A Novel Evaluation algorithm of Urban Comprehensive Carrying Capacity Index System in Northwest China: Lanzhou city as an example

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Abstract. With the rapid growth of the urban population and quick expansion of urban dimensions, the affecting urban development constraints of urban carrying capacity has increasingly been attracting people’s attention. However, the effective synthesization of urban resources carrying capacity, urban environmental carrying capacity, economic carrying capacity, society carrying capacity and traffic carrying capacity hardly acted as an urban comprehensive carrying capacity evaluation system. In this paper, the novel comprehensive index system of urban resources carrying capacity, urban environmental carrying capacity, economic carrying capacity, society carrying capacity and traffic carrying capacity was used for analyzing and evaluating urban comprehensive carrying capacity. Firstly, the standardization of evaluation index was constructed in the urban comprehensive carrying capacity index system. In addition, the past decade data from 2002 to 2011 was analyzed and evaluated in the weighted index system. Finally, the influence mechanism of various carrying capacity factors on urban comprehensive carrying capacity was investigated in Lanzhou. Experimental results can be summarized that the variation tendency of urban comprehensive carrying capacity was the annual increase of levels and the promotion countermeasure was put forward with congenital restricting factors and acquired restricting factors.

1. Introduction

City is the concentration area of population distribution, resources consumption and environmental pollution. Moreover, it is the most important carrier of social life of human and economic development. In the 21st century, China has entered into a phase of rapid urbanization which brings rapid growth of urban population and the rapid expansion of city scale. The urban economic and social structure transforms rapidly, public demands experiences comprehensive and rapid growth, the constraint of resources and environment further tightens, business costs keeps rising. The city is facing increasingly serious ecological environment problems with fragility of city safety and disaster prevention. All of these has seriously affected the sustainable utilization of natural resources and the sustainable development of urban economy, society, ecology and culture[1]. Lanzhou is the capital city of Gansu province. In the 12th five-year plan, urbanization rate will reach 80% in 2015 which the net urbanization rate, rate is 5% compared with the 11th five-year planand the city district population will reach 4.2 million, a net increase of 860000 compared with that of 2010. Under such a heavy population pressure,
the city sustainable development can coordinate with the urban comprehensive carrying capacity not only is related with its own development trends, but also is related with the successful sustainable development of surrounding areas. Therefore it is important to study the changes of Lanzhou’s urban comprehensive carrying capacity, and forecast its future development.

The concept of "carrying-capacity" firstly appeared in the field of ecology. It is used to measure the maximum number of individuals within a species in specific area under certain environment conditions. After entering into the 21st century, the concept of “carrying-capacity” was introduced to the urban system. In January 2005, the concept of urban comprehensive carrying capacity was clearly put forward in the "notice about strengthening the overall urban planning and revision and the work of examination and approval” issued by the ministry of construction. A growing number of scholars at home and abroad express their opinions, and conduct research on this problem at multiple levels. Some scholars take the urban land resources, water resources, environment and resources, mineral resources, cultural resources, and other single factors as the breakthrough point to carry on empirical analysis [2-9].Such kind of research is mainly based on the principle of minimum limiting factor, stressing that the most scarce resources have a decisive impact on urban comprehensive carrying capacity. But it should be clear that for the city which is development system, the influence of single factor on urban comprehensive carrying capacity is significantly weakened due to the flow and complementation of elements. But the synergy effect of multiple factor is significantly enhancing. At the same time, the abundance of natural resources and the city's economic development level is not completely in positive correlation [1]. Although a lot of places in western China, such as Yunnan and Guizhou, these places have beautiful mountains and rivers and abundant natural resources, but their economic development level is much lower than other advanced cities. And the economic development level of the cities like Tokyo in Japan and Shenzhen in China is extremely high, although they have scarce natural resources. According to it, many scholars try to build the evaluation system from the perspective of multiple factors and carry out empirical analysis and quantitative analysis on urban comprehensive carrying capacity[10-12].This kind of research is mainly based on the compensation effect or comprehensive effect of resources carrying capacity[6], and study the influencing degree of various factors on urban comprehensive carrying capacity through factor weight, and further reflects the relationship and compensation among various factor. In other words, when a factor is restricted, it can be compensated through strengthening it. Take the city's natural composite system as an example. Tree-planting, a forestation, and water conservation not only can strengthen the protection of the environment, but also further improve the capacity of water resources supply and production capacity of land resources within certain area. Some scholars carry out a series of beneficial exploration on the study of the carrying-capacity of urban agglomeration on the basis of the above theory and method, discusses the relationship between regional economic development and environment coordination [13-14].In the study of the calculation method and model of carrying-capacity, the scholars adopts the prediction method of ecological footprint, logistic model, system dynamics method, the GM (1, 1) mode in evaluation [15].But in this type of research, clear difference can be seen from the evaluation results concluded from different scholars and it is worth noting that the evaluation result has large deviation with the reality [16].

