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Study on the Variations Characteristics of Compactness of China's Large Cities Based on Entropy Weight Method

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Abstract: This paper, studies on compact city, aiming at improving the efficiency of the urban internal spatial organization, to establish the potential relationship between urban form and urban sustainable development. It builds the comprehensive index system for compactness from six dimensions which include economic development level, population size and structure, infrastructure development level, public service level, land resource utilization structure and ecological environment development index in the paper. This index measures the variations characteristics of compactness of China's large cities in 2002, 2007 and 2012 from EDC, SDC and SDC, and the purpose of those three aspects is to provide basis for policy formulation and adjustment of city development.

Keywords: *City compactness, Comprehensive evaluation index system, Entropy Method, China's large cities*

1. Introduction

Since the 1980s, with the deepening of China's reform and opening up, urbanization in China has been advancing quickly, along which haunt issues such as urban land sprawling, unreasonable spatial structure, increasingly severe social problem, and deteriorating ecological environment [1, 2]. Originating from the West and with sustainable urban development promotion and city sprawling control as its purpose, the "Compact City" theory is likely to provide important reference and theoretical guidance to cities in China for various problems they are facing [3, 4].

Studies on Compact City in the developed countries firstly taken European history town as the prototype, emphasized on compactness and high density of urban external form with Dantzig G and Satty T as main representative [5]. As studies probed deeply and widely, debates on concentration and dispersion were stirred [6, 7] researches on reasonable density of urban space expansion also increased [8], thus it can be seen that absolute concentration of urban external form is not necessarily a sustainable urban development pattern. Later, in developed countries compact city theory had been enriching and improving on these aspects as such urban expansion, urban internal function differentiation and extreme long traffic commuting time [9].

Studies on city sprawling controlling in China concentrated more on urban land intensive utilization [10]. As relevant theories of city sprawling control including new urbanism, edge city, smart growth and so on being introduced into China [11, 12], "Compact City" theory was increasingly in the spotlight. Land intensive utilization theory [13] was aimed at improving the use efficiency and economic benefits of urban land; instead, "Compact City" theory took the macro scale of the urban form research as its starting point; however, research objectives of the two theories were the same, i.e. to control city sprawling and obtain urban sustainable development. Thus, studying on city compactness in China combines domestic intensive utilization of land and compact city theory out of China and developed itself, "it is treated as an urban sustainable development strategy instead of a concrete and specific city form" [14]. It was more involved in the study on use intensity and mixed utilization of city land [15]. Single index and multi-index method [16], frequently adopted in city compactness study by Chinese scholars, though could reflect the current situation of the rapid expansion of Chinese cities, failed to make reasonable evaluation [17, 18] on sustained boom and pace rationality of urban center. Such research runs counter to the purpose to achieve urban sustainable development of compact city theory.

It is considered in this paper that compact city study should lay stress on the potential relationship between urban form and urban sustainable development and aim at improving the efficiency of the urban internal spatial organization [19, 20]. City compactness in the paper is thus not a measurement unit of urban space form but relative concept to describe urban form.

The measure of the city compactness should manifest the sustainable development requirements [21]. For this reason, this paper is to establish the comprehensive compactness index system in economic, social and ecological the three perspectives of sustainable development theory and probe the temporal and spatial features of compactness of 52 large cities in China in 2002, 2007 and 2012, so as to

provide a new perspective for the sustainable development of Chinese cities.

2. Research subject, data source and index system:

2.1. Research subject:

Large city merges a region's major economic, technological, cultural, medical energy and other resources together in China. Land expansion and spatial growth are typically caused by its development; therefore, taking large city as research object, which will well reflect the compactness development of China's city. In this paper, 52 cities in total are selected as research samples from with population more than 1 million, "bigger cities" with local legislative power and urban comprehensive competitiveness of top 30 in China in 2008 (Beijing, Shanghai, Tianjin, Chongqing, Shijiazhuang, Taiyuan, Huhehot, Shenyang, Changchun, Haerbin, Nanjing, Hangzhou, Hefei, Fuzhou, Nanchang, Jinan, Zhengzhou, Wuhan, Changsha, Guangzhou, Nanning, Haikou, Chengdu, Guiyang, Kunming, Xian, Lanzhou, Xining, Urumqi, Shenzhen, Shantou, Xiamen, Dalian, Qingdao, Ningbo, Tangshan, Datong, Baotou, Anshan, Fushun, Jilin, Qiqihar, Wuxi, Huainan, Luoyang, Zibo, Handan, Xuzhou, Suzhou, Dongguan, Yantai, Foshan).

