



# Evaluation of urban comprehensive carrying capacity in the Guangdong–Hong Kong–Macao Greater Bay Area based on regional collaboration

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## Abstract

The Guangdong–Hong Kong–Macao Greater Bay Area (GBA) is the most prominent urban agglomeration in China, with plans for further development. Using the regional collaboration theoretical framework for assessing urban comprehensive carrying capacity (UCC), the improved entropy method is applied to establish an index system based on a social, economic, environment, and transportation perspective to compare UCCs of the GBA's 11 cities for 2000–2016. Results show that the social subsystem is central to the evaluation system. Cities' performances vary significantly, with six becoming overloaded in 2016 and the other five remaining loadable. Guangzhou performed best, with a rising UCC; Shenzhen rebounded after a long period of decline; Hong Kong's capacity rose slightly, with some fluctuation; and Macao performed worse and continues to slide, with no signs of improvement. Overall, the UCC of the urban agglomeration showed a downward trend, with only a few cities continuing to improve. The spatial distribution for UCC was high in the north and low in the south, showing scope for improvement. The study enriches regional collaboration theory and proposes policy implications for GBA development.

**Keywords** Urban comprehensive carrying capacity (UCC) · The Guangdong–Hong Kong–Macao Greater Bay Area (GBA) · Improved entropy method · Regional collaboration · Urban agglomeration · Spatial distribution

## Introduction

Following a study by Arrow et al. (1995), carrying capacity has become a popular focus of both scientific research and

policy discussions. Conventionally, the concept is expressed using the Verhulst logistic equation as the maximum population size of a biological species that can be supported in a given environment (del Monte-Luna et al. 2004; Rees 1996;

### Highlights

- Carrying capacity of the bay area has been explored using improved entropy method;
- Capacity levels of Hong Kong/Macao are estimated in index system with other cities;
- Spatial distribution of carrying capacity is high in the north and low in the south;
- Regional collaboration theory is enriched through consideration of the bay area;
- This study is the first to comprehensively evaluate capacity levels in the bay area.

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Seidl and Tisdell 1999). A range of carrying capacity types have been investigated, including environmental carrying capacity (Han and Shi 2019; Yu and Mao 2002; Zhou et al. 2017), water carrying capacity (Liao et al. 2013; Naimi Ait-Aoudia and Berezowska-Azzag 2016; Zhang et al. 2019), resource carrying capacity (Lei and Zhou 2012; Sun et al. 2020; Yang et al. 2019a), and urban comprehensive carrying capacity (UCC), which takes all aspects of carrying capacity into consideration (Cui et al. 2019; Diao et al. 2019; Liu 2012; Shao et al. 2019; Wang et al. 2018a; Wei et al. 2016). UCC refers to the level of economic, social, transportation, and environmental conditions, based on which researchers calculate an aggregate indicator value by summarizing the various aspects of carrying capacity using multiple methods (Tian and Sun 2018a, b; Wang et al. 2018b).

UCC has been applied to various research areas; however, in recent years, increasing attention has been paid to city-level comparisons of urban agglomerations, such as for cities in the “Belt and Road” initiative (Cheng et al. 2015), the Jing-Jin-Ji metropolitan area (Tang et al. 2016), and the Yangzi River Economic Belt (YREB) (Liu 2012). Focusing on the YREB, as one of the fastest-growing urban agglomerations in the world, Tian and Sun (2018a) revealed the spatial differentiation for the area’s UCC using advanced spatial techniques. In another study, Tian and Sun (2018b) found an inverted U-shaped relationship for the impact of economic growth on UCC, while a U-shaped curve was noted for the impact of UCC on economic growth. Using the same research sample, Liu (2012) analyzed the 16 cities in the YREB from the perspective of resource supply and demand and argued that Shanghai exhibited inferior performance with respect to UCC levels compared to neighboring cities; in addition, land and water were confirmed to be the determining factors for sustainable economic and social development. Moreover, as per Tian and Sun’s (2018a) findings, spatial heterogeneity was found to exist in the YREB, while the differentiation was revealed to have expanded over the past several decades, indicating an increasing development gap between certain cities in the region (Liu 2012).

The Jing-Jin-Ji metropolitan area has also attracted much interest. For example, Wang et al. (2018b) found that the UCC of the Jing-Jin-Ji area is at the upper level as a whole, with cities in the northern and southern parts performing better than those located in the mid-regions. Table 1 presents milestones in national policy and regulations, including the “12<sup>th</sup> Five-Year Plan” and “13<sup>th</sup> Five-Year Plan” (which refer to the periods 2010–2015 and 2016–2020, respectively), and the recently released “Outline Development Plan for the Guangdong–Hong Kong–Macao Greater Bay Area” (hereinafter

referred to as the “Outline Development Plan”), that led to UCC improvement.

In this paper, we evaluate the UCC in the Guangdong–Hong Kong–Macao Greater Bay Area (GBA) and compare and analyze differences among the 11 cities in this region.<sup>1</sup> According to the “Outline Development Plan,” which was released on February 18, 2019 (SC 2019), the GBA is considered a key area in the blueprint for China’s development. The motivation behind establishing the GBA is to deepen cooperation among the two special administrative regions (i.e., Hong Kong and Macao) and the nine cities in Guangdong Province and to promote coordinated regional economic growth so as to develop an internationally renowned bay area that is ideal for living, work, and travel.

To achieve its aims, this study draws on the theory of regional collaboration. According to this theory, population, resources, technology, and environment are the key elements of regional cooperative systems. By adjusting the independent dynamics and the relative influence of each element, the benefits of mutual cooperation can be achieved. In this way, the regional collaboration system can be transformed into a new state, leading to mutually beneficial, “win–win” development within and outside the region, and comprehensive, coordinated, and sustainable development of the regional economy and society (De Noni et al. 2017; Yu et al. 2019). In this light, the present study evaluates the UCC levels of the GBA region using the theoretical framework of regional collaboration. In doing so, it makes three contributions. First, to our knowledge, this is the first attempt to explore the UCC of the GBA by establishing an index system from social, economic, environment, and transportation perspectives. Second, each city’s UCC performance during the research period is analyzed and compared, and the wide differences between them are noted. Third, the study extends theory on regional collaboration and proposes policy implications related to the coordinated development of urban agglomerations (specifically the GBA).

