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# Performance Evaluation of Urban Comprehensive Carrying Capacity of Harbin, Heilongjiang Province in China

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**Abstract:** Urban comprehensive carrying capacity is an important guarantee and external representation of regional sustainable development. Based on urban comprehensive carrying capacity, this paper constructed a performance evaluation index system of urban comprehensive carrying capacity, and used entropy method, urban comprehensive carrying capacity measurement model and urban sustainable development model to measure spatial and temporal comprehensive carrying capacity of Harbin City in Heilongjiang Province from 2012 to 2017. The results show that: 1) index weight analysis suggested the regional development mode in Harbin still followed an epitaxial development mode, which pursued the expansion of scale and the growth of total amount of regional development, neglecting the effective utilization of resources and the improvement of structural benefits. 2) In the pressure system, the index of resource support has dropped sharply. The index of environmental capacity and social progress has risen circuitously, while the degree of agglomeration and the value of transportation facilities have risen steadily; in the pressure system, the index of population development and economic growth tended to fluctuate, while energy consumption and environmental pollution showed a more synchronous change in characteristics, and the livable demand remained at a high level. 3) The carrying capacity index of resources and environment in Harbin has been declining, and the acquired carrying capacity index fluctuated. The long-term regional development model has severely impaired the carrying capacity of resources and environment. 4) The comprehensive carrying capacity of Harbin has clear spatial differentiation characteristics. Finally, the paper proposes that location conditions, economic development level, government regulation, and science and technology are the main factors influencing the spatial differentiation of urban comprehensive carrying capacity.

**Keywords:** comprehensive carrying capacity; natural carrying capacity; performance evaluation; influencing factors; Harbin City

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## 1 Introduction

With the acceleration of urbanization, the size of the urban population and extent of land use increases rapidly, leading urban and surrounding areas incurring problems of tighter resources and environmental constraints, higher business costs, and vulnerable urban safety and disaster prevention capability (Li and Gao, 2018). All of these may affect the improvement of city quality, and have impacts on urban sustainable development.

The term carrying capacity originally comes from ecology, a domain of biology. From it, several related concepts have been developed, such as population carrying capacity, ecological carrying capacity, and land carrying capacity (Cao and Zhou, 2018). The British scholar Malthus discussed the relationship between organisms and their natural environment, and he claimed that organism will follow unlimited growth, but natural resource was finite, so organisms' population growth

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eventually become restricted by natural factors at some point (Malthus, 1798; Guan et al., 2018). Malthus's theory of population dynamics conveys the basic concept of carrying capacity. From a geographer's view, urban space is a complex system, comprehensive carrying capacity theory derives from theories of urban capacity and urban scale; it not only maintains resources, ecology, economy, and other dimensions, but also frequently appears in studies of urban planning and urban development policies (Malthus, 1798; Guan et al., 2018). To promote high-quality city development, many scholars are engaged in the research of urban comprehensive carrying capacity.

Two different views on carrying capacity are prominent. Many scholars hold the opinion that the urban comprehensive carrying capacity adheres to the law of the minimum limiting factor. This view emphasizes that a single factor has a decisive influence on urban carrying capacity. It is undeniable that the socioeconomic development of any city is based on the synergy of various factors, and natural resource endowment is not always positively correlated with economic development (Sun and Li, 2013). Other scholars have posited a theory about the compensation effect of urban comprehensive carrying capacity. The difference from law of the minimum limiting factor is that it emphasizes integration with other resource elements to evaluate the urban comprehensive carrying capacity (Zhang and Fang, 2002).

To investigate urban comprehensive capacity, studies and theories such as the DPSIR (Driving forces-Pressures-States-Impacts-Responses) analysis framework and conceptual model (David et al., 2015), the ecological footprint method (Peng et al., 2016), energy value analysis (Gong and Jin, 2009), and the dynamic system model (Meng et al., 2009) are widely used for evaluating the status of urban development. Some scholars have theorized on the importance of urban comprehensive carrying capacity for sustainable development, urging that the stability of city carrying capacity should be improved as soon as possible (Jiang and Luo, 2011; Feng and Li, 2018). This is the theoretical basis to realizing regional sustainable development. Lei and Qiu (2016) conducted an empirical study on the comprehensive carrying capacity of each city in Anhui Province during year 2000–2013, based on an entropy weight TOPSIS model. Their analysis showed that after 2005, economic development and urban comprehensive carrying capacity complement each other, showing steady development. Li and Lu (2018) then proposed that the speed of current improvement on urban governance lags behind the urbanization change rate. It turned the relation between urbanization and carrying capacity response from a positive response to a negative response, and they also pointed out the quality of urban economy and urbanization in China facing a crisis of unsustainable development. Although the research findings of urban comprehensive carrying capacity are relatively common, there are still some shortcomings. Firstly, research on urban comprehensive carrying capacity is not sufficiently in depth, and its detailed theoretical system has not yet been reasonably constructed, leaving much room for research on urban comprehensive carrying capacity to be strengthened. Secondly, mainly research is concerned with urban carrying capacity, however, the index construction on material basis and socioeconomic power get less attention. At the same time, relevant research on old industrial cities in Northeast China remains noticeably absent.

