Analysis of Urban Comprehensive Carrying Capacity of the prefecture-level city in Gansu province

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Abstract. Based on the theory of urban carrying capacity, this paper put forward twenty-two indexed applied to assess the problems of the prefecture-level city in Gansu province. The results show that resource carrying capacity is the most important factor that influences city development; the way of improving the urban comprehensive carrying capacity is the improvement of pressure-bearing index; the supply index does not match demand index; the urban comprehensive carrying capacity presents stair-step decline; the leadership of two biggest cities are weaker relatively. To solve these problems, some measures are put forward such as changing the speed and mode of development, improving the pattern of the human behaviors, etc.

1. Introduction
China's urbanization has developed rapidly in the 21st century with an average annual rate of 3.1% growth and the urbanization rate reached 53.73% in 2013. The increasing scale of cities and the rapidly accumulating population have caused changes in the process of social and economic development. These changes not only represent an improving civilization, but also have brought great pressure to the urban resource, environment, transportation, and further affecting the further improvement of the quality of urbanization.

The word "capacity" first appeared in ecology, then gradually permeated into the environmental science, demography, economics. Now, it has become a concept which is closely related with resource endowment, technology, social choice and values with a relative limit connotation of ethical character [1].The concept of urban carrying capacity first appeared in 2002. K.O defined the concept of urban carrying capacity as as the material development of human activities, population growth and land utilization, which can realize the sustainable development of living environment system without causing degradation or irreversible damage [2].The concept was clearly put forward by the ministry of construction in January,2005, in "the notification about strengthening the revision and approval of overall urban planning." .The study about urban comprehensive carrying capacity is relatively late. It mainly started after 2000, but it has produced certain achievements. Some scholars have carried on quantitative analysis on the urban land resources, water resources, environment resources, mineral resources and other single factor of bearing capacity, and put forward the corresponding countermeasure [3] [4] [5] [6] [7].While, some scholars comprehensively evaluate the urban (land) bearing capacity from the perspective of multi-factors, construct evaluation index system, carry out
empirical analysis and quantitative evaluation, and put forward the measures to improve the bearing capacity. At the same time, some scholars expand the research scope to the comprehensive carrying capacity of urban agglomeration and have probed into the methods and ideas. The study mainly concentrates on the study of single urban bearing capacity factor and involves less comprehensive research that regards the city as a system. (3) the quantitative method has not formed a general calculation model, thus the evaluation results are diversified. (4) the study area is given priority to the southeast coastal developed areas, and the city carrying capacity related problems are rarely involved. To sum up, this paper argues that the urban comprehensive carrying capacity refers to the coordination and balance between population and human activities under certain resource constraints as well as the organic combination of human activity and natural resources, environment, economic and social conditions. At the same time, it should be realized that natural resource abundance and the city's economic development level do not have complete positive correlation and any social and economic development of a city is built on the basis of the synergy of many factors.

As the pressure of the cities in the southeast coast continues to increase, western cities will become one important position of accepting transferring agricultural population, therefore the research of their comprehensive carrying capacity is especially important. This paper takes 12 district cities in the Gansu province as the research object, then establishes the index system of the urban comprehensive carrying capacity to conduct objective measurement and evaluation on the comprehensive carrying capacity of those 12 cities, with the purpose of analyzing the methods of improving the urban comprehensive carrying capacity and promoting the coordinated development of the urban population, resources and environment.

2. Establish the evaluation index system of urban comprehensive carrying capacity

The data mainly comes from the 2012 development yearbook of Gansu province. The research object of this study is the 12 prefecture-level cities of Gansu province (Lin Xiazhou, Gan Nanzhou will not be evaluated due to the lack of data), including Lanzhou, Jiayuguan, Jinchang, Baiyin, Tianshui, Wuwei, Zhangye, Pingliang, Jiuquan, Qingyang, Dingxi, Longnan. Starting from the connotation of urban comprehensive carrying capacity and according to the regional characteristics, and the principles of being scientific, systematic, feasible, operational, the comprehensive carrying capacity index system of those 12 prefecture level cities is established (figure 1), including target layer, base layer, criterion layer and index layer. Among them, the criterion layer includes two parts, the pressure index and pressure-bearing index. The pressure index refers to the demand pressures the city bears. Because the resources are limited and irrefragable, the greater the demand of the city for a certain resource, the more pressure the resource bears and the more limitation the urban development may face. Pressure bearing index refers to supply ability of the city. The more resources the city provides, the more development space the city has and the greater comprehensive bearing capacity the city has.