## Evaluation of comprehensive carrying capacity: a theoretical framework

Based on regional collaboration theory, this section analyzes the evolutionary mechanism of UCC and clarifies the structure of the UCC system. Further, it considers the coordinated development of cities based on their comparative advantages, using the positioning and division of labor among cities in the GBA under regional coordination as its main focus (Wang et al. 2018b).

<sup>1</sup> This GBA region includes the special administrative regions of Hong Kong and Macao and the nine municipalities of Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen, and Zhaoqing in Guangdong Province.

**Table 1** Milestones in national policy and regulations leading to UCC improvement

| Year | Policy and regulations   | Relevant content   |
|------|--------------------------|--|
| 2010 | The 12th Five-Year Plan  | This plan aimed to increase the overall UCC of cities and towns; determine the boundaries of urban development and prevent the excessive expansion of megacities; and prevent and control “urban diseases.” In addition, it sought to expand urban green spaces and public activity spaces, and increase the speed of development of sports facilities for the general public.   |
| 2015 | The 13th Five-Year Plan  | This plan aimed to facilitate green production and lifestyles; improve energy efficiency; and substantially reduce total emissions of major pollutants. It laid out a path of civic development characterized by increased production; affluent lifestyles and sound ecology; and a more resource-conserving and environmentally friendly society so as to form new patterns of modernization that promote harmonious development between human beings and nature.   |
| 2019 | Outline Development Plan | This plan seeks to benefit fully from pilot free-trade zones; strengthen cooperation with Hong Kong and Macao; and accelerate the building-up of GBA as a hub for international shipping, finance, and technological innovation so as to become a gateway for high-level opening-up. It is based around enhancing the GBA via a resource-conserving and environmentally friendly spatial blueprint; an enhanced industrial structure, mode of production, and way of life; and green, low-carbon, and sustainable development. |

**Analysis of the evolution mechanism of UCC based on regional collaboration theory**

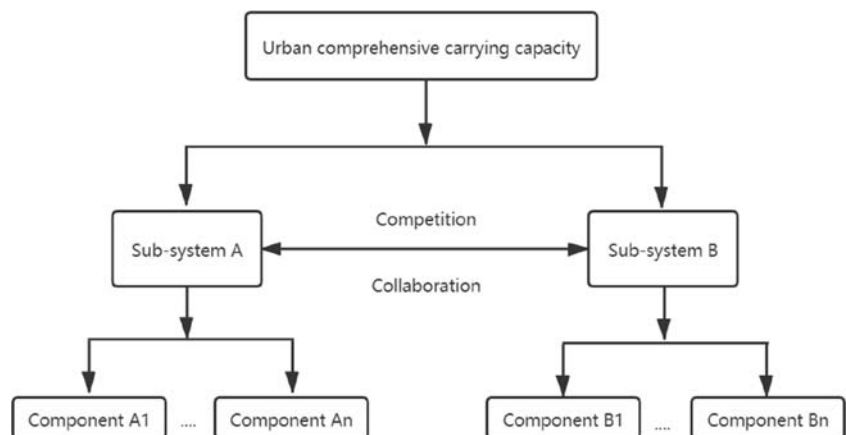
In 1976, Haken proposed synergetic theory, in which the stimulus behind a system’s evolution from disorder to order comes from a collaborative force that pushes the system toward a multi-dimensional ordered state (Haken 1997). As shown in Fig. 1, the evolutionary power of the comprehensive carrying capacity of each city in an urban agglomeration is derived mainly from competition and collaboration. Competition arises among subsystems within the urban agglomeration, such as the environment, economy, and transportation, as well as among components of each system. In the process of competition, the subsystem and its constituent elements produce

synergies and promote the orderly development of urban agglomeration.

**Composition of a carrying capacity system of urban agglomeration**

The UCC of urban agglomeration takes the urban agglomeration system as the spatial carrier. The agglomeration system can be divided into the original carrying capacity system and the derived carrying capacity system. The former mainly refers to the carrying capacity, which can be assumed to remain basically unchanged under conditions such as resource carrying capacity and environment carrying capacity. For example, resources and environment comprise the material basis for

**Fig. 1** Evolutionary analysis of the comprehensive carrying capacity of urban agglomeration



human survival and development, as well as the essential conditions for urban agglomeration to facilitate social and economic activities. Without the support of resources and environment, cities cannot grow. The latter is derived from the former, and the former can meet the demands of human production and life, which mainly pertain to economic carrying capacity and social carrying capacity. The economic system is the most obvious indicator of the developmental vitality and the potential of the urban agglomeration. On the one hand, the economic system is constrained by hard resources and the environment and influences the evolution of other subsystems; in this regard, sufficient resources can accelerate economic development. On the other hand, an economic system that is buoyant and offers significant development potential also helps to improve the efficiency of resources and harness sustainable energy sources, which promotes the development of the urban agglomeration. Figure 2 depicts the composition of a comprehensive carrying capacity system of urban agglomeration.

### The UCC of GBA under regional collaboration

The “Outline Development Plan” summarizes the development orientation and goals of each city in the GBA. With regard to the two special administrative zones, it is stipulated that Hong Kong should consolidate and enhance its status as an international financial, shipping, trade, and aviation hub; strengthen its position as a global center for offshore RenMinBi (RMB) business; and build an international legal and dispute-resolution service center in the Asia-Pacific region with the aim of constructing a more competitive global metropolis. Macao, in turn, is to build a world tourism and leisure center and a service platform for business cooperation between China and Portuguese-speaking countries. Regarding two other core cities in the GBA, Guangzhou should enhance the functions of its international business center and integrated transportation hub, while Shenzhen is to be built into a capital of innovation and creativity with global influence, and, for the

first time, pursue the goal of building a global ocean center city (SC 2019).