It should be pointed out that, although the study of urban comprehensive carrying capacity has achieved certain progress, but the theoretical framework and method system which can be widely accepted and get better reflect in the process of practical application has not been set up. This paper argues that there are several problems need to pay attention to in future research: (1) the structural problems of the carrying-capacity of cities in different area are different. And the main restricting factors are different, thus different index systems should be built for evaluation. It is obvious that the level of the urban comprehensive carrying capacity of cities in eastern region has significant differences with that of the cities in the western region.(2) the structural problems of the carrying-capacity of cities in different area are different, thus different index systems should be built for evaluation. The paper believes that the scale here should be divided on the basis of urban population rather than on the basis of urban administrative levels. There are many eastern counties have a population scale over millions,
while the population of many western cities only are hundreds of thousands of. Obviously, there are no much comparison to use urban administrative levels to carry out analysis of the level of carrying-capacity. The structural problem of urban comprehensive carrying capacity at different development stages is not the same, thus different index systems should be built for evaluation. The city focusing on development speed is different from the city focusing on development quality in the aspect of main constraint factors, thus their methods of improving urban comprehensive carrying capacity are different. The urban comprehensive carrying capacity of the same city will be different if it stays at different functional zones. The evaluation should be based on classification quantification. The urban public service quality and management level of urban government has significant impact on urban comprehensive carrying capacity, but they have totally different influences on cities with different locations, cities with different scales, cities at different development stage. Besides, the determination of weight is also different.

In this paper, the novel comprehensive index system of urban resources carrying capacity, urban environmental carrying capacity, economic carrying capacity, society carrying capacity, traffic carrying capacity was used for analyzing and evaluating urban comprehensive carrying capacity. Firstly, the standardization of evaluation index was constructed in the urban comprehensive carrying capacity index system. In addition, the past decade data from 2002 to 2011 was analyzed and evaluated in the weighted index system. Finally, the influence mechanism of various carrying capacity factors on urban comprehensive carrying capacity was investigated in Lanzhou. Experimental results can be summarized that the variation tendency of urban comprehensive carrying capacity was the annual increase of levels and the promotion countermeasure was put forward with congenital restricting factors and acquired restricting factors.

2. Urban Comprehensive Carrying Capacity Index System

2.1. Construction of index system

The social and economic development of all cities are built on the basis of the synergistic effect of many factors, therefore comprehensive index should be adopted to measure the urban comprehensive carrying capacity. Thus on the basis of previous research, and according to the actual situation of the research region, this article will measure the urban comprehensive carrying capacity of Lanzhou city from five aspects including resources carrying capacity, environmental carrying capacity, economic carrying capacity, society carrying capacity, traffic carrying capacity. All of these elements include two indicators, namely the supply of the city for the supporting ability of human activity and the need of the impact of human activities on urban system. The element carrying-capacity reflects the concept of "threshold", and it is characterized by the "short board" in the process of urban development. While the comprehensive carrying-capacity more reflects the concept of "ability", and it is characterized by the "potential" in the process of urban development.