3. Modeling Method

3.1. The normalization of evaluation index

Testing matrix method was used to calculate coefficients. According to the criteria of every testing matrix, two neighboring elements can be compared. The importance and degrees of importance will be judged by reciprocal scale methods from 1 to 9. The pairwise comparison matrix can be determined by the comparison of the average score for each element. The data collected by evaluation index has different dimensions and units, thus needing to be standardized. Suppose that, X is the index for the urban comprehensive carrying capacity, corresponding to the sample matrix of city j and i evaluation index, namely the equation is $X = x_{ij}$. This paper divides the evaluation index into two major categories, namely the cost index and the efficiency index. The cost index refers to the indicators, the attribute value of which is negatively related to the urban comprehensive carrying capacity and the attribute value should be as small as possible. The efficiency index refers to the indicators, the
attribute value of which is positively related to the urban comprehensive carrying capacity and the attribute value should be as big as possible [16]. In order to eliminate the influence of the dimensions and dimensional units, this paper uses the fuzzy subjection function to nondimensionalize these two types of indicators.

**Table.1** Evaluation index systems of urban comprehensive carrying capacity of the refecture-level city in Gansu Province

| Target layer | Base layer | Criterion layer | Index layer |
|--------------|------------|----------------|-------------|
| Urban comprehensive carrying capacity | Resources carrying capacity b1 0.3075 | Pressure index 0.1944 | Per capita daily water consumption c1 0.1001 |
| | | Pressure bearing index 0.1131 | Comprehensive energy consumption c2 0.0943 |
| | Environmental carrying capacity b2 0.1847 | Pressure index 0.034 | The proportion of the days when the air quality reaches or above the second level in one year c5 0.0216 |
| | | Pressure bearing index 0.1507 | Sewage emissions c6 0.0124 |
| | Economic capacity b3 0.2142 | Pressure index 0.1297 | Green coverage ratio of construction land area c7 0.0809 |
| | | Pressure bearing index 0.0845 | Processing capacity of municipal sewage plant per day c8 0.0698 |
| | Infrastructure capacity b3 0.1643 | Pressure index 0.0759 | Per capita gdp pc9 0.0705 |
| | | Pressure bearing index 0.0884 | Proportion of primary industry c10 0.0592 |
| | Public service capacity b4 0.1293 | Pressure index 0.0578 | Proportion of tertiary industry c11 0.0413 |
| | | Pressure bearing index 0.0715 | Growth rate of gross value of production c12 0.0432 |
| | | | Number of bed in health agency per ten thousand persons c17 0.0251 |
| | | | The proportion of the person who have the lowest living ensure in the cities and towns c18 0.0148 |
| | | | Primary and secondary school enrollment c19 0.0179 |
| | | | The proportion of the person participating in new rural cooperative medical system c20 0.0098 |
| | | | The proportion of the medical treatment and public health |
expenditure in each area c21
0.0286
The proportion of the education expenditure in each area c22 0.0331

The cost indicators use the glower semi-trapezoid fuzzy subjection function to nondimensionalize

\[
x_j^* = \begin{cases} 
0 & x_{ij} = M_{x_{ij}} \\
\frac{M_{x_{ij}} - x_{ij}}{M_{x_{ij}} - m_{x_{ij}}} & m_{x_{ij}} < x_{ij} < M_{x_{ij}} \\
1 & x_{ij} = m_{x_{ij}}
\end{cases}
\]

The efficiency indicators use the glower semi-trapezoid fuzzy subjection function to nondimensionalize

\[
x_j^* = \begin{cases} 
0 & x_{ij} = m_{x_{ij}} \\
\frac{x_{ij} - m_{x_{ij}}}{M_{x_{ij}} - m_{x_{ij}}} & m_{x_{ij}} < x_{ij} < M_{x_{ij}} \\
1 & x_{ij} = M_{x_{ij}}
\end{cases}
\]  

In the equation: \(x_j^*\) is the result of normalization and its value is between zero and one; \(x_{ij}\) is the original value of the index; \(m_{x_{ij}}\) is the minimum value of the original values of different areas at the same period; \(M_{x_{ij}}\) is the maximum value of the original values of different areas at the same period.