## Model specification and data collection

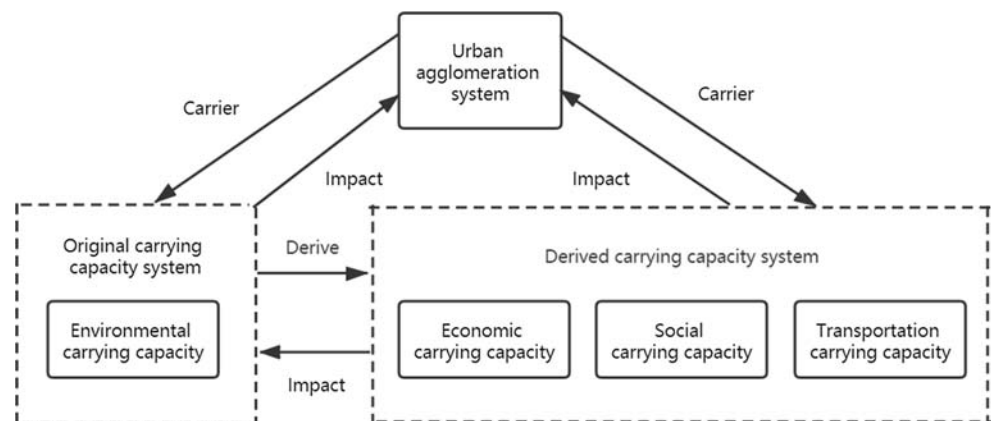
### Model specification

In general, both subjective- and objective-based methods have previously been employed to evaluate UCC levels. The Delphi method relies on experts’ experience and opinions, while analytical hierarchical process (AHP) combines qualitative and quantitative merits and provides a multi-dimensional analysis (Lu et al. 2017). Nevertheless, experts’ opinions are subjective, and personal views may affect the results. Thus, other studies have used the more objective method of principal component analysis (PCA). PCA uses dimensionality reduction to transform multiple indicators into a few comprehensive indicators (Salim et al. 2019); however, the evaluation relies on exigent data quality (Wei et al. 2016). By comparison, the entropy method measures the uncertainty contained within each variable for the whole theoretical concept; the approach essentially provides a deeper description of the uncertainty and can eliminate uncertainty in the evaluation analysis to the maximum extent possible, thus making the evaluation more objective. This objectivity also explains why most previous carrying capacity evaluation studies have used the entropy method (Zhou et al. 2017; Wang et al. 2018a; Shao et al. 2019; Cao and Ning 2019; Wei et al. 2020). In this light, the current study follows Wang et al. (2018b) and Yang et al. (2019b), who both employed the improved entropy method, and uses this method to measure the UCC level of the 11 cities in the GBA.

First, the data are treated as dimensionless and are standardized via standard deviation. The steps are as follows:

Assume that there are  $m$  schemes to be evaluated and  $n$  evaluation indexes, which form the original index data matrix  $X = (x_{ij})_{m \times n}$ .

**Fig. 2** Composition of a comprehensive carrying capacity system of urban agglomeration



- ①  $y_{ij} = (x_{ij} - \bar{x}_j) / s_j$ ,  $x_{ij}$  represents the  $j^{th}$  index of the  $i^{th}$  scheme,  $\bar{x}_j$  is the mean value of the  $j^{th}$  index, and  $s_j$  is the standard deviation of the  $j^{th}$  index. The negative sign should be added to reverse the index, and each city represents one scheme;
- ②  $X_{ij} = y_{ij} + 5$ . In general, the range for  $y_{ij}$  is from  $-5$  to  $5$ . To eliminate the negative value, the coordinate is shifted.

Second, after the same degree of quantification of each index, the weight is assigned and the UCC of each scheme is calculated. The steps are as follows:

- ①  $p_{ij} = X_{ij} / \sum_{i=1}^m X_{ij}$ , where  $p_{ij}$  means to calculate the proportion of the  $i^{th}$  scheme index of the  $j^{th}$  index;
- ②  $e_j = -k \sum_{i=1}^m (p_{ij} \times \ln p_{ij})$ ,  $k = \frac{1}{\ln m}$ , where  $e_j [0, 1]$  represents the entropy value of the  $j^{th}$  term;
- ③  $g_j = 1 - e_j$ ,  $w_j = g_j / \sum_{j=1}^n g_j$ , where  $g_j$  represents the difference coefficient of the  $j^{th}$  index,  $w_j$  represents the index weight, and the sum of all index weights is 1;
- ④  $v_i = \sum_{j=1}^n (w_j \times p_{ij})$ , ( $i = 1, 2, 3, \dots, m$ ). The UCC evaluation model is constructed with  $v_i$  representing the UCC index of scheme  $i$ .

### Data collection and description

This study used the improved entropy method to evaluate the UCC levels of the 11 cities in the GBA. Indicators were selected based on three principles: (1) the phrase “urban carrying capacity improvement” appeared in national official documents and local government development plans<sup>2</sup> that cover economic, social, and environmental aspects and are regarded as the foundation of new urbanization and a necessary condition for sustainable development of cities<sup>3</sup>; (2) the index system constructed by related studies was followed, and indicators used in previous literature were applied, to ensure the rationality of the index system and avoid statistical bias; (3) missing values were excluded consider the data accessibility, and indicators not presented in Hong Kong and Macao’s yearbooks were removed. This latter point is especially important with respect to GBA municipal samples because the two

special administrative regions have different measurement systems compared to the nine cities in Guangdong Province, and thus, certain common indicators, such as industrial sulfur dioxide emissions, had to be removed. This directly reduced the number of available indicators. Following Wei et al. (2016), we present the specific criteria used to select the indicators for constructing our carrying capacity index system construction in a table (see Table 2).

After considering the development plans outlined in official documents, and considering the availability of data, in particular with respect to the differences between datasets for mainland China versus the two special administrative regions, we selected 14 indicators with four dimensions: social, economic, environment, and transportation. Specifically, following Wei et al. (2016), we included transportation as a dimension because transportation is important for the megacities in the GBA. For example, the “Action Plan for Shenzhen to Build a National Transportation Hub (2019–2035)” states that the main cities in the GBA should be reachable from Shenzhen within half an hour and that Shenzhen should play an important role as a Belt and Road hub (Hui et al. 2018).