As an important core city of the old industrial base in Northeast China, Harbin is rich in natural and human resources. In recent years, the lack of resources support for urban development has become increasingly prominent in Harbin. The greater shortage of water resources, the continuous encroachment of land resources, and the widening gap between cities and regions are bound to restrict the sustainable development of cities. Based on this, this paper studied the comprehensive carrying capacity of Harbin City by econometric means in order to provide a useful reference tool for its future sustainable development.

## 2 Materials and Methods

### 2.1 Study area

Harbin, located in the southern of Heilongjiang Province, is the political, economic, cultural, and transportation center in the northern China (Fig. 1). Harbin's municipal area ranks first among the 15 sub-provincial cities in China, and it contains 9 districts, 2 cities, and 7 counties with a total population of 9621 000. The per capita disposable income of urban residents was 33 190 yuan (RMB) in 2016, which is lower than the national average (33 616 yuan), but the per capita disposable

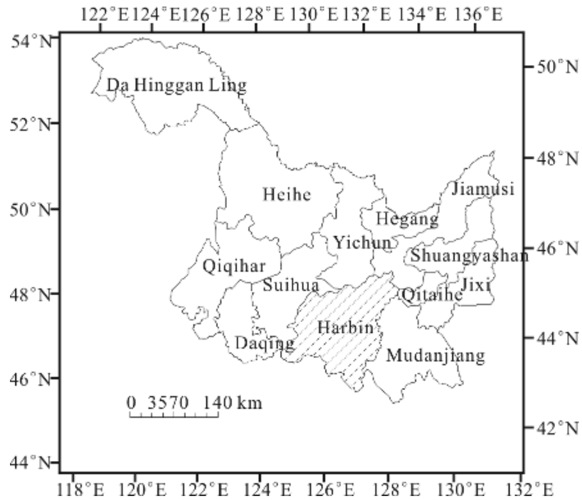


**Fig. 1** The location of study area

income of rural residents was 14 339 yuan in 2016, which was 15.98% higher than the national average (12 363 yuan). The total area of the city is 53 068 km$^2$, while the municipal area covers 10 198 km$^2$. The materials in this paper mainly come from the Heilongjiang Statistical Yearbook (2012–2017) and Harbin Statistical Yearbook (2012–2017).

## 2.2 Methodology

### *2.2.1 Construction of evaluation index system*

Urban comprehensive carrying capacity (*UCCC*) provides the underlying premise for urban development, and it is the cornerstone of urbanization construction. The sustainable development of a city is inseparable from the improvement of *UCCC*. *UCCC* have an accelerating or restricting effect on city development. In other words, both are interdependent. *UCCC* has an objective threshold interval, which can be used as a standard for evaluation (Zhang and Liu, 2003). *UCCC* is a complex system encompassing resources, environment, population, economy, and society, and all of these subsystems can interact with each other. *UCCC* has sustainability characteristics, which include not only the efficient development and utilization of resources but also the sustainable development of economy and society. At the same time, the factors of *UCCC* are dynamic. To analyze the changing regular of *UCCC*, we need to properly characterize the flow of resources, environment, population, economy, and society. Therefore, *UCCC* provides a way to measure and define the population and scale of various economic and social activities within a spatio-temporal scope.

*UCCC* depends on the joint effect of congenital factors (i.e., natural resources, environmental capacity, geological conditions) and acquired factors (i.e., natural resources use, degree of foreign capital introduction, level of urban infrastructure construction, material requirements). It has two aspects: for the carrier, it means human capital stock, hardware devices, science and technology, while for the carrying objects, it includes population socioeconomic activities, various consumption and livability metrics. Among them, carrying capacity consists of 5 indicators and 13 factors, covering resource support, environmental capacity, transportation facilities, social progress, and degree of agglomeration. Resources and environment represent the internal supporting capacity of urban ecosystem, which is natural. In pressure system, it contains 5 indicators: population development, economic growth, resource consumption, environmental pollution, and livable demand, and 15 specific indicators that correspond to the socioeconomic sub-levels. These indexes of social and economic development represent the pressure on the urban system, as well as the external development capacity.