2.2. Data source:

Data involved in this paper mainly comes from China City Statistical Yearbook, China Urban Construction Statistical Yearbook (Report) of corresponding years, statistical yearbook of each city and government gazettes of part of those cities; it was meanwhile added according to the adjacent years interpolation, such as 2007 and 2012 Shanghai construction land classification data, and 2012 Shenzhen construction land classification data.

2.3. Index system and research method:

2.3.1. Index system establishment: Based on sustainable development, this city compactness study focuses on economic development compactness (EDC), social development compactness (SDC), resources and environment compactness (REC) those three aspects. Measure of economic development compactness (EDC) reflects the scale and structure of the economic development of a city through per capita GDP (ten thousand yuan/person), the proportion (%) of output of the secondary and the tertiary industry in the GDP (%), economic growth elasticity (%), input intensity per unit area (ten thousand yuan /km^2) and output intensity per unit area (ten thousand yuan /km^2) those 5 economic development indicators. While, social development compactness (SDC) is measured by population size and structure, infrastructure development level and public service level. 4 indicators are selected for population size and structure, i.e. urban population density (person / km^2), proportion of population in urban areas (%), proportion of practitioners in secondary and tertiary industry (%) and per capita living area(m^2/person). 4 indicators i.e. road area per capita (m^2/person), road network density (km/k m^2), drainage density (km/km^2) and proportion of infrastructure land(%) for infrastructure development level. 5 indicators i.e. Education level(%),Green space per capita(km^2/person), cultural service (%), public transportation service (10 thousand people/vehicle) and medical service (%) for public service level. Resources and environment compactness (REC) can be mainly measured by land resource utilization structure and ecological environment development indicators. 4 indicators can be adopted to reflect land resource utilization compactness of one city, i.e. land use intensity (%), construction land utilization rate (%), production land rate (%) and living land rate (%). 4 indicators i.e. built up area greening coverage (%), discharge standard-meeting rate of industrial wastewaters (%), comprehensive utilization rate of industrial solid wastes (%) and hazard-free treatment rate of household garbage (%) for the capacity of ecological environment sustainable development. There are 3 first level indicators and 26 second level indicators in this index system (***Table 1***).

2.3.2. Entropy weight method: Entropy weight method in this paper is used to empower the established index system [22]. Basic principle of entropy weight method will be illustrated with specific cases as below. Supposing evaluation objects cover n cities, m compactness evaluation indexes,$\boldsymbol{x_i}$ ***(i=1,…,m)*** respectively, each evaluation index statistic of each city has obtained, its matrix is:

$$\boldsymbol{R' = \left(r'_{ij}\right)_{m\times n}(i = 1, \dots, m\ j = 1, \dots, n)}$$

Here, $\boldsymbol{r'_{ij}}$ is the statistic of index $\boldsymbol{i}$ for city $\boldsymbol{j}$. eliminate the effect of the different units of indicators, standardizeR', and then get the standardized matrix of each index. Considering $\boldsymbol{r'_{ij}}$ is affected by $\boldsymbol{min\left|r'_{ij}\right|}$ and $\boldsymbol{max\left|r'_{ij}\right|}$ after standardization, extremum method will be used to standardize the statistical data. Let standardized matrix, $\boldsymbol{R' = \left(r'_{ij}\right)_{m\times n}}$, standardized formula is:

$$\boldsymbol{r_{ij} = \frac{r'_{ij} - \min\limits_j \left|r'_{ij}\right|}{\max\limits_j \left|r'_{ij}\right| - \min\limits_j \left|r'_{ij}\right|} \times 10} \quad (1)$$

Standardize the statistical data and then calculate information entropy of each index. Entropy H_i of index i can be defined as:

$$\boldsymbol{H_i = -k\sum_{j=1}^{n} f_{ij}\, ln\, f_{ij}} \quad (2)$$

Here, $\boldsymbol{f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}}$, $\boldsymbol{k = \frac{1}{ln\, n}}$ (supposing: when, $\boldsymbol{f_{ij} = 0}$, $\boldsymbol{f_{ij}\, ln\, f_{ij} = 0}$).