In addition, in order to estimate the UCC from both supply and demand aspects, the 14 indicators were divided equally into two categories: seven were attributed to the supply aspect (positive indicators) and considered beneficial for the UCC (yielding higher values), while the other seven (reverse indicators) were attributed to the demand aspect and considered detrimental to the UCC (lower values). Table 3 presents the four evaluation systems and the grading standards for the GBA.<sup>4</sup>

Data were extracted mainly from the *China Statistical Yearbook* (2001–2017) (CSY 2019), the *China Energy Statistical Yearbook* (2001–2017) (CESY 2019), and the *Guangdong Statistical Yearbook* (2001–2017) (GSY 2019). Noteworthy data for Hong Kong and Macao were sourced from the *Hong Kong Annual Digest of Statistics* (2001–2017)<sup>5</sup> and the *Macao Yearbook of Statistics* (2001–2017),<sup>6</sup> respectively. As noted above, due to the difference in measurements for Hong Kong and Macao versus the other nine cities in Guangdong, variables that were not included in the Hong Kong and Macao statistical yearbooks were not used in the study. Further, to ensure the quality of the data, indicators with a significant number of missing values were excluded. Where necessary, missing values were supplemented by an interpolation method.

<sup>2</sup> For example, the document “Decisions on major issues concerning upholding and improving the system of socialism with Chinese characteristics and promoting the modernization of China’s governance system and capacity” contains a requirement to improve the capacity of central cities and urban agglomerations to comprehensively support and optimize the allocation of resources. Please refer to [http://www.gov.cn/zhengce/2019-11/05/content\\_5449023.htm](http://www.gov.cn/zhengce/2019-11/05/content_5449023.htm)

<sup>3</sup> Please refer to: <http://dzb.jryccm.com/shtml/jryc/20190516/158155.shtml>

<sup>4</sup> With respect to grading standards, “poor value” denotes the lowest value of a given indicator while “excellent value” denotes the highest value of a given indicator. This is because some indicators show negative attributes, such as industrial solid waste produced, where a higher value equates to greater harm to the environment, so the highest value is denoted as “poor value.”

<sup>5</sup> Please refer to: [https://www.censtatd.gov.hk/hkstat/sub/sp460\\_tc.jsp?productCode=B1010003](https://www.censtatd.gov.hk/hkstat/sub/sp460_tc.jsp?productCode=B1010003)

<sup>6</sup> Please refer to: [https://www.dsec.gov.mo/home\\_zhcn.aspx](https://www.dsec.gov.mo/home_zhcn.aspx)

**Table 2** Criteria for indicator selection

| Items | Contents   |
|-------|--|
| i.    | “Scientific accuracy, operability, hierarchy, completeness and dynamic” (Yu and Mao 2002, p.181).    |
| ii.   | Representative and sensitive to the state of present conditions.                                     |
| iii.  | Direct link between human’s impacts and their causing activities and events (Button 2002).           |
| iv.   | Rich policy implications for forecasting the trends of changes.                                      |
| v.    | Offering a meaningful ground for testing the relevant theories.                                      |
| vi.   | Avoiding the repetitive information due to the inclusion of too many indicators.                     |
| vii.  | Reliably measurable and quantifiable (Button 2002; Graymore et al. 2010).                            |
| viii. | Ensuing the uniformity and consistency of indicators across different city prototypes (Button 2002). |

Sources: Wei et al. (2016)

## Empirical analysis and discussion

### Weights of the 14 indicators

As noted above and shown in Table 3, of the 14 indicators, seven were considered positive and the other seven negative (reverse indicators). All indexes were dimensionless. The entropy weighting method was used to calculate the weight of each index. The results are shown in Fig. 3.

The weights are largely similar, with values of between 0.142840 and 0.142870. The weights for the number of beds in health care institutions (X5) and the share of tertiary industry to GDP (X8) are the highest indicators, and both are positive, indicating the positive role of the social and economic subsystems. These are followed by population density (X2) and turnover volume of passenger traffic (X14); the former is a reverse indicator and belongs to the social subsystem, while the latter is a positive indicator and belongs to the transportation subsystem. These results illustrate the significant role of the social subsystem in the evaluation system.

### Comprehensive carrying capacity levels of the 11 cities in the GBA

The UCC values of the 11 cities were calculated using the improved entropy method from the perspective of supply and demand. In Fig. 4, the darker the color, the higher the magnitude of the value. The UCC values in 2016 were ranked from high to low order as follows: Guangzhou (15.4547), Zhuhai (2.5443), Foshan (2.4313), Huizhou (1.9230), Zhaoqing (1.1936), Dongguan (−0.0004), Hong Kong (−1.0488), Jiangmen (−3.5474), Zhongshan (−6.1534), Shenzhen (−7.7681), and Macao (−14.8557).

Generally speaking, Guangzhou’s UCC level far exceeds that of the surrounding cities, thanks to its vast land area, abundant higher education and medical resources (with high social subsystem scores), and ongoing efforts to control urban pollution and improve waste disposal. This is followed by Zhuhai and Foshan, with similar carrying capacity levels. Both cities have advanced manufacturing industries and have built innovative and entrepreneurial platforms in recent years, and performed well with respect to both social and economic subsystems. Although Huizhou and Zhaoqing did not score as

**Table 3** Social, economic, environment, and transportation evaluation index systems and grading standards for the GBA

| System layer             | Indicator layer (units)                                  | Serial number | Poor value   | Medium value | Excellent value | Attributes |
|--------------------------|--|---------------|--------------|--------------|-----------------|------------|
| Social subsystem         | Population (10,000 persons)                              | X1            | 1190.84      | 491.79       | 43.67           | −          |
|                          | Population density (persons/sq.km)                       | X2            | 21,400.00    | 3201.92      | 227.00          | −          |
|                          | University/College enrollment (persons)                  | X3            | 1,057,281.00 | 126,656.29   | 3241.00         | −          |
|                          | Health care institutions (unit)                          | X4            | 60.00        | 1118.48      | 3806.00         | +          |
|                          | Number of beds in health care institutions (unit)        | X5            | 1099.00      | 11,838.11    | 34,798.00       | +          |
| Economic subsystem       | GDP per capita (yuan)                                    | X6            | 7422.00      | 93,417.68    | 579,066.20      | +          |
|                          | GDP growth rate (%)                                      | X7            | −21.60       | 11.30        | 26.80           | +          |
|                          | Share of tertiary industry to GDP (%)                    | X8            | 27.70        | 49.12        | 96.30           | +          |
| Environment subsystem    | Electricity consumption per capita (kWh)                 | X9            | 9126.72      | 3365.57      | 0.10            | −          |
|                          | Volume of tap water supplied (tons)                      | X10           | 263.05       | 133.96       | 15.29           | −          |
|                          | Volume of industrial solid wastes produced (10,000 tons) | X11           | 691.79       | 177.30       | 10.44           | −          |
| Transportation subsystem | Public green areas per capita (m <sup>3</sup> )          | X12           | 7.87         | 14.34        | 19.70           | +          |
|                          | Passenger traffic (10,000 persons)                       | X13           | 223,879.00   | 24,128.91    | 1599.00         | −          |
|                          | Turnover volume of passenger traffic (10,000 person-km)  | X14           | 137,897.00   | 1,135,967.30 | 8,610,825.00    | +          |

