the assessment of carrying capacity should also pay attention to the key characteristics of potential impacts such as urban ecosystem, urban resources, urban ecological security and urban ecological activities [13]. Ranwang et al. applied subjective and objective comprehensive weighting method, comprehensive evaluation method and coupled coordination model to the evaluation system of resources and environmental carrying capacity of mining economic zones in China [14]. Jin Yue et al. divides the ecosystem of resource-based cities into four subsystems: resources, environment, society and economy. Based on the regional characteristics of resource-based cities and the characteristics of economic and social development, a complete quantitative evaluation index model of ecological capacity of resource-based cities is proposed [15]. Wang Geng and Dong Rui constructed a complex ecological carrying capacity evaluate model and index system from the four aspects of ecoelastic force, support force, pressure, human potential [16]. By quantitatively evaluating the sustainability of urban lake development, Lei Ding established a multi-objective model, which represents the water ecological carrying capacity [17]. Hai Long Liu et al. Liu Hailong et al. used elasticity, bearing capacity and load pressure to explore the relationship between ecological carrying capacity and urban scale structure [18].

Although the research methods or emphases are different, the calculation methods of ecological carrying capacity have not been unified yet, but there is a common trend in the research of ecological carrying capacity. In other words, the relevant research focuses on multi-factor coordination and systematic approach, rather than regarding human or environment as a single factor.

Taking Chongqing as a typical mountainous city as an example, on the basis of P-S-R model, the evaluation model of urban ecological carrying capacity was constructed, including ecological support model, ecological pressure model and ecological carrying capacity model. Based on the evaluation index system, the ecological carrying capacity of Chongqing from 2007 to 2016 was evaluated comprehensively, which provides theoretical reference for the study of the index system of ecological carrying capacity of mountain cities, and has practical significance for urban ecological construction and sustainable development 2 Data and methods

1.1 Study Area and Data

Based on the literature review, it is found that the research on urban ecological carrying capacity has gradually begun to focus on specific areas [19]. So this paper takes Chongqing as a case to evaluate the ecological carrying capacity. Chongqing is one of the 4 municipalities, one of China's five major cities. The upper Yangtze River economic and financial center, inland export processing base and first area of explanding the opening, an important morden manufacturing base in China. In 2017, the permanent population of Chongqing is 307.516 million, and the regional GDP is 1950.207 billion yuan (Chongqing statistical yearnbook 2017). As the youngest municipality in China, Chongqing always maintains a high economic growth rate, especially ranking first in the country for three consecutive years from 2014 to 2016 (China statistical yearbook 2014–2016). Chongqing has some common urban problems, such as population concentration, traffic congestion, air pollution and so on. Therefore, the coordinated development of economic growth and ecological environment has become an unavoidable problem in the development process of Chongqing. Moreover, Chongqing's landforms are dominated by hills and mountains, and its mountains account for 76%. So the comprehensive evaluation of ecological carrying capacity in Chongqing is a representative example.

The data in this paper are from: Chongqing Statistical Yearbook (2007–2016), China Statistical Yearbook (2007–2016), China Environmental Statistical Yearbook (2007–2016), Chongqing Environmental Status Report (2007–2016), Chongqing Land Resources and Housing Management Bulletin (2007–2016).

1.2 Methods

This paper divides ecosystems into support system, pressure system, and the load pressure capacity, which is shown in Fig. 1.

1.2.1 The Establishment and Standardization of the Index System

The comprehensive evaluation index system of ecological carrying capacity in Chongqing adopts the Pressure-State-Response (P-S-R) model. The P-S-R model integrates social, economic, resource, and environmental considerations to provide a theoretical framework for sustainable development. Within the framework of P-S-R, eco-environmental problems can be expressed as three interacting but different types of indicators: pressure indicators, state indicators and response indicators [20]. Among them, the pressure index is used to measure the changes in the ecosystem caused by