Once determine the index entropy value, entropy weight W_i of index i can be got with below formula:

$$\boldsymbol{w_i = \frac{1 - H_i}{m - \sum_{i=1}^{m} H_i}} \quad (3)$$

Hence one can see that the bigger difference of index value for evaluated objects, the smaller the entropy is, and the bigger entropy weight is; which indicates that more useful information the indexes has provided to decision makers. As the entropy weight, it has special significance.

Comprehensive evaluation method is described as to determine the importance or weight of each index in the research field on the basis of evaluation index system of research object; make out quantitative comprehensive evaluation by using composite index calculation according to the chosen evaluation model. Thus the evaluation model adopted for compactness measure of each city is:

$$C_r = \sum_{i=1}^{m} w_i \times C_i \quad (4)$$

Here, $\boldsymbol{C_i} = \frac{\boldsymbol{X - X_{min}}}{\boldsymbol{X_{max} - X_{min}}} \times \mathbf{10}$,

City compactness score is $\boldsymbol{C_r}$, standardized results of index statistics $\boldsymbol{C_i}$, index statistics $\boldsymbol{X}$, maximum value of index statistics of each city $\boldsymbol{X_{max}}$, the minimum value $\boldsymbol{X_{min}}$, then get the city compactness score.

It is found that there are 14 indexes with weighted value over 3%, 2 for economic compactness, 2 population size and structure indexes for social development compactness, 3 for infrastructure development level, 4 for public service level and 3 for resources and environment compactness respectively. Cumulative weight influencing compactness are economic development index (20.6%), public service level index (20.2%), ecological environment development index (18.1%), infrastructure development level index (16.4%), land resource utilization structure index (14%) and population size and structure indexes (10.7%). Obviously, urban internal function compactness is mainly influenced by economic development, public service and resources and environment. It suggests that the development of large cities in China is shifting landscape of development. Public service and ecological environment are increasingly concerned, which just comply with the requirements of urban sustainable development (Table 1).

3. Result analysis:

3.1. Analysis on the results of city compactness measure index:

From the results of urban compactness measure index, economic development has the greatest effects on urban compactness, while public service level and infrastructure development level also matters a lot. The increasing ecological environment development index implies the development trends of large cities in China (Figure 1).

Table 1: *Comprehensive evaluation index system of city compactness*

Element name	Index name	Implication	Weight
EDC 20.6%	Per capita GDP (ten thousand yuan/person)	GDP/Population in urban areas	2.6
	Economic growth elasticity (%)	GDP growth rate / Urban construction land growth	0.6
	Input intensity per unit area (ten thousand yuan / km^2)	Fixed-asset investment / Urban area	8.1
	Output intensity per unit area (ten thousand yuan / km^2)	GDP/ Urban area	8.4
	Output of the secondary and the tertiary industry in the GDP (%)	Output of the secondary and the tertiary industry / GDP	0.9
SDC 47.3%	Urban population density (person / km^2)	Population in urban areas / Urban area	4.0
	Proportion of urban population (%)	Built-up area permanent population / Population in urban areas	2.7
	Per capita living area (m^2/ person)	Urban permanent population / Residential land area	3.1
	Proportion of practitioners in secondary and tertiary industry (%)	Practitioners in secondary and tertiary industry / Total practitioners	0.9
	Road area per capita (m^2/person)	Urban road area / Urban permanent population	5.1
	Road network density (km/km^2)	Urban road length / Urban area	5.5
	Drainage density (km/km^2)	Built-up area drainage pipe length / Built-up area	3.0
	Proportion of infrastructure land (%)	Infrastructure land / Built-up area	2.8
	Education level (%)	Number of full-time teachers of urban primary and secondary schools / Number of students of urban primary and secondary schools	1.9
	Medical service (%)	Number of doctors for every 100,000 people / Number of beds (unit /100,000 people)	4.6
	Cultural service (%)	Number of books in public library for every 100 people (piece/100 people)	3.7
	Public transportation service (10 thousand people/vehicle)	Urban permanent population / Bus number	5.3
	Green space per capita (km^2/Person)	City park green land area / Urban permanent population	47
REC	Land use intensity (%)	Built-up area / Urban area	6.8

32.1 %	Construction land utilization rate (%)	Built-up area / Construction land area	2.3
	Production land rate (%)	production land area / Built-up area	1.6
	Living land rate (%)	Living land area / Built-up area	3.3
	Built up area greening coverage (%)	Built up area greening area / Built up area	1.1
	Discharge standard-meeting rate of industrial wastewaters (%)	Discharge standard-meeting volume of industrial wastewaters / Discharge volume of industrial wastewaters	14.2
	Comprehensive utilization rate of industrial solid wastes (%)	Comprehensive utilization volume of industrial solid wastes / Volume of industrial solid wastes	1.4
	Hazard-free treatment rate of household garbage (%)	Hazard-free treatment volume of household garbage / Volume of household garbage	1.4