Based on the above, and following the principles of diversity, reliability, feasibility, stability and dynamic, this paper selects 13 indicators for the carrying capacity system and 15 indicators for the pressure system, as shown in Table 1. The weight of evaluation index is calculated according to entropy method. The detailed steps are in references (Ou et al., 2008; Chen et al., 2009). According to the calculation steps of the entropy method, 28 indicators for Harbin from 2012 to 2017 were standardized. For positive indicators, the following standardized formulas are used:

$$x'_{ij} = \frac{x_{ij} - \min\limits_{1 \le i \le n}\{x_{ij}\}}{\max\limits_{1 \le i \le n}\{x_{ij}\} - \min\limits_{1 \le i \le n}\{x_{ij}\}} \tag{1}$$

For negative indicators, the following standardized formulas are used:

$$x'_{ij} = \frac{\max\limits_{1 \le i \le n}\{x_{ij}\} - x_{ij}}{\max\limits_{1 \le i \le n}\{x_{ij}\} - \min\limits_{1 \le i \le n}\{x_{ij}\}} \tag{2}$$

Based on the above analysis, the standardization matrix is constructed:

**Table 1** Evaluation index system for urban comprehensive carrying capacity

| Coefficient layer | Index item | Indicator name | Weight |
|---|---|---|---|
| Carrying capacity system | Resource support | The supply of state-owned construction land ($km^2$) (+) | 0.0430 |
| | | Per capita built-up area ($km^2$) (+) | 0.0406 |
| | | Per capita daily water consumption ($m^3$) (+) | 0.0216 |
| | | The supply of annual water ($m^3$) (+) | 0.0355 |
| | Environmental capacity | The ratio of air quality (%) (+) | 0.0342 |
| | | The ratio of domestic garbage biosafety disposal (%) (+) | 0.0314 |
| | | The total investment in pollution control / GDP (%) (+) | 0.0302 |
| | Transportation | Paving road area per $10^4$ people ($m^2$) (+) | 0.0417 |
| | | Car owned per $10^4$ people (car) (+) | 0.0347 |
| | Social progress | R&D expenditures / GDP (%) (+) | 0.0404 |
| | | The number of minimum living security for urban and rural residents (person) (–) | 0.0497 |
| | Agglomeration level | Population intensity (person/ $km^2$) (+) | 0.0303 |
| | | Land per capita GDP (yuan/ $km^2$) (+) | 0.0316 |
| Pressure system | Population development | The ratio of non-agricultural population (%) (+) | 0.0259 |
| | | Population growth rate (%) (+) | 0.0379 |
| | Economic increase | Per capita GDP (Yuan) (+) | 0.0424 |
| | | Annual growth rate of GDP (%) (+) | 0.0239 |
| | | Annual growth rate of output value of secondary industry and tertiary industries (%) (+) | 0.0306 |
| | Resource consumption | Increased area of inter-annual construction land ($km^2$) (+) | 0.0327 |
| | | water consumption in per $10^4$ yuan GDP ($m^3$) (+) | 0.0428 |
| | | Power consumption in per $10^4$ yuan GDP (kw) (+) | 0.0366 |
| | Environment pollution | Industrial solid waste production in per $10^4$ yuan GDP (ton) (+) | 0.0274 |
| | | Industrial exhaust emissions in per $10^4$ yuan GDP ($m^3$) (+) | 0.0416 |
| | | Industrial wastewater discharge in per $10^4$ yuan GDP (ton) (+) | 0.0404 |
| | Livable demand | Engel coefficient in urban area (+) | 0.0360 |
| | | Per capita housing construction area in urban ($m^2$) (+) | 0.0401 |
| | | Per capita green area ($m^2$) (–) | 0.0411 |
| | | The ratio of Green area in built-up area (%) (–) | 0.0357 |

Notes: + means positive indicators; – means negative indicators

$$Y = \{y_{ij}\}_{m\times n},\ y_{ij} = x'_{ij}/\sum x'_{ij} \tag{3}$$

Therefore, the value of entropy, as well as the difference coefficient and the weight, are obtained:

$$e_j = (-1/\ln m)\sum y_{ij}\ln y_{ij}$$
$$g_j = 1 - e_j \tag{4}$$
$$w_j = g_j/\sum g_j$$

where $x_{ij}$ is indictor value; $x'_{ij}$ is standardized indictor value; $Y$ is standardized matrix; $e_j$ is the entropy; $g_j$ is the difference coefficient; $w_j$ is the weight.

### *2.2.2 Urban comprehensive carrying capacity measurement model*

Complexity of factors influences urban comprehensive carrying capacity, so a comprehensive measurement of urban resources, environmental carrying capacity, and social-economic system pressure should not be a simple weighted summation, but should be constructed according to effect size of factor. By referring to the immune model (GRAYMORE M, 2005), a coupled model of urban comprehensive carrying capacity was built from two aspects: natural carrying capacity and acquired carrying capacity, for which the submodel was calculated as follow (Di et al., 2013):

$$N = \alpha^2 e^{\beta} \tag{5}$$

where $N$ is the natural carrying capacity index; $\alpha$ is the resource support index; $\beta$ is the environmental capacity index. The acquired carrying capacity submodel as follow:

$$A = T\mu\theta \tag{6}$$

where $A$ is the acquired carrying capacity index; $T$ is the transportation facility index; $\mu$ is the social progress index; $\theta$ is the agglomeration degree index. The comprehensive carrying capacity of city can be measured as follow:

$$CCC = Ne^{A} \tag{7}$$

where $CCC$ is the index of urban comprehensive carrying capacity; $N$ is the natural carrying capacity index; $A$ is the index of acquired carrying capacity.