3.2. The determination of index weight

The entropy value method is a kind of objective weighting method. It can better avoid the deviation of the subjective assignment and determine the index weight according to the information provided by the original values of the indicators. And the indicators actually involved are expressed by the standardized value. The ultimate evaluation value and the level of the comprehensive carrying capacity is the product of both parts. The weight of the evaluation index system determined by the entropy method can fully reflect the description required by the level of urban comprehensive carrying capacity in the stress levels, pressure levels and coordination and the statistics also meet the requirements of entropy value method. Therefore, it is scientific to use the entropy method to evaluate comprehensive carrying capacity [17]. Calculation steps are as follows:

1. Calculate the weight of index layer

First step: suppose that the index of the base layer (or criterion layer) is \(i\), the index of the target layer is \(j\), then the index weight \(p_{ij}\) of the Jth sample under the ith index is

\[
p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, \quad n = 12
\]

The second step: calculate the entropy \(e_j\) of the jth index:

\[
e_j = \frac{-\sum_{i=1}^{n} p_{ij} \ln p_{ij}}{\ln p_{ij}}
\]

The third step: calculate the utility value of the jth indicator: \(g_j = 1 - e_j\)
The fourth step: calculate the weight of the jth index:

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j}$$

The fourth step: calculate the weight of the jth index:

2. Calculate the weight of the criterion layer and the base layer
The evaluation system of the multilayer structure can, according to the additivity of the entropy, take advantage of the utility value of indexical information of lower to determine the weight value $w_j$ corresponding to the upper structure value in proportion. In the previous steps, the utility value of each index has been calculated. Calculate sums of the utility value of each index of the lower structure, then get the utility value of all kinds of index, with the detonation $G_j, (j = 1, 2, \cdots)$. And subsequently obtain the sums of the utility value of all index:

$$G = \sum G_i$$

the weight of the corresponding index:

$$w_j = \frac{G_j}{G}$$

3.3. The construction of index model
For further research of the bearing capacity level used to evaluate the city, this paper adopts the urban comprehensive carrying capacity evaluation model. The comprehensive carrying capacity index systematically reflects the overall level of urban development ability under certain resources and environment constraints. At the same time, we can also find out the short slab factors influencing the comprehensive carrying capacity, thus putting forward the corresponding countermeasures.

The evaluation value of subsystem of the base layer adopts the following evaluation model:

$$Y_i = \sum_{j=1}^{m} w_j x_{ij}$$

In equation: $Y_i$ is the integrated assessment value of the ith subsystem in the base layer; $m$ is the number of the evaluation index contained in the ith subsystem; $w_j$ is the weight of the jth indicator in the ith subsystem; $x_{ij}$ is the evaluation value of the jth indicator in the ith subsystem.

The urban comprehensive carrying capacity value $A$ of the base layer adopts the following evaluation model:

$$A = \sum_{i=1}^{n} w_i Y_i$$

Obviously, the bigger $A$ is, the better $A$ is. Therefore, as the weight is known, we can easily determine every scheme or sort them according to the value of urban comprehensive carrying capacity.

4. The analysis of the comprehensive carrying capacity of the cities in Gansu province

4.1. The resources bearing capacity has the greatest impact on the comprehensive carrying capacity of the prefecture-level cities in Gansu province.

It can be seen from Table 1 that among the weights of all subsystems which are determined by the entropy method, the bearing capacity of resources has the greatest influence, with a weight of 0.3075. The following are respectively economical capacity, environmental capacity, infrastructure capacity, and public service capacity. The daily water consumption per capita is the single index, far more than the second index, which illustrates that the problems of water resources is the main factor influencing the comprehensive carrying capacity of the prefecture level cities in the Gansu province.

4.2. The analysis and calculation of indexes
Step 1 The analysis of pressure bearing index
It can be seen from table 2 that, the pressure bearing index of the prefecture-level cities in Gansu province are not identical. In general, the comprehensive capacity pressure pressuring bearing indexes of three cities are more than 1, which respectively are Jiayuguan, Jinchang and Jiuquan. The pressure bearing indexes of other nine cities including the provincial capital Lanzhou are less than 1, which shows that for most of the prefecture-level cities in Gansu province, the main method of improving the urban comprehensive carrying capacity in the future is to improve the bearing capacity. Seen from the perspective of resources pressure bearing index, the jiayuguan city is the highest and Longnan city is the lowest; seen from the perspective of environmental pressure bearing index, the highest is the Dingxi city, the lowest is the Jinchang city; From the perspective of economic pressure bearing index, the highest is Dingxi city, the lowest is the Jinchang city; from the perspective of infrastructure pressure bearing index, the pressure index of each city is similar; from the perspective of public service pressure index, it can be seen that most of the cities have low pressure bearing index. Except for the Jiayuguan city which is above 1, the dat of 10 cities are below 0.5.