In the process of selecting elements, the principle of being systematic, scientific, operable, flexible and comparable is abide by. The Lanzhou urban comprehensive carrying capacity index system is constructed, including five secondary indexes, namely resources, environment, economy, society, and traffic, ten third class indexes such as supply index and demand index, and 20 specific indicators (see figure 1)[1]. The contribution of this work is the society-carrying-capacity which has six indicators, thus breaking the normal situation of only focusing on hard power and ignoring the soft power in such kind of study.

The data of this paper is mainly from the Lanzhou statistical yearbook from 2003 to 2012, Lanzhou water gazette, Lanzhou environment gazette in 2003-2012, and the traffic data mainly comes from Lanzhou traffic detachment.

2.2. Standardization of evaluation index

The indicators of urban comprehensive-carrying-capacity are different from each other with, large numerical difference. Due to impact of dimensional effect on need of elimination, the original data
should be standardized. The 20 specific indicators of the index system can be divided into positive effect indicators and negative effect indicators. The greater the value of the positive effect indicator is, the higher the degree of carrying-capacity is. And the smaller the value of the negative effect indicators is, the higher the degree of carrying-capacity is. Two types of indicators are all processed under range standardization method, but their formulas are different. The specific method is shown as follows:

The normalization equation of the positive effect indicator:
\[
x^*_i = \left( \frac{x_{ij} - mx_j}{Mx_j - mx_j} \right)
\]
\(i = 1,2,...m; j = 1,2,...m\)

The normalization equation of the positive effect indicator:
\[
x^*_i = \left( \frac{Mx_j - x_{ij}}{Mx_j - mx_j} \right)
\]
\(i = 1,2,...m; j = 1,2,...m\)

Among them, \(Mx_j\) and \(mx_j\) respectively are the maximum value and minimum value of \(x^*_j\).

2.3. The determination of the weight of index system

The method of determining the weight of the multi-indicators comprehensive evaluation system can mainly be divided into subjective weighting method and objective weighting method[17]. The Klee method, Delphi method, AHP method all belong to subjective weighting method. Although this kind of research method is relatively more mature, it has poor objectivity. The advantage of objective weighting method is the calculation based on actual data without relying on persona judgment, thus having strong objectivity.

3. The determination the weight of single indicator

The calculation of the weight of specific indicator in the paper will adopt the mean square error decision-making method of objective weighting method which has relatively clear concept, relatively simple calculation, relatively clear meaning. The basic idea of this method is take the attribute value which is result of the dimensional elimination of scheme \(A_j\) under the indicator \(I_j\) as the value of the random variable. Firstly calculate the mean square error of all random variables and then unify all these mean square errors. The final results will be the weight coefficients of all single specific indicators. The calculation steps are as follows:

Calculate the mean value of all variables:
\[
\overline{I}_j = \frac{1}{n} \sum_{i=1}^{n} x^*_i
\]

Calculate the mean square error of \(I_j\):
\[
\delta(I_j) = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x^*_i - \overline{I}_j)^2}
\]

The weight coefficient of indicator \(I_j\) is:
\[
\omega(I_j) = \frac{\delta(I_j)}{\sum_{j=1}^{m} \delta(I_j)}
\]

3.1. The determination of the weight of the secondary and the third class indicator

After determining the weight of a single specific indicator, multi-objective linear weighting function method is adopted to calculate the attribute value of the first class and secondary indicator. \(C_k = \sum x^*_j \omega(I_j)\), \(B_j = \sum C_k \omega_k\), \(C_k\) for the attribute value of the third class indicator, \(B_j\) for the attribute value of the secondary indicator, \(\omega_k\) for the weight of the third class indicator.

The calculation of the weight of third class indicator adopts the mean square error decision-making method, just like the calculation of the weight coefficient of single indicator. Respectively take the second and third level attribute values \(B_j\) and \(C_k\) as random variable to calculate the mean square error.
of the random variable at second and third level, and normalize these mean square errors. The final results will be the weight coefficient of secondary and tertiary indicators, namely \( \omega_i \) and \( \omega_k \).