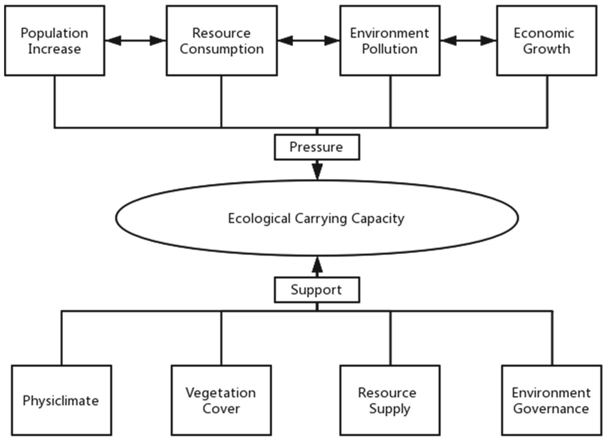

Fig. 1. Famework of ecological capacity

human behavior; the state index is used to express the status of the current ecosystem; the response index is the measure that people take for sustainable development. In the establishment of P-S-R model, due to the selection of many indicators, the indicators may be associated and overlapped, and the difference between indicators is very great, the units of the index are inconvenient, resulting in the unreasonable and inaccurate index selection. However, the model is highly systematic and has a reference for building an index system.

In the process of evaluating the ecological carrying capacity of Chongqing, a comprehensive evaluation index system including system layer, standard layer and index layer was established. The system layer is composed of the support system and the pressure system that reflect the ecological carrying capacity of Chongqing. The support system is composed of the response and status indicators of the PSR model. The pressure system is composed of the pressure indicators of the PSR model. The criteria layer is formed by reflecting the specific influencing factors of each evaluation index. The index layer is composed of specific evaluation indicators of various influencing factors. The support system includes annual average rainfall, annual average temperature, forest coverage rate, green coverage of build-up area, per capita park green area, per capita arable land area, innocuous treatment rate of domestic waste, comprehensive utilization of industrial solid waste and wastewater treatment rate. While the pressure system includes population density, natural population growth rate, urban unemployment rate, urbanization rate, million yuan of GDP energy consumption, million yuan of GDP power consumption, resident's per capita domestic water consumption, resident's per capita electricity consumption, annual average annual average of nitrogen dioxide in the main city, annual average value of sulfur dioxide in the main city, annual mean value of atmospheric inhalable particulates in urban areas, per capita GDP, GDP growth rate, annual per capita disposable income of urban residents and engel coefficient of urban residents. The final index system is shown in Table 1. The detailed values of each indicator layer are shown in Table 2.

Table 1. Comprehensive evaluation index system of ecological carrying capacity in Chongqing city

System layer	Criteria layer	Serial number	Index layer	Attributes
Support system	Physioclimate	x_1	Annual average rainfall (mm)	+
		x_2	Annual average temperature (mm)	+
	Vegetation cover	x_3	Forest coverage rate (%)	+
		x_4	Green coverage of bulid-up area	+
		x_5	Per capita park green area (m^2)	+
	Resource supply	x_6	Per capita arable land area (m^2)	+
		x_7	Innocuous treatment rate of domestic waste (%)	+
	Environment governance	x_8	Comprehensive utilization of industrial solid waste (%)	+
		x_9	Wastewater treatment rate (%)	+
		x_{10}	Urban population density (person/km^2)	−
Pressure system	Population increase	x_{11}	Natural population growth rate (‰)	−
		x_{12}	Urban unemployment rate (%)	−
		x_{13}	Urbanization rate (%)	+
		x_{14}	Million yuan of GDP energy consumption	−
	Resource consumption	x_{15}	Million yuan of GDP power consumption	−
		x_{16}	Per capita daily water consumption of residents (L)	−
		x_{17}	Resident's per capita electricity consumption (municipal districts)/(kWh/person)	−
		x_{18}	Annual average annual average of nitrogen dioxide in the main city (mg/m^3)	−
	Environment pollution	X_{19}	Annual average value of sulfur dioxide in the main city (mg/m^3)	−
		x_{20}	Annual mean value of atmospheric inhalable particulates in urban areas (mg/m^3)	−
		x_{21}	Per capita GDP (yuan)	+
	Economic growth	x_{22}	GDP growth rate (%)	+
		x_{23}	Annual per capita disposable income of urban residents (yuan)	+
		x_{24}	Engel coefficient of urban residents (%)	+

In this paper, extreme standard method is used to eliminate the influence of different dimensions and sizes of raw data, and normalize the index data, so that the index value is between [0, 1].