Table.2 The pressure-bearing index of urban comprehensive carrying capacity of the prefecture-level city in Gansu Province

| Area      | resources pressure bearing index | Environmental pressure bearing index | economic pressure bearing index | infrastructure pressure bearing index | public service pressure bearing index | urban comprehensive carrying capacity pressure bearing index |
|-----------|----------------------------------|--------------------------------------|---------------------------------|---------------------------------------|--------------------------------------|----------------------------------------------------------|
| Lanzhou   | 0.48812                          | 0.49395                              | 0.21186                         | 1.16654                               | 0.28120                             | 0.92730                                                  |
| Jiayuguan | 1.20267                          | 0.11739                              | 0.07546                         | 1.15813                               | 1.65863                             | 1.84320                                                  |
| Jinchang  | 0.89133                          | 0.08263                              | 0.07828                         | 1.15716                               | 0.96980                             | 1.53113                                                  |
| Baiyin    | 0.57339                          | 0.22621                              | 0.15509                         | 1.16210                               | 0.30970                             | 0.96405                                                  |
| Tianshui  | 0.26019                          | 0.51621                              | 0.51679                         | 1.15967                               | 0.20125                             | 0.68492                                                  |
| Wuwei     | 0.32454                          | 1.42605                              | 0.29218                         | 1.15917                               | 0.22667                             | 0.75078                                                  |
| Zhangye   | 0.62585                          | 2.44142                              | 0.18114                         | 1.15621                               | 0.29181                             | 0.95697                                                  |
| Pingliang | 0.46513                          | 0.85420                              | 0.36989                         | 1.16057                               | 0.22434                             | 0.79130                                                  |
| Jiuquan   | 0.73667                          | 0.33471                              | 0.13035                         | 1.15341                               | 0.38058                             | 1.11419                                                  |
| Qingyang  | 0.37449                          | 0.79551                              | 0.20158                         | 1.16175                               | 0.25355                             | 0.80511                                                  |
| Dingxi    | 0.35204                          | 3.32301                              | 0.79569                         | 1.15869                               | 0.19820                             | 0.70291                                                  |
| Longnan   | 0.23569                          | 2.09464                              | 0.66957                         | 1.15590                               | 0.19533                             | 0.66407                                                  |

Table.3 The analysis of factors carrying capacity and urban comprehensive carrying capacity of the prefecture-level city in Gansu Province

| Area      | resources carrying capacity | Environmental carrying capacity | economic carrying capacity | infrastructure carrying capacity | public service carrying capacity | urban comprehensive carrying capacity | Ranking |
|-----------|-----------------------------|---------------------------------|-----------------------------|---------------------------------|---------------------------------|--------------------------------------|---------|
| Lanzhou   | 0.08681                     | 0.05465                         | 0.16252                     | 0.05517                         | 0.10979                         | 0.46894                              | 6       |
| Jiayuguan | 0.11377                     | 0.05226                         | 0.34437                     | 0.04686                         | 0.03281                         | 0.59008                              | 3       |
| Jinchang  | 0.10456                     | 0.05394                         | 0.34704                     | 0.04877                         | 0.04328                         | 0.5760                               | 2       |
| Baiyin    | 0.09976                     | 0.06085                         | 0.21475                     | 0.05606                         | 0.10316                         | 0.53458                              | 4       |
| Tianshui  | 0.06117                     | 0.04509                         | 0.06271                     | 0.04153                         | 0.10754                         | 0.31804                              | 10      |
| Wuwei     | 0.07059                     | 0.04996                         | 0.10496                     | 0.04616                         | 0.10870                         | 0.38037                              | 8       |
| Zhangye   | 0.10195                     | 0.05995                         | 0.18564                     | 0.05531                         | 0.10681                         | 0.10681                              | 9       |
| Pingliang | 0.07709                     | 0.04981                         | 0.08760                     | 0.04604                         | 0.10934                         | 0.36988                              |         |
Step 2 The analysis of the comprehensive carrying capacity index