3.2. The construction of Lanzhou urban comprehensive carrying capacity model

The secondary indicators reflect the development level of urban comprehensive carrying capacity from various factors. The obtained structure of overall level should be comprehensively evaluated. Therefore multi-objective linear weighting function method is adopted to solve the indicator (A) of urban comprehensive carrying capacity, namely \( UCCC(A) \). Finally, the greater the value of \( UCCC(A) \)is, the higher the level of urban comprehensive carrying capacity is. Under the circumstance that the weight vector is known, the results over the years can be easily compared according to the value of urban comprehensive carrying capacity and targeting countermeasures and advice can be put forward to improve urban comprehensive carrying capacity.

4. LANZHOU URBAN COMPREHENSIVE CARRYING CAPACITY RESULTS IN 2002-2011

4.1. The contribution of society carrying capacity to urban comprehensive carrying capacity keeps increasing

The urban comprehensive carrying capacity system in Lanzhou is made up of five index system including resources carrying capacity, environmental carrying capacity, economic carrying capacity, society carrying capacity, traffic carrying capacity. The results of calculating weight are: resources carrying capacity is 0.1725, environmental carrying capacity is 0.2025, economic carrying capacity is 0.180, society carrying capacity is 0.2537, traffic carrying capacity is 0.1913. Thus the order of the contributing factors of comprehensive carrying capacity is: society carrying capacity > environmental carrying capacity > traffic carrying capacity > economic carrying capacity-resources carrying capacity. The contributing score of carrying-capacity in every year to comprehensive carrying capacity is shown in figure 2.

Thus, urban development has entered into a stage that both the hard loading factors including resources, environment and the soft loading factors including public services must be taken into consideration. And the city competition in future will mainly focus on soft power.

4.2. Constraint effects of resources carrying capacity keeps strengthening every year

In figure 3, resources carrying capacity shows a decreasing trend year by year, and its constraint effect on urban development tends to strengthen. The reason is that with the development of the city and the increasing pressure of population increase, the contradiction between the supply of urban water resources and land resources and increasing per capita resources utilization becomes more and more prominent with an imbalance between supply and demand. It also can be seen from the data in table 1 that during 2002-2011, the falling range of Lanzhou resources carrying capacity exceeded more than 110% with an average annual decline of 11%.

4.3. The role of environmental carrying capacity has significant changes

In Figure 3 and Table 1, the impact of environmental carrying capacity in 2002 is the lowest, only reaching 0.0481. After treatment, it reached the peak in 2007, and then presented a downward trend year by year, which was closely related with the heavy industry surrounding the Lanzhou city, the rapidly increasing vehicle possessing in the past five years and the frequent hazy weather. The urban environment pressure is great.
Fig 1 Indicators of urban comprehensive carrying capacity evaluation system

Fig 2 The rate of contribution of factors carrying capacity to urban comprehensive carrying capacity in 2002-2011

Fig 3 The variation tendency of factors carrying capacity and urban comprehensive carrying capacity in Lanzhou
4.4. Economic carrying capacity shows a steady rising trend

In Figure 3, economic carrying capacity shows a steady rising trend, thus having an more important role in promoting urban comprehensive carrying capacity. Due to the impact of financial crisis, the decline range was larger in 2009. But, generally speaking, the growing rate of the per capita GDP of Lanzhou city in recent three years is great with a significant growth in people's income, economic life and other aspects. And the attraction of being a central city is also strengthening.

4.5. The traffic carrying capacity does not play an important role

In Figure 3, the changes of Lanzhou traffic carrying capacity are not regular, sometimes big and sometimes small. Seen from the data provided by Figure 3, the overall level of traffic carrying capacity is not high during ten years. And its peak in 2010 was only 0.0902. The reason is the land form of Lanzhou city: “the east and the west are wide, the north and the south are narrow”. Besides, the hinder of the Yellow River also limits the traffic aisle. The urban road capacity is low. Moreover, the exceeding overlap coefficient of bus routes, single public transit system, limiting scope of bus services all lead to great obstacles to the priority of developing public transport.