Positive indicators:

$$I_i = 1 - \frac{x_i - x_{im}}{x_{iM} - x_{im}} \tag{1}$$

Negative indicators:

$$I_i = \frac{x_i - x_{im}}{x_{iM} - x_{im}} \tag{2}$$

Where, x_i is the actual value of i-th index of j-th research object, x_{im} is the minimum value of i-th index, x_{iM} is the maximum value of i-th index, and I_i is the value of single normalization index.

According to the standardized treatment formula of the indicator, the standardized value can be obtained, which is shown in Table 3.

1.2.2 The Weighting of Evaluation Indicators

When determining the weight of evaluation index, there are generally two methods of determining the weight, subjective and objective. The objective weight method does not depend on people's subjective judgment, and the method is more convincing. In order to ensure the objectivity of the index weight distribution and improve the rationality and scientificity of the evaluation results, this paper uses the entropy weight method to assign the objective weight.

Therefore, the information entropy is used to calculate the weight of indicators to reflect the difference of indicators. The calculation steps are as follows:

(1) The proportion p_{ij} of *i*-th index was evaluated as:

$$p_{ij} = \frac{I_{ij}}{\sum_{i=1}^{n} I_{ij}} \tag{3}$$

Where, I_{ij} is the calculated index of i-th index of j-th grade, and n was the samples' number.

(2) The entropy e_i of *i*-th index was evaluated as:

$$e_i = -k \sum_{i=1}^{n} p_{ij} lnp_{ij} \tag{4}$$

Where, k is Boltzmann constant, $k = \frac{1}{lnn}$.

Table 2. The detailed values of each indicator layer for ecological carrying capacity in Chongqing City during 2007–2016.

Serial number	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
x_1	1439.2	985.3	1198.9	1044.7	992.8	1104.4	1026.9	1452.5	1448.7	1217.8
x_2	19	18.6	19	18.7	17.7	18.3	19.9	18.6	19.6	19.5
x_3	32	34	35	37	39	41	42.1	43.1	45	45.4
x_4	31.8	35.9	38.5	40.6	40.2	42.9	41.7	41	40.3	40.78
x_5	7.61	9.62	11.25	13.24	17.87	18.13	18.04	17.3	16.99	16.86
x_6	0.0795	0.0788	0.0747	0.0847	0.0839	0.0832	0.0827	0.082	0.0805	0.0782
x_7	70.22	79.1	89	94	97	99.17	98.85	99.25	98.85	100
x_8	76.7	79.1	79.8	80.4	76.86	81.6	84	84.2	84.5	88.94
x_9	74.4	84.2	88.4	91.7	94.62	90.07	94	93	94.8	94.74
x_{10}	1527	1574	1637	1860	1830	1832	1847	1872	1904	1953
x_{11}	8.73	5.76	4.5	7.25	6.54	3.88	4.67	5.1	4.01	4.53
x_{12}	4	3.86	3.96	3.9	3.5	3.3	3.4	3.46	3.6	3.7
x_{13}	48.3	50	51.6	53	55	57	58.3	59.6	60.9	62.6
x_{14}	1.333	1.25	1.181	0.991	0.953	0.886	0.685	0.659	0.618	0.575
x_{15}	0.46	0.38	0.35	0.3	0.29	0.27	0.23	0.14	0.134	0.127
x_{16}	140.6	143.6	141.5	136.8	145.4	148.8	154	146.1	152	151.6
x_{17}	417.75	221.8265	204.8077	218.4819	262.0578	270.1014	339.7169	312.236	339.7169	369.894
x_{18}	0.044	0.043	0.037	0.039	0.032	0.035	0.038	0.039	0.045	0.046
x_{19}	0.065	0.063	0.053	0.048	0.038	0.037	0.032	0.024	0.016	0.013
x_{20}	0.108	0.106	0.105	0.102	0.093	0.09	0.106	0.098	0.087	0.077
x_{21}	16629	20490	22920	27596	34500	38914	42795	47859	52330	57902
x_{22}	15.9	14.5	14.9	17.1	16.4	13.6	12.3	10.9	11	10.70%
x_{23}	12590.78	14367.55	15748.67	17532.43	20249.7	22968.14	23058	25147	27239	32193
x_{24}	37.2	39.6	37.7	37.6	39.1	41.5	35	34.5	33.6	32.7