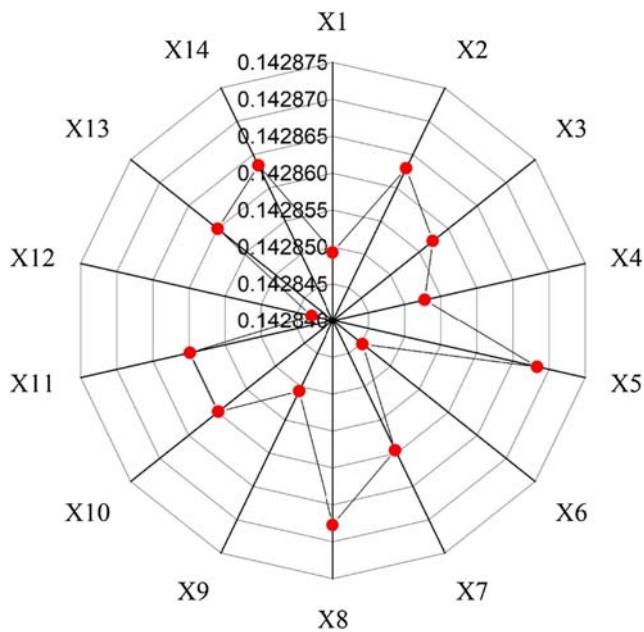
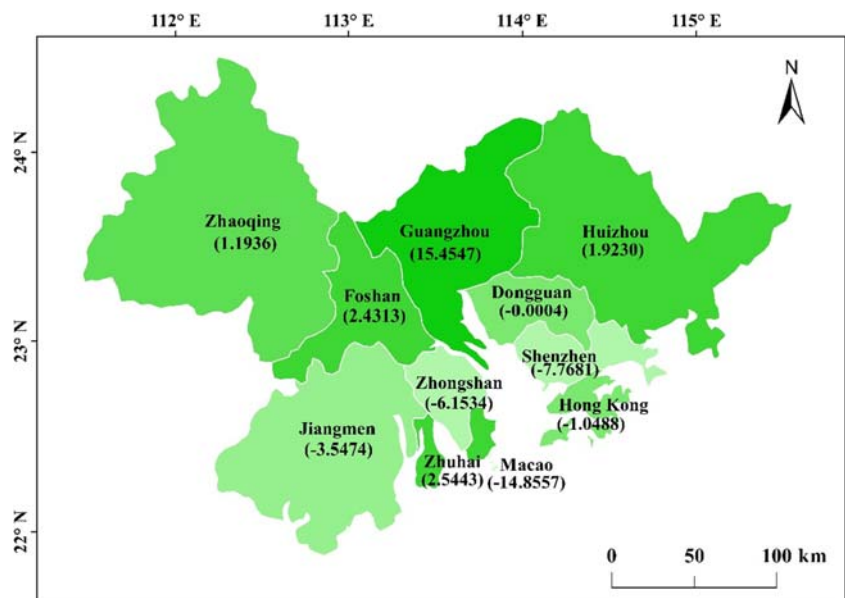


Fig. 3 The weights of the 14 indicators

highly as the former three cities in terms of industrial structure and economic development, they are rich in land resources, making their carrying capacity values positive.

The remaining six cities exhibited a negative UCC level. The score for Dongguan was close to 0: although the manufacturing industry is developed, the land area is limited and the large population puts pressure on the city. Hong Kong and Shenzhen both have highly developed economies and societies, but in each of these cities, the land area is in seriously short supply, the population is too large, and damage to the environment is great, which limits development. Further, although Jiangmen and Zhongshan have sufficient land resources, they lack supporting industries and exhibit poor

Fig. 4 Carrying capacity values of the 11 cities in the GBA for 2016



economic performance. Macao is the worst-performing city in the GBA, as it has very limited land resources and a large population, and lacks the upstream financial industry of Hong Kong and the high-end manufacturing of Shenzhen.

Overall, based on the spatial perspective, the distribution of UCC values in the GBA urban agglomeration is high in the north and low in the south, mainly because the northern cities, such as Guangzhou, Zhaoqing, Foshan, and Huizhou, have abundant land resources.

Table 4 and Fig. 5 provide a more complete picture of UCC values for the 11 cities during the period 2000–2016. As can be seen from the table and figure, among the cities with positive UCC values, only Guangzhou has been growing steadily, from 4.0724 in 2000 to 15.4547 in 2016—a nearly fourfold increase, with an annual average growth rate of 8.69%, which indicates outstanding performance for Guangzhou with respect to carrying capacity. Zhuhai, Foshan, Zhaoqing, and Huizhou all experienced fluctuations and declines during the study period, with Zhaoqing experiencing the largest decrease, from 6.1140 in 2000 to 1.1936 in 2016.