| Year | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|------|------|------|------|------|------|------|------|------|------|------|
| Resources Carrying Capacity | 0.1564 | 0.1164 | 0.0828 | 0.1159 | 0.1094 | 0.1205 | 0.0962 | 0.0901 | 0.0755 | 0.0741 |
| Environmental Carrying Capacity | 0.0481 | 0.0764 | 0.0925 | 0.0910 | 0.0574 | 0.1372 | 0.1314 | 0.1172 | 0.1086 | 0.0820 |
| Economic Carrying Capacity | 0.0874 | 0.0440 | 0.0617 | 0.1218 | 0.0954 | 0.0868 | 0.1010 | 0.0865 | 0.1143 | 0.1306 |
| Society Carrying Capacity | 0.0988 | 0.1159 | 0.1305 | 0.0797 | 0.0762 | 0.1447 | 0.1342 | 0.1573 | 0.1723 | 0.1855 |
| Traffic Carrying Capacity | 0.0170 | 0.0256 | 0.0098 | 0.0692 | 0.0659 | 0.0138 | 0.0225 | 0.0515 | 0.0902 | 0.0575 |
| Comprehensive Carrying Capacity | 0.4077 | 0.3783 | 0.3775 | 0.4777 | 0.4043 | 0.5029 | 0.4853 | 0.5026 | 0.5609 | 0.5297 |

4.6. The urban comprehensive carrying capacity has periodical increase year by year

In Figure 3, Lanzhou urban comprehensive carrying capacity has good development momentum, showing a periodically ascending trend year by year. As a central city in western China and the capital of Gansu province, it should be said that this ascending trend corresponds with the economic and social development trend of the city over the years. The comprehensive carrying capacity from 0.4077 in 2002 to 0.5297 in 2011, with an increase of 29.92% during ten years and an average annual growth of 2.6%.

5. CONCLUSION

The composition of urban comprehensive carrying capacity is not the simple sum of the carrying capacity of various factors but the organic combination of them. At the same time, it also should be recognized that the short board factors of the urban comprehensive carrying capacity reflect in congenital aspect and acquired aspect. And the starting points of breaking through these two constraint factors are different. Congenital short factors is difficult to make a breakthrough, such as land resources, water resources; Acquired short factors have a relative big room to improve, including public services
and infrastructure construction which can make a breakthrough through government planning, institutional innovation.

The local resources of all research area are limited. Improving carrying-capacity through increasing the resources needs to break through the congenital constraint factors, which requires for huge cost, and is temporary. Compared with "open source", the starting point of “throttling” based on the demand is more likely to produce results, and are consistent with the spirit of sustainable development. Strengthen the crisis consciousness of the resources and environment from the government, enterprises and individuals at the same time, and establish the idea of sustainable development. The urban development strategy launched by the government should be within the urban carrying-capacity. Beside the reward system of encouraging saving behavior also should be established to guide enterprises and personal resources demand, thus achieving the purpose of “throttling” from the macroscopic aspect. Companies and individuals should be the implementer of "throttling". Enterprises should follow the idea of circular economy, carry out clean production, reduce pollution, and provide green products for the society. Especially, the real estate enterprises should also provide green energy-saving housing for the society, enabling people to save water resource and classify garbage, in daily life, so as to truly achieve "a green four sections ".

Acquired short factors play an important role in improving urban comprehensive carrying capacity. The government can focus on this aspect. The reason of starting from supply is based on urban economic carrying capacity, social carrying capacity and traffic carrying capacity. The government can remove some weak economic increment, diffuse part of population and increase economic vitality through adjusting industrial policy, layout and strengthening. The practice of adjusting and controlling urban scale through adjusting the industrial structure has already been fully understood by many cities and implemented to urban planning and management [4].The improvement of urban-society carrying capacity fundamentally is related with government policy orientation and system innovation. The government should continue to strengthen education, medical and other inputs related with the livelihood of people and provide fair education for the migrant population as well as all kinds of social security. The ascension of urban-traffic-carrying-capacity is to strengthen infrastructure construction and government investment in public transport, set up the new concept of "using public spending to buy public transport service", strive to achieve the new idea arranging prior investment, prior fiscal support, policy support in place, develop the public transport service, so as to further improve the bus trip proportion of citizens.

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