Table 3. Standardized data of comprehensive evaluation index system for urban ecological carrying capacity of Chongqing City during 2007–2016

Serial number	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
x_1	0.0285	1	0.5428	0.8729	0.9839	0.7451	0.9110	0	0.0081	0.5024
x_2	0.4091	0.5909	0.4091	0.5455	1	0.7273	0	0.5909	0.1364	0.1818
x_3	1	0.8507	0.7761	0.6269	0.4776	0.3284	0.2463	0.1716	0.0299	0
x_4	1	0.6306	0.3964	0.2072	0.2432	0	0.1081	0.1712	0.2342	0.1910
x_5	1	0.8089	0.6540	0.4648	0.0247	0	0.0086	0.0789	0.1084	0.1207
x_6	0.52	0.59	1	0	0.08	0.15	0.2	0.27	0.42	0.65
x_7	1	0.7018	0.3694	0.2015	0.1007	0.0279	0.0386	0.0252	0.0386	0
x_8	1	0.8039	0.7467	0.6977	0.9869	0.5997	0.4036	0.3873	0.3627	0
x_9	1	0.5196	0.3137	0.1520	0.0088	0.2319	0.0392	0.0882	0	0.0029
x_{10}	0	0.1103	0.2582	0.7817	0.7113	0.7160	0.7512	0.8099	0.8850	1
x_{11}	1	0.3876	0.1278	0.6948	0.5485	0	0.1629	0.2515	0.0268	0.1340
x_{12}	1	0.8	0.9429	0.8571	0.2857	0	0.1429	0.2286	0.4286	0.5714
x_{13}	1	0.8811	0.7692	0.6713	0.5315	0.3916	0.3007	0.2098	0.1189	0
x_{14}	1	0.8905	0.7995	0.5488	0.4987	0.4103	0.1451	0.1108	0.0567	0
x_{15}	1	0.7598	0.6697	0.5195	0.4895	0.4294	0.3093	0.0390	0.0210	0
x_{16}	0.2209	0.3953	0.2733	0	0.5	0.6977	1	0.5407	0.8837	0.8605
x_{17}	1	0.0799	0	0.0642	0.2689	0.3066	0.6335	0.5045	0.6335	0.7753
x_{18}	0.8571	0.7857	0.3571	0.5	0	0.2143	0.4286	0.5	0.9286	1
x_{19}	1	0.9615	0.7692	0.6731	0.4808	0.4615	0.3654	0.2115	0.0577	0
x_{20}	1	0.9355	0.9032	0.8065	0.5161	0.4194	0.9355	0.6774	0.3226	0
x_{21}	1	0.9065	0.8476	0.7343	0.5670	0.4601	0.3660	0.2433	0.1350	0
x_{22}	0.9294	0.1530	0.1295	0	0.0412	0.2060	0.2825	0.3649	0.3590	1
x_{23}	1	0.9094	0.8389	0.7479	0.6093	0.4706	0.4660	0.3594	0.2527	0
x_{24}	0.5114	0.2159	0.4318	0.4432	0.2727	0	0.7386	0.7955	0.8977	1

(3) The entropy right w i of the *i*-th index was evaluated as:

$$w_i = \frac{1 - e_i}{\sum_{i=1}^{n} (1 - e_i)} \tag{5}$$

(4) The regional composite evaluation index I was calculated based on the entropy right w_i of each index.

$$I = \sum_{i=1}^{n} w_i I_{IJ} \tag{6}$$

As shown in Table 4, we can see the calculation results of weights that the population density and per capita GDP have higher weights, which illustrates that population increase and economic growth bring greater pressure on the ecological carrying capacity of Chongqing.