The UCC values for Hong Kong, Zhongshan, Dongguan, and Jiangmen fluctuated around zero, with the values for Hong Kong varying significantly from 5.0977 in 2011 to -5.9490 in 2015. The carrying capacity for Shenzhen was initially negative, with the values showing a slight declining trend; after 2015, there was a significant rebound in values, indicating an improvement in carrying capacity. Unlike Shenzhen, the UCC values for Macao were found to decline rapidly, from -0.8935 in 2000 to -14.8557 in 2016—a nearly 17-fold drop—and this shows no sign of improvement. The overall outlook for the UCC of the GBA is not optimistic. The carrying capacity of most cities continues to deteriorate and only Guangzhou has witnessed continual improvements in carrying capacity over the study period. Thus, there is clear

**Table 4** Comprehensive carrying capacity index values from 2000 to 2016 for the 11 cities in the GBA

| Year | Hong Kong | Macao    | Guangzhou | Shenzhen | Zhuhai | Foshan | Zhongshan | Dongguan | Zhaoqing | Huizhou | Jiangmen |
|------|-----------|----------|-----------|----------|--------|--------|-----------|----------|----------|---------|----------|
| 2000 | -2.2298   | -0.8935  | 4.0724    | -6.5975  | 4.6844 | 1.5173 | 0.7226    | 0.5518   | 6.1140   | 3.2448  | 0.8856   |
| 2001 | -4.7133   | -4.6709  | 3.7576    | -9.6081  | 4.0736 | 2.3073 | -0.2251   | -0.6395  | 5.4080   | 4.6441  | 0.7843   |
| 2002 | -3.0732   | -3.2542  | 3.8531    | -10.0901 | 4.2987 | 2.0783 | -0.0483   | -1.3244  | 5.4270   | 5.4598  | 1.2261   |
| 2003 | -2.2609   | -3.5517  | 4.9148    | -10.5439 | 4.5087 | 2.0314 | 0.2979    | -1.9216  | 5.6778   | 5.7955  | 2.4030   |
| 2004 | 1.1816    | -4.3158  | 4.8513    | -10.8759 | 5.0777 | 2.0656 | -0.0990   | -0.0867  | 5.4752   | 6.0661  | 0.9230   |
| 2005 | -2.7941   | -7.2602  | 5.8618    | -11.7580 | 5.1979 | 1.9318 | -0.9843   | 0.3954   | 6.0128   | 5.3735  | 0.3250   |
| 2006 | -0.4660   | -7.8672  | 6.2076    | -11.0288 | 5.1032 | 1.4625 | -1.6675   | -0.0988  | 6.2911   | 4.2653  | 0.0767   |
| 2007 | 1.0575    | -10.2315 | 8.6074    | -10.1160 | 5.0753 | 1.6048 | -3.1514   | 0.3114   | 6.2124   | 3.7001  | -0.6905  |
| 2008 | -1.2991   | -10.3623 | 8.4326    | -11.1327 | 3.5648 | 1.2770 | -3.6085   | -0.8708  | 4.9143   | 2.3010  | -3.4534  |
| 2009 | -2.7687   | -10.9107 | 8.5653    | -10.7326 | 4.2666 | 0.6956 | 1.1862    | -2.0350  | 4.8999   | 2.2215  | -4.4076  |
| 2010 | 4.7279    | -9.6152  | 10.8050   | -10.7072 | 4.9765 | 1.2019 | 1.8547    | -0.0448  | 5.1551   | 2.8135  | -2.1034  |
| 2011 | 5.0977    | -11.9799 | 11.4035   | -12.8559 | 3.9879 | 1.7446 | 2.2995    | 0.2515   | 3.6170   | 3.3795  | -2.1154  |
| 2012 | 2.9430    | -12.4123 | 11.6287   | -12.8053 | 3.4798 | 1.0175 | 2.5344    | -0.3290  | 2.6226   | 3.8743  | -3.0666  |
| 2013 | 4.0705    | -11.3078 | 13.1175   | -12.2514 | 3.7955 | 0.9920 | 2.8975    | -0.3721  | 2.8505   | 4.6137  | -1.7954  |
| 2014 | 0.8368    | -15.1411 | 12.4400   | -12.4084 | 2.7348 | 0.7685 | -4.7883   | -0.3435  | 2.2433   | 2.6052  | -2.6965  |
| 2015 | -5.9490   | -14.5306 | 14.1643   | -12.2672 | 2.9003 | 0.8840 | -5.5590   | -0.2478  | 1.8980   | 3.1444  | -2.7717  |
| 2016 | -1.0488   | -14.8557 | 15.4547   | -7.7681  | 2.5443 | 2.4313 | -6.1534   | -0.0004  | 1.1936   | 1.9230  | -3.5474  |

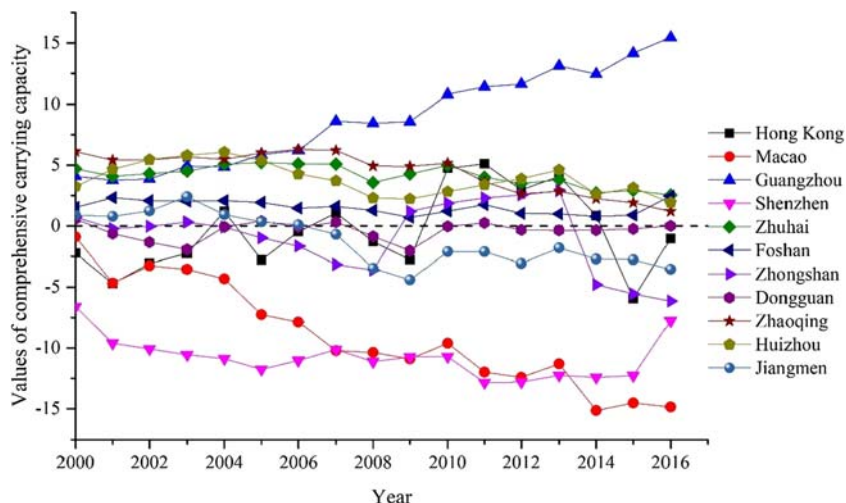
spatial heterogeneity in terms of UCC in the GBA, and this is not conducive to sustainable development.