It can be seen from the table 3 that the comprehensive carrying capacity of the prefecture-level cities in Gansu province are echeloned, reflecting in that the west is high and the east is low. The standard deviation of the urban comprehensive carrying capacity of the five cities, Jiuquan, Jiayuguan, Jinchang, Baiyin, Zhangye is above the mean value of 0.5, thus belonging to the higher bearing capacity. And the comprehensive carrying capacity of other cities is below the mean value of 0.5. The cities with medium bearing capacity are Lanzhou, Qingyang (0.42 < A < 0.48). The urban comprehensive carrying capacity of the five cities, Tianshui, Wuwei, Pingliang, Dingxi, Longnan, are below 0.4 with more than two standard deviations, which shows that these cities belong to low bearing capacity.

Seen from the figure 1, the contribution of each factor system for comprehensive carrying in each city of Gansu province is not the same. The improvement of the urban comprehensive carrying capacity is a systematic and coordinated process. The weakening of the function of any elements will have great impact on the coordination degree of the whole city system and the decline of the comprehensive carrying capacity.

![Figure 1: The rate of contribution of factors carrying capacity to urban comprehensive carrying capacity of the prefecture-level city in Gansu Province](image)

Step 3 The Lanzhou city and Tianshui city carrying capacity among the urban agglomeration

The Lanzhou city and Tianshui city are the first and second largest city of Gansu province. They also respectively are the center of the Lanzhou-Xining urban agglomeration the Guanzhong - Tianshui economic zone, playing a leading role in the region. But seen from table 3, the comprehensive ability of Lanzhou city only ranks fourth in the province, and the resource carrying capacity is its short board factor. What is different other big cities is that, the development of Lanzhou city is more limited by the shortage of land resources. While the development problem of Tianshui city is different from Lanzhou’s. Tianshui’s economic bearing capacity has a large gap with other cities’ with a low contribution rate. And its problems of resource bearing capacity are mainly manifested in the shortage of water resources.

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.

5.1. Make full use of resources and improve the urban comprehensive carrying capacity
Take the demand for resources and the utilization of resources as breakthrough, reasonably guide demands, and improve the efficiency. Transform the concept of resource utilization of enterprises and residents in daily production and life, implement the system that encourages and rewards saving and gird their reasonable resource demand orientation. Encourage to develop circular economy to realize the efficient utilization of resources, strive to build a conservation-minded society, improve the urban comprehensive carrying capacity.

5.2. Improve the bearing capacity of system factor according to local conditions and improve urban comprehensive carrying capacity
Seen from the above analysis, the factors affecting the urban comprehensive carrying capacity of the prefecture-level cities in Gansu province are not the same, thus it is necessary to improve the bearing capacity of system factor according to local conditions so as to eventually realize the purpose of improving the urban comprehensive carrying capacity. Take the Lanzhou city as an example, improving the urban comprehensive carrying capacity needs to take promoting resources bearing capacity as the breakthrough and carry out order construction of new city zone through further revitalization and deep mining of the existing land resource. To sum up, when a certain element of the city comprehensive carrying capacity system becomes short slab, not only its breakthrough needs to be considered, the further optimization of the system structure also should be considered.

5.3. Steadily push forward the urbanization process, improve the quality of urbanization, guide the reasonable distribution of population, form reasonable structure of the urban comprehensive carrying space carrier
The prefecture-level cities of Gansu province have become the important front for acceptance of the transferring rural population. But it can be seen from the analysis that the urban resource utilization efficiency is low with the problems of waste of land expansion, environmental problems, lack of infrastructure and public service ability existing, which shows that the urban development pattern has certain problems. It is suggested that the future population distribution not be too concentrated in the big cities so as to alleviate the pressure of the big city. Under policy guidance, the population transfer can be concentrated in small and medium-sized cities, thus enhancing the connotation of the city.

Acknowledgement
Urbanization of Institutional transformation and Institutional Innovation in Gansu Province of Minorities Areas (1111-06); Mechanism of new-type promoted Urbanization in Gansu Province of Minorities Areas (2011-GSCFY - KJ08); Ecological Civilization intensive Perspectives for intensive development strategies in middle-sized and small cities of Northwest Minorities Regions (2013-GSCFY- RW30)

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