Table 4. The weight of comprehensive evaluation index of ecological carrying capacity in Chongqing

Index	Weight	Index	Weight
x_1	0.0447	x_{13}	0.0329
x_2	0.0295	x_{14}	0.0448
x_3	0.0416	x_{15}	0.0456
x_4	0.0441	x_{16}	0.0261
x_5	0.0777	x_{17}	0.0418
x_6	0.0394	x_{18}	0.0251
x_7	0.0930	x_{19}	0.0352
x_8	0.0211	x_{20}	0.0205
x_9	0.0894	x_{21}	0.0301
x_{10}	0.0270	x_{22}	0.0545
x_{11}	0.0543	x_{23}	0.0232
x_{12}	0.0324	x_{24}	0.0262

1.2.3 Construction of Evaluation Model of Ecological Carrying Capacity

This paper uses the support index, the pressure index and the load pressure index to quantitatively describe the ecological carrying capacity of Chongqing. The support index represents the target carrying capacity of urban ecosystem, and the pressure index represents the ecological pressure caused by economic development and social progress. The load pressure index is used to evaluate the urban ecological carrying capacity [21].

(1) The calculation of ecosystem support index

$$S = \sum\nolimits_{i=1}^{m} Z_i W_i \tag{7}$$

Where, S is the carrying index of the ecosystem. Z_i and W_i are the normalized values and weights supporting index i, respectively.

(2) The calculation of ecosystem pressure index

$$P = \sum\nolimits_{j=1}^{m} Y_j W_j \tag{8}$$

Where, P is the pressure index of the ecosystem. Y_j and W_j are the normalized values and corresponding weights of pressure index j, respectively.

(3) The calculation of ecosystem load pressure index

$$D = P/S \tag{9}$$

The carrying capacity of the ecosystem is reflected by the ecosystem support index and the ecosystem pressure index. The greater the support index, the greater the carrying capacity of the ecosystem. The greater the pressure index, the greater the pressure on the ecosystem, the lower the carrying capacity of the ecosystem. The load pressure index is used to express the overall bearing status of the ecosystem, and the analysis of the load pressure index can be used to know the reasons for overloading, and then take some measures to improve the ecological carrying capacity.

1.2.4 The Determination of the Evaluation Criteria for the Analysis of Ecological Carrying Capacity

In this paper, the uniform distribution function is used to draw up the grading evaluation standard, and the comprehensive evaluation of the ecological carrying capacity is carried out. The grading evaluation standard of each system is shown in Table 5.

Table 5. Classification evaluation standard of ecological carrying capacity

Index value	The evaluation of support system	The evaluation of pressure system	Index value	The evaluation of load pressure index
0 − 0.2	Low	Low	<1	Low load
0.21 − 0.4	Lower	Lower		
0.41 − 0.6	Medium	Medium	1	Achieve balance
0.61 − 0.8	Higher	Higher		
>0.8	High	High	>1	High load

2 Results and Analysis

2.1 Results

The comprehensive evaluation of ecological carrying capacity is based on the evaluation of support subsystem and pressure subsystem respectively, and takes into account the impact of the two subsystems on the whole regional system, so as to evaluate the urban ecological carrying capacity quantitatively.

2.1.1 The Evaluation of Support Subsystem

The comprehensive evaluation value of the support subsystem is represented by the support index, and formula (7) is used to calculate the support index of each year in Chongqing,as shown in the Table 6.