The pressure of population, economic and social development index (*PESDPI*) is mainly manifested in the comprehensive effects of population development, economic growth, consumption, pollution, livable demand, and other factors. According to the mechanism of each factor, the pressure model of population and social and economic development constructs as follow (Di et al., 2013):

$$PESDPI = \left[\alpha'\left(P+E\right)\right]^{2} e^{\beta'}\left(P+E\right)R \tag{8}$$

where $PESDPI$ is the index of population and socio-economic pressure; $\alpha'$ is the index of resource consumption; $\beta'$ is the index of environmental pollution; $P$ is the index of population development; $E$ is the index of economic growth; $R$ is the index of livable demand.

#### 2.2.3 Urban sustainable development model

By analyzing changes of *CCC* and *PESDPI*, can we study the development situation of a city and guide its human activities (Liu et al., 2018). In practice, *CCC* covaries with the *PESDPI*. In order to eliminate the dimension difference, the normalized model can be used to deal with the carrying capacity. The calculation formulas are (Di et al., 2018):

$$RECCC_{Ri} = \frac{RECCC_{Ai} - \min RECCC_{Ai}}{\max RECCC_{Ai} - \min RECCC_{Ai}} \tag{9}$$

$$PESDPI_{Ri} = \frac{PESDPI_{Ai} - \min PESDPI_{Ai}}{\max PESDPI_{Ai} - \min PESDPI_{Ai}} \tag{10}$$

where $RECCC_{Ri}$ is the relative carrying capacity of a certain period of time; $RECCC_{Ai}$ is the absolute capacity for a certain period of time; $\min RECCC_{Ai}$ is the absolute minimum capacity; $\max RECCC_{Ai}$ is the absolute maximum capacity; $PESDPI_{Ri}$ is the relative pressure; $PESDPI_{Ai}$ is the absolute pressure; $\min PESDPI_{Ai}$ and $\max PESDPI_{Ai}$ are the minimum and maximum value of the absolute pressure for a time series, respectively.

The state index (Zhao et al., 2009) is to classify the statue of urban sustainable development in two-dimen according to the angle ($\delta$) of $\Delta RECCC$ *and* $\Delta RESDPI$. When $\delta \le -1$, the sustainable development of cities is in crisis state; when $-1 < \delta < 0$, the sustainable development of cities is in early warning state; when $0 < \delta < 1$, the sustainable development of cities is in general state; when $\delta \ge 1$, the sustainable development of the city is in good condition.

## 3 Results

### 3.1 Variation characteristics of index layer in Harbin

From Table 1, weight analysis shows that the top three indicators are the number of minimum living security for urban and rural residents (person) (0.0497), the supply of state-owned construction land (0.0430) and paving road area per $10^4$ people (0.0417) in carrying capacity system. The indicator of supply of state-owned construction land and paving road area per $10^4$ people are positive. While the indicator of the number of minimum living security for urban and rural residents is negative, that is mean when we have more residents enjoy the minimum living security in urban and rural, it will reduce the carrying capacity extremely.

The top three indicators are water consumption in per $10^4$ yuan GDP (0.0428), per capita GDP (0.0424) and the industrial exhaust emissions in per $10^4$ yuan GDP (0.0416) in pressure system. All of these indicators are positive, showing that it would increase pressure when we maintain current industrial development and economic growth in Harbin City.

Based on the immunological model, the development trend of comprehensive carrying capacity of Harbin can be seen from 2012 to 2017. The numerical changes of each index are shown in Fig. 2. From Fig. 2, we can see that in the carrying capacity system, the resource support index shows a significant downward trend, while the environmental capacity and social progress index rise circuitously, the degree of agglomeration and the value of transportation facilities increase steadily. It shows that the improvement of material basis and socioeconomic power in Harbin depends on a reduction in the resource support.