**Comprehensive carrying capacity evaluation for the four subsystems**

Figure 6 presents the carrying capacity values for the four subsystems—social, economic, environment, and transportation—for each city in 2016. As can be seen from the figure, the values for the social subsystem are generally higher than those for the other three subsystems. This finding is consistent with the results outlined in “Weights of the 14 indicators”: the weights of the

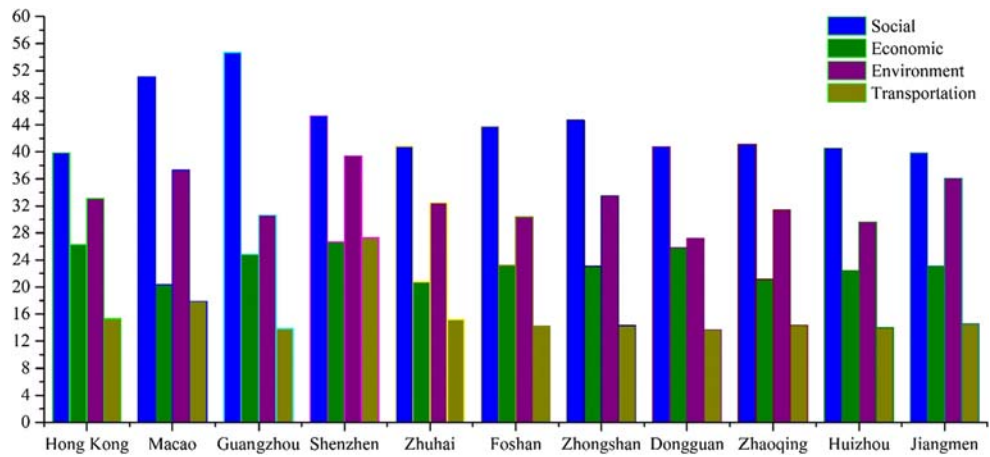
social subsystem are comparatively high and play an important role in the evaluation system, followed in order by the environment, economic, and transportation subsystems. Specifically, Guangzhou performed best in the social aspect due to its excellent provision of education and medical resources; Macao, Shenzhen, and Hong Kong also had a high score in this category. Shenzhen was ranked first in both the environment and economic subsystems due to its investments in pollution control and waste disposal; Shenzhen was also well-placed in terms of innovative industries and high-end manufacturing. Hong Kong and Dongguan performed well in the economic category, reflecting Hong Kong’s mature financial and real estate industry and

**Fig. 5** Variations in comprehensive carrying capacity values from 2000 to 2016 for the 11 cities in the GBA





**Fig. 6** Comprehensive carrying capacity of the four subsystems for the 11 cities in the GBA in 2016



Dongguan’s renowned manufacturing base. Finally, Macao had the highest score in the transportation category, followed closely by other cities.

**Supply and demand analysis of UCC level**

UCC can be divided into the two aspects of supply and demand, with indicators X1, X2, X3, X9, X10, X11, and X13 signifying UCC demand, and the remaining indicators representing UCC supply. To remove the effect of variations in quantities of indicators in the calculation, the supply and demand indicators were unitized. By calculating the product of the index weight and the corresponding standardized index for each city, the supply and demand index data for each city in 2016 were derived (see Table 5).

The GBA urban agglomeration includes Guangzhou, Zhuhai, Foshan, Zhaoqing, and Huizhou, which are in a sustainable state and have great potential for improvement. Due to the clear advantages, these cities offer with respect to

provision of land, education, and medical resources, Guangzhou maintains a relatively high UCC level despite rapid population migration and economic growth. The difference between unit supply and unit demand is 2.2078, ranking Guangzhou first in urban agglomeration and indicating that it is capable of guaranteeing long-term sustainable development. The differences between long unit supply and unit demand for Zhuhai, Foshan, Huizhou, and Zhaoqing are 0.3635, 0.3473, 0.2747, and 0.1705, respectively; these data imply a relatively healthy load-bearing capacity.

The remaining cities in the GBA are in a state of overload, and there is a significant gap between the cities’ unit supply and demand; the exception is Dongguan, where the difference between unit supply and unit demand is - 0.0001. Macao has the largest difference between unit supply and unit demand at - 2.1222; this imbalance is highly significant, indicating an urgent need to optimize the structure of resource allocation in this city.

**Table 5** The balance between supply and demand for comprehensive carrying capacity for the 11 cities of the GBA in 2016

| City      | Supply indicator value | Supply unit value | Demand indicator value | Demand unit value | Difference between supply and demand unit value | Balance situation | Comprehensive carrying capacity situation |
|-----------|------------------------|-------------------|------------------------|-------------------|---|-------------------|---|
| Hong Kong | 56.7699                | 8.1100            | 57.8187                | 8.2598            | - 0.1498  | Supply < demand   | Overload                                  |
| Macao     | 55.8710                | 7.9816            | 70.7266                | 10.1038           | - 2.1222  | Supply < demand   | Overload                                  |
| Guangzhou | 69.7704                | 9.9672            | 54.3157                | 7.7594            | 2.2078  | Supply > demand   | Loadable                                  |
| Shenzhen  | 65.4309                | 9.3473            | 73.1989                | 10.4570           | - 1.1097  | Supply < demand   | Overload                                  |
| Zhuhai    | 55.9182                | 7.9883            | 53.3739                | 7.6248            | 0.3635  | Supply > demand   | Loadable                                  |
| Foshan    | 56.9530                | 8.1361            | 54.5216                | 7.7888            | 0.3473  | Supply > demand   | Loadable                                  |
| Zhongshan | 54.6816                | 7.8117            | 60.8351                | 8.6907            | - 0.8791  | Supply < demand   | Overload                                  |
| Dongguan  | 53.7442                | 7.6777            | 53.7446                | 7.6778            | - 0.0001  | Supply < demand   | Overload                                  |
| Zhaoqing  | 54.5993                | 7.7999            | 53.4058                | 7.6294            | 0.1705  | Supply > demand   | Loadable                                  |
| Huizhou   | 54.2286                | 7.7469            | 52.3056                | 7.4722            | 0.2747  | Supply > demand   | Loadable                                  |
| Jiangmen  | 55.0508                | 7.8644            | 58.5983                | 8.3712            | - 0.5068  | Supply < demand   | Overload                                  |

## Discussion

Given that major cities such as Guangzhou, Shenzhen, Hong Kong, and Macao are well-endowed with key resources, it is rational to promote coordinated development of the GBA. According to the “Outline Development Plan,” Hong Kong will be supported to develop high-end and high-value-added finance, trade, logistics, and professional services; Macao will be transformed into a world-class tourism and leisure center; developments in Guangzhou will focus on its role as an international business center and integrated transport hub; and Shenzhen will be given assistance to become a world leader in innovation and creativity. The resources and distinct strengths of these four major cities complement each other, but it is also important that these strengths impact on surrounding areas so that, collectively, they become the core driving force behind the future development of the GBA.