Table 6. The comprehensive evaluation value of Chongqing support index from 2007 to 2016

Year	The support index	Rank	The evaluation of support system
2007	0.40	1	Lower
2008	0.34	2	Lower
2009	0.26	4	Lower
2010	0.19	5	Low
2011	0.16	6	Low
2012	0.13	7	Low
2013	0.10	8	Low
2014	0.30	3	Lower
2015	0.08	10	Low
2016	0.10	9	Low

2.1.2 The Evaluation of Pressure Subsystem

The comprehensive evaluation value of the pressure subsystem is expressed by the pressure index, and the pressure index for each year of Chongqing in 2007–2016 is calculated using formula (8), as shown in Table 7.

Table 7. The comprehensive evaluation value of Chongqing pressure index from 2007 to 2016

Year	The pressure index	Rank	The evaluation of pressure system
2007	0.45	10	Medium
2008	0.30	9	Lower
2009	0.25	8	Lower
2010	0.24	7	Lower
2011	0.19	5	Low
2012	0.15	1	Low
2013	0.20	6	Low
2014	0.16	3	Low
2015	0.16	2	Low
2016	0.19	4	Low

2.1.3 The Evaluation of the Load Pressure Index

The evaluation of load pressure index is based on the quantitative evaluation of the ratio of pressure index to support index, which comprehensively reflects the situation of ecological carrying capacity. The annual load pressure index of Chongqing from 2007 to 2016 is calculated by formula (9), as shown in Table 8.

Table 8. The comprehensive evaluation value of Chongqing load pressure index from 2007 to 2016

Year	The load pressure index	Rank	Index value	The evaluation of load pressure index
2007	1.1288	4	>1	High load
2008	0.8728	2	<1	Low load
2009	0.9730	3	<1	Low load
2010	1.2465	7	>1	High load
2011	1.2153	6	>1	High load
2012	1.1427	5	>1	High load
2013	1.9566	9	>1	High load
2014	0.5398	1	<1	Low load
2015	2.0700	10	>1	High load
2016	1.8944	8	>1	High load

2.1.4 The Comprehensive Evaluation of Ecological Carrying Capacity

Load pressure index reflects the comprehensive evaluation of ecological carrying capacity, and there is a negative correlation between them. Based on the evaluation of support subsystem and pressure subsystem, the ecological carrying capacity of the city is evaluated comprehensively considering the impact of the two subsystems. The final comprehensive evaluation results are shown in Table 9 and Fig. 2.

Table 9. The comprehensive evaluation of the ecological carrying capacity in Chongqing from 2007 to 2016

Year	The support index	The evaluation of support system	The pressure index	The evaluation of pressure system	The load pressure index	Index value	The evaluation of load pressure index
2007	0.40	Lower	0.45	Medium	1.1288	>1	High load
2008	0.34	Lower	0.30	Lower	0.8728	<1	Low load
2009	0.26	Lower	0.25	Lower	0.9730	<1	Low load
2010	0.19	Low	0.24	Lower	1.2465	>1	High load
2011	0.16	Low	0.19	Low	1.2153	>1	High load
2012	0.13	Low	0.15	Low	1.1427	>1	High load
2013	0.10	Low	0.20	Low	1.9566	>1	High load
2014	0.30	Lower	0.16	Low	0.5398	>1	Low load
2015	0.08	Low	0.16	Low	2.0700	>1	High load
2016	0.10	Low	0.19	Low	1.8944	>1	High load

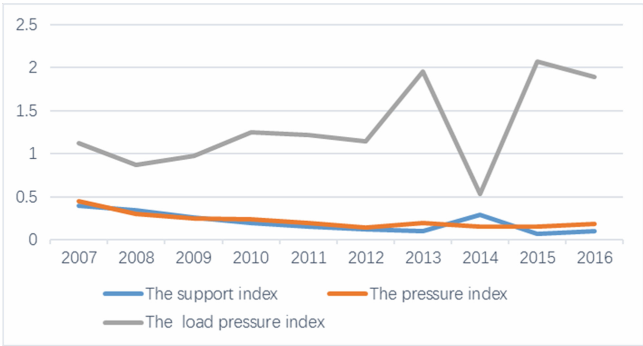

Fig. 2. The comprehensive evaluation of the ecological carrying capacity in Chongqing from 2007 to 2016