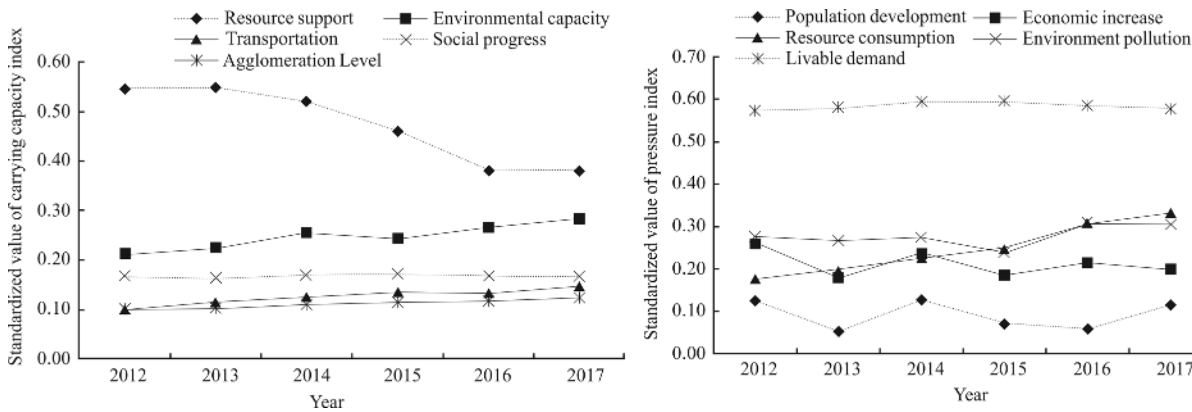


**Fig. 2** Urban comprehensive carrying capacity of Harbin from 2012 to 2017

According to the pressure indexes, population development and economic growth is fluctuating, with population pressure and economic growth curve changing consistent relatively. Energy consumption and environmental pollution shows synchronous upward trend, which indicates the current development of Harbin City depending on energy consumption of material resources. The linear development model of high input, high consumption, and high emission of resources is still prevalent; hence, it is imperative to change the development mode in the future. Turning to a green development mode is urgent. The fluctuation of livable demand is subtle and generally maintains in a relatively high level, showing the impact of living demand on pressure system is small from 2012 to 2017 to some extent.

### 3.2 Variation characteristics of system layer in Harbin

From Fig. 3, we can see that the comprehensive carrying capacity of Harbin City showing a downward trend, mainly because the nature carrying capacity is on a downward trend. The index of acquired carrying capacity shows an upward trend fluctuation, mainly because of the indicator of transportation facility, social progress and agglomeration degree showing growth from 2012 to 2017. The population and socioeconomic development index shows a consistent change with the acquired carrying capacity.

The comprehensive carrying capacity shows the change characteristics consistent with the nature carrying capacity. Although the acquired carrying capacity increases slightly, the effect of improving the comprehensive carrying capacity is less than the decrease of the nature carrying capacity. It indicates that the nature carrying capacity plays a leading role in comprehensive carrying capacity compared with the acquired carrying capacity index.

### 3.3 Characteristics of sustainable development in Harbin

Table 2 shows the calculated annual rates of comprehensive carrying capacity and pressure of population

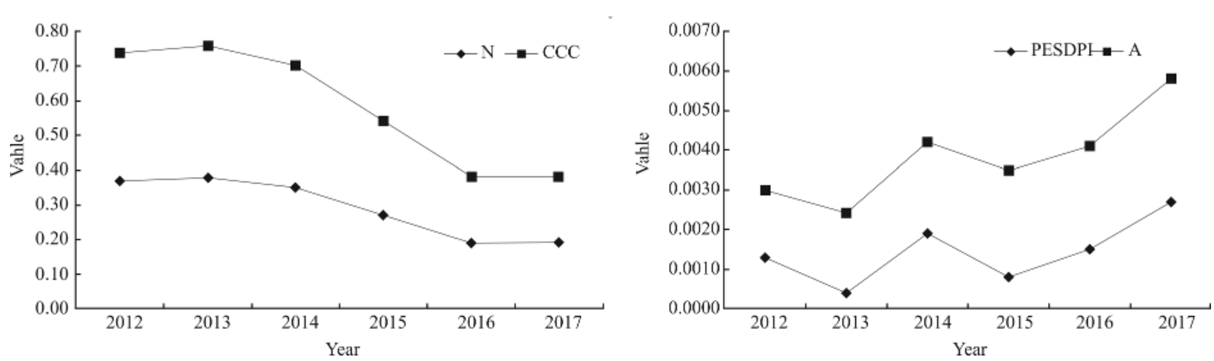


**Fig. 3** Evolution of urban comprehensive carrying capacity of Harbin from 2012 to 2017. N is the natural carrying capacity index; CCC is the index of urban comprehensive carrying capacity; A is the acquired carrying capacity index; PESDPI is the index of population and socio-economic pressure

and socio-economic development in Harbin; its sustainable development status is judged by comparing adjacent two values. Those results are shown in Table 3. For the comprehensive carrying capacity, the larger index is, the higher the comprehensive carrying capacity is, on the contrary, the lower index is, the lower the comprehensive carrying capacity is. For the pressure of population and socio-economic system, the higher the index is, the greater the pressure is, on the contrary, the smaller the pressure is. According to the angle ($\delta$) of $\Delta RECCC_{Ri}$ and $\Delta RESDPI_{Ri}$, the sustainable development state of Harbin could be judged.

From Table 3, we can see that the rate of comprehensive carrying capacity is less than the rate of pressure in 2014, 2016 and 2017. The sustainable development of Harbin has been in the early warning state in 2014, 2016 and 2017. After 2016, this status was continuous. The result reflects the severe divergence from sustainable development in Harbin. The long-term extensive economic growth pattern had led to the destruction of the ecological environment approaching the limit of ecological endurance. In the future, it is imperative to change the scale development pattern of scale expansion and total growth, and take the road of intensive, healthy and sustainable development.

### 3.4 Spatial differentiation characteristics of urban comprehensive carrying capacity in Harbin

In this part, using the county unit, the spatial differentiation characteristics of comprehensive carrying capacity of Harbin City are investigated. According to the above-mentioned evaluation index system of comprehensive carrying capacity of Harbin City, the comprehensive carrying capacity of each county (district, city) and the pressure index of population, economic and social development in 2017 were calculated. The spatial overlay of human and population economic and social development pressure was done in Arc GIS, and spatial differentiation characteristics of Harbin city's comprehensive carrying capacity are discernable (Fig. 4).