On a city level, Guangzhou, which is resource-rich in terms of land, education, and medical provision, is in a position to provide the impetus for sustainable self-development and drive forward plans for the coordinated development of surrounding cities through a spillover effect. The carrying capacity of Guangzhou is markedly higher than that of the other cities in the GBA, and it is the only one capable of maintaining long-term stable growth. Guangzhou is rich in land resources; hence, the Nansha free-trade zone can be used to attract advanced industries, help optimize industrial structures, and enhance its status as a business center. Moreover, Guangzhou can rely on superior resources to develop distinctive educational and medical resort industries; it can also further develop its role as a core transportation hub of the GBA by taking advantage of its geographical position.

Shenzhen should enhance its standing in scientific and technological innovation and mitigate its shortage in carrying capacity by developing various forms of cooperation with surrounding cities so as to expand its development space. Shenzhen’s carrying capacity was historically among the lowest in the GBA, until 2014 when it surpassed Macao and showed a rapid recovery. This is mainly because Shenzhen has a small land area and a large population, with more than 20 million permanent residents living on fewer than 2000 km<sup>2</sup> of land. In 2016, the population density was 5962 people per square kilometer, ranking it first in mainland China in this regard. However, its land-development intensity ranks highest, land resource constraints are getting tighter, and high-quality land utilization is especially urgent. According to the data in this study, the rebound UCC level of Shenzhen mainly came from an increase in turnover volume of passenger traffic. In recent years, Shenzhen has successfully implemented policies to attract talent and become the city with the largest number of newly registered residents. Shenzhen is also building a core transportation hub that will enable people to reach other cities in the GBA within half an hour. These

initiatives have all improved the city’s transportation carrying capacity. According to a report issued in 2019 by the Shenzhen municipal government, reforms are needed to improve land use and land conservation. To this end, it is necessary to examine the development history of Singapore, Tokyo, and other cities; to learn how best to use existing construction land, mixed-use land, and underground space; and to manage plot ratios. In addition, the Shenzhen–Shanwei Special Cooperation Zone represents a useful case study with respect to solving the problem of insufficient land resources by expanding development space through cooperation with surrounding cities.

With respect to the two special administrative regions of Hong Kong and Macao, the most urgent problem is how to accelerate their integration into the GBA. Only through integration can the sharing of resources and the coordinated development of industries be realized. As indicated above, Hong Kong’s carrying capacity levels have fluctuated widely, from 5.0977 in 2011 to – 5.9490 in 2015. This is because of the city’s unbalanced industrial structure: its economy is mainly supported by finance and real estate, while the emerging high-end service industry and technology industry have not yet been established. In this light, Hong Kong should take the initiative to accelerate its integration with the mainland, such as by improving transport links (e.g., the Guangzhou–Shenzhen–Hong Kong high-speed railway) and more quickly establishing the “one-hour traffic circle” so that residents who live in Guangdong can commute to Hong Kong, thus promoting the exchange of talents and skills. Hong Kong should take full advantage of its rich educational, medical, financial, and other resources to create a spillover effect on surrounding cities. In addition, the model of the Shenzhen–Shanwei Special Cooperation Zone may be followed to develop new land in neighboring cities so as to solve the serious shortage of land resources.

Macao’s carrying capacity levels declined during the research period, and show no signs of improving. This is because Macao’s population density is more than three times that of Shenzhen (20,203 people per square kilometer in 2016), with more than 650,000 people living on 32.8 km<sup>2</sup> of land. In addition, Macao’s economy relies mainly on gambling and tourism and is greatly affected by external economic changes. To tackle this problem, Macao should take advantage of the favorable policies and resources of the Hengqin pilot free-trade zone in Zhuhai to promote the diversified development of its economy. As a tourism and leisure center, Macao can provide education and training in tourism. In addition, Macao can serve as a platform for strategic development and business service cooperation between China and Portuguese-speaking countries and can promote collaboration with neighboring cities in the GBA. In so doing, it can target new business opportunities in overseas markets.

## Conclusion and implications

Based on the regional collaboration theoretical framework for the UCC of an urban agglomeration, this study used the improved entropy method to examine the UCC levels of the Guangdong–Hong Kong–Macao GBA during the period 2000–2016. Four specific findings can be highlighted. First, six of the cities (Hong Kong, Macao, Shenzhen, Zhongshan, Dongguan, and Jiangmen) were overloaded in 2016, while the other five were in a loadable condition (Guangzhou, Zhuhai, Foshan, Zhaoqing, and Huizhou). The difference between supply and demand unit values varied greatly between cities, with the highest value found for Guangzhou (2.2078) and the lowest value for Macao (−2.1222). Second, among the four subsystems (social, economic, environment, and transportation), the social subsystem was found to play the most important role in the evaluation system. In general, Guangzhou was the best-performing city and its high carrying capacity is likely to continue to rise; Shenzhen rebounded after a long period of decline; Hong Kong's carrying capacity levels have risen slightly, but with some fluctuation; and Macao was the worst performer and continues to decline with no signs of improvement. Third, the overall UCC level of all cities in the GBA urban agglomeration is considered to be at the medium level (with UCC values fluctuating around zero), and there is a large gap between the various cities. The spatial distribution is high in the north and low in the south; hence, there is great potential for development and room for improvement, in particular with respect to the spatial aspect of development. Fourth, the UCC level of the GBA showed a downward trend. Only a few cities, such as Guangzhou, continue to improve their carrying capacity. Shenzhen began to recover rapidly in 2015 after a long and slow decline. Due to a lack of resources and large populations, the carrying capacity of Macao and of the other remaining cities has been in a negative state for a long time; this needs to be improved from the standpoint of optimizing the GBA's economic structure.

Hong Kong and Macao and the nine provinces of Guangdong Province have extensive cooperation potential with respect to industrial development. To overcome the low level of regional coordination, as also outlined as a key aim of the development plans for the GBA, both sides should seek to expand areas of cooperation, find mechanisms to promote mutual progress in the Belt and Road initiative, and realize the complementarity of advantages. There is a need to deepen the cooperation between Hong Kong and Shenzhen and Macao and Zhuhai; accelerate the integration of Guangzhou and Foshan to enhance their global influence; and enable the GBA to participate in international cooperation. By utilizing the GBA's rapid transportation network, which includes a high-speed railway, intercity railway, and high-grade highway, as well as several ports and airports, a network spatial pattern of efficient connection between major cities can be formed.

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