2.2 Analysis

As can be seen from Table 6, the support index of the ecological carrying system in Chongqing from 2007 to 2016 is relatively low, and it is declining year by year. In 2014, the support index of Chongqing increased, but it gradually declined after 2014. It shows that in 2014, Chongqing City adopted more effective measures, such as reducing the emission of pollutants and increasing production efficiency, making the supporting capacity of the Chongqing support system more effective. In general, during 2007–2016, the support capacity of Chongqing's support system showed a downward trend, indicating that Chongqing needs to take measures to increase the support capacity and alleviate the contradictions brought about by the sharp increase in population and insufficient resources.

As can be seen from Table 7, the pressure on Chongqing's ecological carrying capacity has been declining since 2007–2016. Especially, during the period of 2007–2012, the pressure index of the Chongqing ecological carrying capacity dropped year by year. This shows that Chongqing achieved some achievements on environmental governance, and solved some problems about the environmental pollution, waste of resources, and insufficient resources due to economic growth. In general, the pressure on Chongqing's carrying system during 2007–2016 has been on the decline. It shows that the damage to the environment in Chongqing is gradually decreasing.

From Table 8, it can be concluded that the load pressure index in Chongqing was low during the period of 2008–2009, which shows under the background of population and economic growth at that time, its ecological environment capacity was relatively surplus. Except for 2014, the ecological carrying capacity was overloaded during the period of 2010–2016, which explained that due to a series of problems such as excessive resource consumption, waste generation and emission increase, the ecological environment of Chongqing was destroyed. However, the load pressure index gradually decreased, which shows that a series of measures such as energy saving, emission reduction, population control, and environmental protection planning in Chongqing slowed the pace of ecological environmental damage in 2014.

From Table 9 and Fig. 2, we can see that in 2007–2016, the ecological support and pressure system in Chongqing beared relatively low support and pressure. Except for 2014, the ecosystem load in 2010–2016 is high and the ecological environment capacity is relatively tight. In 2014, a series of environmental protection measures were introduced and the seven ecological civilization reform tasks were implemented to improve the ecological carrying capacity of Chongqing.

3 Conclusion

(1) Based on the comprehensive evaluation of the ecological carrying capacity in Chongqing, the ecological carrying capacity system is mostly under high load in recent years. The support subsystem has always been under a state of low load bearing, and the pressure on the pressure subsystem is mostly in a relatively low state. Therefore, Chongqing needs to increase the support subsystem and thus improve the comprehensive ecological carrying capacity.

(2) Chongqing must adhere to the principle of paying equal attention to ecological protection and economic development, and regard improving ecological carrying capacity as the primary task. Actively change the economic development mode and adjust the industrial structure, and guide the urban planning and construction with the ecological concept, build the ecological economy system with the recycling economy as the core, build the ecological atmosphere with the guidance of the ecological civilization, attach importance to the development and application of ecological technologies, and strengthen the environmental pollution Comprehensive prevention and control, strictly control population growth. At the same time, it will increase the propaganda of ecological environment protection and enhance the people's ecological awareness. From government to individuals, improve the overall ecological carrying capacity of cities from all aspects so as to achieve sustainable development.

Acknowledgment. This study was supported by the National Planning Office of Philosophy and Social Science Foundation of China under Grant No. "17ZDA062", "15BJY038" and "15AZD025".