From Fig. 4, it can be seen that the comprehensive carrying capacity of Harbin city has obvious spatial differentiation characteristics and could be divided into four categories. Nangang District and Daoli District belong to the low carrying capacity and high-pressure type. Nangang District is the commercial center of Harbin City. As the central urban area of Harbin, Daoli District is also the political, economic, cultural-tourism center of Harbin. In 2017, Daoli District gained national investment potential and was among the top 100 regions for innovation and entrepreneurship. Nangang District and Daoli District have always been the agglomeration areas of population distribution. Industrialization and urbanization have brought huge pressure on population and economic and social development, resulting in the low comprehensive carrying capacity of the region. In the future, to alleviate this situation of overload will require improving the acquired carrying capacity in an orderly manner.

Shuangcheng District, Pingfang District, Xiangfang District, Daowai District, Songbei District, and Wuchang City belong to low carrying capacity and medium- pressure type. These areas are the core places to undertake

**Table 2** Evaluation index system for the comprehensive carrying capacity of resource and environment

| Evaluation index | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| *N* | 0.3686 | 0.3790 | 0.3502 | 0.2707 | 0.1899 | 0.1918 |
| *A* | 0.0017 | 0.0020 | 0.0023 | 0.0027 | 0.0026 | 0.0031 |
| *CCC* | 0.3692 | 0.3798 | 0.3510 | 0.2714 | 0.1904 | 0.1924 |
| *PESDPI* | 0.0013 | 0.0004 | 0.0019 | 0.0008 | 0.0015 | 0.0027 |

Notes: *N* is the natural carrying capacity index; *A* is the acquired carrying capacity index; *CCC* is the index of urban comprehensive carrying capacity; *PESDPI* is the index of population and socio-economic pressure

**Table 3** Evaluation of sustainable development from 2012 to 2017 for Harbin

| Item | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| $RECCC_{Ri}$ | 0.9940 | 1.0000 | 0.8479 | 0.4277 | 0.0000 | 0.0106 |
| $PESDPI_{Ri}$ | 0.3913 | 0.0000 | 0.6522 | 0.1739 | 0.4783 | 1.0000 |
| $\Delta RECCC_{Ri}$ | – | 0.0060 | −0.1521 | −0.4202 | −0.4277 | 0.0106 |
| $\Delta PESDPI_{Ri}$ | – | −0.3913 | 0.6522 | −0.4783 | 0.3044 | 0.5217 |
| Sustainability | – | Ordinary development state | Warning status | Ordinary development state | Warning status | Warning status |

Notes: $RECCC_{Ri}$ is the relative carrying capacity of a certain period of time; $PESDPI_{Ri}$ is the relative pressure; $\Delta RECCC_{Ri}$ is the variation of comprehensive carrying capacity; $\Delta RESDPI_{Ri}$ is the pressure variation of population economic and social systems

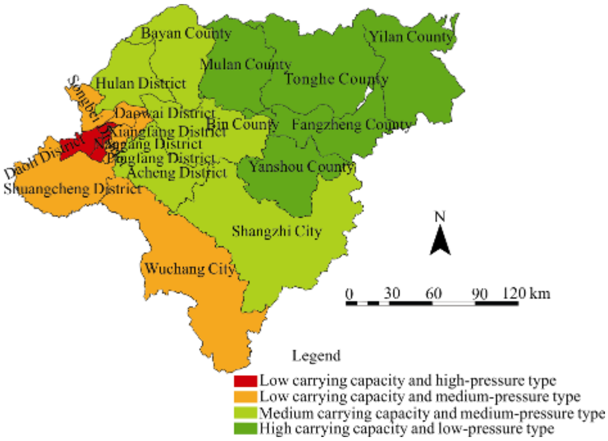


**Fig. 4** Spatial differentiation about sustainability development of Harbin

population and industry transfer into central urban areas. Compared with Daoli District and Nangang District, the population and economic development level in these areas is relatively low, which is reflected in population concentration and industry. The impact of economic development on regional carrying capacity is relatively light, but with the accelerated implementation of the policy of 'retreat into two and enter into three' in central urban areas, regional carrying capacity will face severe challenges in the future. Hulan District, Acheng District, Shangzhi City, Bin County, and Bayan County belong to the medium carrying capacity and medium-pressure type. Being farther away from the central city, those regions have disturbance factors that are mostly economic and industrial which arose there. Their effect size is relatively small, and so insufficient to seriously impact the comprehensive carrying capacity; hence these regions possess greater potential development in the future. Mulan County, Tonghe County, Fangzheng County, Yanshou County, Yilan County and other counties all belong to the high carrying capacity and low-pressure type. The pressure index of population economic and social development in this region is the lowest, and the comprehensive carrying capacity is relatively high, thus offering the greatest potential development in the future.