References

1. Costanza, R.: Economic growth, carrying capacity, and the environment. Ecol. Econ. **15**(2), 89–90 (1995)
2. Ru, X., Wu, H., Zhangqing, Q.: Comprehensive evaluation for ecoIogicaI carring capacity of JInan. **26**(01), 87–92 (2013)
3. Chen, H.S., Chen, C.Y., Chang, C.T., Hsieh, T.: The construction and application of a carrying capacity evaluation model in a national park. Stochast. Environ. Res. Risk Assess. **28**(6), 1333–1341 (2014)
4. Yan, C., Zhang, Z.: Interspecific interaction strength influences population density more than carrying capacity in more complex ecological networks. Ecol. Model. **332**, 1–7 (2016)

5. Kang, P., Xu, L.: The urban ecological regulation based on ecological carrying capacity. Proc. Environ. Sci. **2**, 1692–1700 (2010)
6. Yuan, B., Ren, S., Chen, X.: Can environmental regulation promote the coordinated development of economy and environment in china's manufacturing industry?–a panel data analysis of 28 sub-sectors. J. Clean. Prod. **149**, 11–24 (2017)
7. Mori, K., Christodoulou, A.: Review of sustainability indices and indicators: towards a new City sustainability index (CSI). Environ. Impact Assess. Rev. **32**(1), 94–106 (2012)
8. Wang, J., Wei, X., Guo, Q.: A three-dimensional evaluation model for regional carrying capacity of ecological environment to social economic development: model development and a case study in China. Ecol. Indic. **89**, 348–355 (2018)
9. Zhang, M., Liu, Y., Jing, W., Wang, T.: Index system of urban resource and environment carrying capacity based on ecological civilization. Environ. Impact Assess. Rev. **68**, 90–97 (2018)
10. Peng, J., Yueyue, D., Liu, Y., Xiaoxu, H.: How to assess urban development potential in mountain areas? an approach of ecological carrying capacity in the view of coupled human and natural systems. Ecol. Indic. **60**, 1017–1030 (2016)
11. Peng, J., Yueyue, D., Liu, Y., Xiaoxu, H.: How to assess urban development potential in mountain areas? an approach of ecological carrying capacity in the view of coupled human and natural systems. Ecol. Indic. **60**, 1017–1030 (2016)
12. Li, Y., Zhou, G.J.: Construction of the Evaluation Model for Ecological Carrying Capacity of Shallow Mountain Area in Beijing. Proc. Environ. Sci. **11**, 874–879 (2011)
13. Xu, L., Xie, X.: Theoretic research on the relevant concepts of urban ecosystem carrying capacity. Proc. Environ. Sci. **13**, 863–872 (2012)
14. Wang, R., Cheng, J., Zhu, Y., et al.: Evaluation on the coupling coordination of resources and environment carrying capacity in Chinese mining economic zones. Res. Policy **53**, 20–25 (2017)
15. Jin Yue, L., Zhaohua, T.F., et al.: Assessment of ecological carrying capacity on the typical resources-based cities: a case study of Tangshan City. Acta Ecol. Sin. **35**(14), 4852–4859 (2015)
16. Geng, W., Rui, D.: Dynamic evaluation and adaptive management countermeasures of ecological carrying capacity of the green transformation in Taiyuan city. Res. Ind. **20**(2), 28–35 (2018)
17. Ding, L., Kun-lun, C., Cheng, S., Wang, X.: Water ecological carrying capacity of urban lakes in the context of rapid urbanization: a case study of East lake in Wuhan. Phys. Chem. Earth **89**, 104–113 (2015)
18. Liu, H.L., Shi, P.J., Zhang, S.W., Chen, L.: Research on the urban system scale structure in loess plateau based on the ecological carrying capacity — taking qingyang city as case study, vol. 5, pp. 6018–6023 (2012)
19. Navarro, J., Damian, I.M., Fernandez-Morales, A.: Carrying capacity model applied in coastal destinations. Ann. Tour. Res. **43**, 1–19 (2013)
20. Peng, W., Chen, M., Yuan, S., et al.: Comprehensive evaluation of ecological carrying capacity in Wuhan city. Hubei Agri. Sci. **57**(3), 37–40 (2018)
21. Ban, X., Wen, H., Song, B., et al.: Evaluation of ecological carrying capacity based on ecological footprint in Shijiazhuang city. resource. Dev. Mark. **26**(12), 1074–1077, 1100 (2010)