## 4 Factors influencing spatial differentiation of urban comprehensive carrying capacity in Harbin

There are many factors affect the comprehensive carrying capacity in Harbin, apart from above-mentioned analysis factors, location, economic development level, administrative power, and social science and technology factors are also essential.

### 4.1 Location condition

Location condition is not only the material basis for the development of urban comprehensive carrying capacity, but also the basic driving force for the interaction of various elements of urban comprehensive carrying capacity. Regions with superior location condition will promote the flow of economic factors in the region. The frequency and intensity of interactions among these factors directly affect the comprehensive carrying capacity of regional cities (Guo et al., 2015). Due to the dual effects of historical development and realistic objective conditions, the traffic conditions of Harbin's counties and cities (districts) are spatially heterogeneous. The traffic lines in the central core areas, such as Nangang District and Daoli District, are densely netted and the eastern and western wings are sparsely branched. Therefore, the central core area has become the most advantageous area in terms of traffic conditions. Due to the continuous agglomeration of people flow, logistics, capital flow, information flow, energy flow and technology flow along the transportation line, the central core area has become the economic growth uplift area.

### 4.2 Economic development level

Urban economic carrying capacity is the internal basis for the evolution of urban comprehensive carrying capacity system. When urban economic carrying capacity exceeds urban comprehensive carrying capacity seriously, the city is in a state of uncoordinated development; when urban economic carrying capacity and urban comprehensive carrying capacity are improved in parallel and matched each other, the city was in a state of coordinated development; when the gap between economic carrying capacity and urban comprehensive carrying capacity is large or small, and when the coordination between them is good or time-lagged, the city is in a neutral fluctuating state of development. For a long time, Nangang District and Daoli District, as the economic centers of Harbin City, have functioned as the main drivers of regional economic growth, yet Harbin City is still in a stage of scale expansion and its total growth relies mainly upon factor agglomeration. Regional polarization effects still prevail. Peripheral areas are still in the stage of 'self-contained system and self-sufficiency', with obvious hues of a planned economy and serious convergence of industrial structure, which will inevitably hinder the free market-oriented exchange of goods and services. A spatial differentiation between the center of urban comprehensive carrying capacity and its periphery is inevitable.

### 4.3 Government regulation

Government regulation is the external driving factor underpinning the dynamic evolution of urban comprehensive carrying capacity. The environmental behavior of urban economic subjects has a strong negative externality. Government regulation thus plays a pivotal role in guiding and controlling the rate and path of urban evolution. Under the guidance of GDP-oriented performance appraisal, the government tends to pay more attention to developing the urban economy, ignoring the degree of intervention on the negative externalities of the economy, thus possibly forming a structural imbalance between the urban carrying system and economic development. By adopting appropriate control measures and adjusting the internal structural contradictions of urban comprehensive carrying capacity system, the government can promote the evolution of urban comprehensive carrying capacity to coordinated development. To some extent, it can be said that without the existence of government regulation, the urban comprehensive carrying capacity will not actively change from the evolutionary model of uncoordinated or neutral fluctuation to the evolutionary model of coordinated development. In addition, China's administrative management system is hierarchical system. Regional central areas play the role of 'referee' in regional development, becoming the makers of game rules and dictators, depriving low-level regional development of its space. For a long time, Nangang District and Daoli District, being key regional central areas of Harbin, were able to get more construction projects and special funds allocated to themselves by provinces and cities, enabling them to become the growth poles of regional development. In 2016, the total investment in fixed assets in Nangang and Daoli districts was 60.52 billion yuan and 60.6 billion yuan, respectively; both are significantly exceed that received by other regions, and this disparity undoubtedly aggravates the spatial differentiation of comprehensive carrying capacity among regions.

### 4.4 Science and technology

Science and technology is the premise and important guarantee for the coordinated development of urban comprehensive carrying capacity systems. Although the role of government regulation can guide the scientific development of urban comprehensive carrying capacity to a certain extent, the specific means of its scientific and rational development will depend on science and technology. Scientific and technological progress not only creates efficient industries and industrial sectors but also uses new industrial technology and equipment to transform the original industry, and thus constantly promotes the optimization and upgrading of industrial structure. In addition, scientific and technological progress can promote the cleaner production of enterprises, extend the industrial chain, and enhance the efficiency of resource utilization, while reducing pollution and damage to the environment (Guo et al., 2016b). Overall, Nangang District and Daoli District are relatively advantaged in terms of scientific and technological resources. In 2016, their number of full-time teachers (in primary and secondary schools) and the number of patent authorizations were 7868, 4489 and 6155 and 675, respectively. At the same time, the conditions of scientific and technological resources in Xiangfang District, Pingfang District, and Songbei District have developed rapidly, which shows that regional differences in scientific and technological conditions lead to the development of scientific and technological resources. This in part causes the spatial differentiation of urban comprehensive carrying capacity, and the steady improvement of scientific and technological conditions in the whole region promotes the continuous improvement of urban comprehensive carrying capacity.

## 5 Discussion

The comprehensive carrying capacity of a city is the threshold of the scale and intensity of various factors that can be sustained in a certain period, in a certain space area and under certain social, economic, ecological, and scientific and technological conditions. The study on Harbin's urban comprehensive carrying capacity should not be limited in analyzing one single factor, while, we should instead on exploring the urban comprehensive carrying capacity how to be effect with multi-factors interaction. In Harbin City case, comprehensive carrying capacity contain natural carrying capacity and acquired carrying capacity, covering many dimensions such as natural conditions and social conditions, in order to have the result as realistic as possible. The method of constructing comprehensive indicators for evaluation is also widely accepted (Liu et al., 2018; Zhi et al., 2019).

The concept of urban comprehensive carrying capacity has been used widely; however, there are also some problems such as lack of regulatory mechanisms, insufficient execution and inadequate estimation methods. The size of urban comprehensive carrying capacity shows dynamic spatial and temporal change. Different cities in different locations may have different thresholds at the same stage of development, and the same city also has different thresholds at different stages of development, which undoubtedly makes the study of urban comprehensive carrying capacity even more challenging. In addition, this paper tried to construct an evaluation index system of urban comprehensive carrying capacity from material basis and socioeconomic power. Indicators such as energy consumption per unit GDP and industrial waste discharge per unit GDP indicate the 'input-output' relationship of the city, are effective for conveying the advantages and disadvantages of its sustainable development, and for evaluating the comprehensive carrying capacity of the city as in-depth and scientifically as possible.

The spatial differentiation of comprehensive carrying capacity of Harbin City is mismatched seriously with the current economy and urban spatial structure. That is to say, for those areas with better economy development and high population concentration, their comprehensive carrying capacity needs to be promoted urgently. The areas with greatest potential for the comprehensive carrying capacity of Harbin City are located on the edge. The pattern of comprehensive carrying capacity shows the characteristics of 'strong core-weak periphery' differentiation model clearly. The pattern is similar to the evolution of comprehensive carrying capacity in Chinese megalopolises (Ge et al., 2018).

Based on analysis, the following recommendations are put forward: firstly, promoting the urbanization process steadily and adjusting the industrial structure accordingly, exerting the positive synergistic effect of regional development. Secondly, building an early warning mechanism of urban comprehensive carrying capacity, striving to achieve the sustainable development process of regional resources, environment, and social economy. Thirdly, devising adaptive measures to different type areas. Low carrying capacity and high-pressure type areas should pay more attention to intensive use of resources. Low carrying capacity and medium-pressure type areas should pay more attention to regulating their dynamic balance in the flux and flow of urban internal factors. In generally, both medium carrying capacity and medium-pressure type areas and high carrying capacity and low-pressure type areas are potential areas, especially for high carrying capacity and low-pressure type areas, which have greater potential power, should actively develop leisure industry such as leisure agriculture and idyllic complex in land-use.

In the future research topic about comprehensive carrying capacity, we can detailed urban land use and evaluate capacity of various facilities, including carrying capacity of industrial land, commercial land, traffic land, residential land, sanitation and disaster prevention systems, *etc*. Based on city comprehensive carrying capacity, we can give quantitative grades with different urban function in city. Besides, we can intensive study on basic theory of urban comprehensive carrying capacity.

## 6 Conclusions

(1) Weight analysis shows that the number of minimum living security for urban and rural residents (person) (0.0497) is the key obstacle factor for improving carrying capacity, but the supply of state-owned construction land (0.0430) and Paving road area per $10^4$ people (0.0417) are positive factors to improve it in carrying capacity system. Per capita GDP and resource consumption and environment pollution are key parts to heighten pressure.

(2) ecline of natural carrying capacity will be the primary factor weakening the comprehensive carrying capacity of Harbin in the future. Resource consumption is the bottleneck of its sustainable development. Development depends on the consumption of resources, pursuing expansion of city scale and economic growth in regional development is not smart. The regional devel-

opment model should be upgraded. The regional development pursues expansion of scale and the growth of total amount of regional development, neglecting the effective utilization of resources. We should seek to green practice and improve resource utilization in the process of industrialization.

(3) From 2012 to 2017, the sustainable development of Harbin presents alternative warning status with ordinary development state. The spatial differentiation of comprehensive carrying capacity of Harbin City is mismatched seriously with the current economy and urban spatial structure. The pattern of comprehensive carrying capacity shows the characteristics of 'strong core-weak periphery' differentiation model clearly. Nangang District and Daoli District belong to low carrying capacity and high-pressure type. Shuangcheng District, Pingfang District, Xiangfang District, Daowai District, Songbei District, and Wuchang City belong to low carrying capacity and medium-pressure type. Hulan District, Acheng District, Shangzhi City, Bin County and Bayan County belong to medium carrying capacity and medium-pressure load type. Lastly, Mulan County, Tonghe County, Fangzheng County, Yanshou County, Yilan County and other counties belong to high carrying capacity and low-pressure type.

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