Table 2: *Analysis of city compactness comprehensive evaluation*

City	2002		2007		2012	
rank	City	Score	City	Score	City	Score
Top 5	Shanghai	599.71	Dongguan	554.20	Dongguan	474.45
	Shenzhen	564.43	Shenzhen	483.48	Shenzhen	343.68
	Changsha	415.14	Suzhou	453.28	Shijiazhuang	314.32
	Guangzhou	410.72	Beijing	431.34	Wuhan	268.26
	Shijiazhuang	401.25	Changsha	382.65	Shanghai	261.57
Last 5	Yantai	175.26	Harbin	230.66	Chongqing	213.88
	Huainan	163.32	Haikou	223.98	Nanning	206.52
	Datong	149.49	Huainan	198.50	Haikou	181.99
	Qiqihar	147.31	Nanning	194.84	Huainan	109.73
	Chongqing	96.85	Chongqing	120.51	Shantou	95.67
Median		271.13		226.22		274.49
Bias		1.33		1.06		1.27
Standard error		92.38		106.25		85.51

Table 3: *Compactness features of different functional cities*

City function	City number	Score of city compactness		
		2002	2007	2012
Comprehensive	20	304.97	223.68	196.09
Industrial	14	238.90	204.87	187.61
Mining	11	205.03	150.41	157.15
Service	7	274.41	157.72	163.34

Based on the analysis results, different functional cities present different compactness features: comprehensive cities are highest development compactness at the same stage. Industrialization still in a strong position in our country, industrial growth mode is undergoing constant adjustment and transformation, the land utilization intensity becomes great in large industrial cities whose compactness is second ones. Service cities concern the construction and development of urban infrastructure and resources and environment and are also with higher compactness. Mining cities whose compactness is the lowest compare to others in the same year due to their single function.

Growing importance has been attached to the urban sustainable development; the development pattern is shifting from traditional extensive to intensive and efficient mode, all those are consistent with the development of Chinese cities at present. On the one hand, economic development secures social development and helps to improve the ecological environment; on the other hand, due to the rapid economic development, increasing social issues and ecological environment problems are looming large; thus, to develop city compactness under the requirements of sustainable development is inevitably put on the agenda.

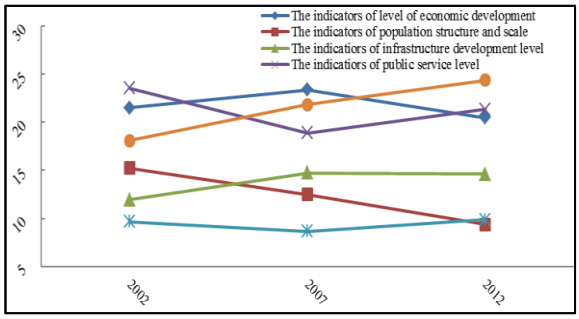

Figure 1: *The change of city compactness measure index*

3.2. Analysis on the change of overall gap of large city compactness:

On the basis of city compactness index system said above and with entropy weight method and comprehensive evaluation model, compactness of 52 cities can be the comprehensively scored. Top 5 and last 5 cities in the three years are respectively listed (Table 2); here we can find that compactness of Shenzhen was the first apart from its following Shanghai in 2002. Compactness of Shanghai, Changsha and Shijiazhuang rank top too. Chongqing, Huainan and Haikou are among the last 5 cities with rather lower compactness scores. On a whole, median of compactness scores of those 52 cities increase from 271.13 to 274.49, skewness coefficient decrease from 1.33 to 1.27, which indicates that compactness of megacities in China have been improved as a whole and number of cities with compactness over average are increasing.

Meanwhile, compactness gap between cities is narrowing step by step. Based on the analysis on scores of the 5 cities compactness on the 3 time sections, compactness scores of the top 5 cities falls down, while last 5 up; difference between the two scores drops from 331.81 in 2002 to 170.9 in 2012, coefficient of standard deviation down from 92.38 to 85.51, implying that discreteness of compactness score is gradually weakening and so is the compactness difference between cities.

3.3. Research on compactness of different functional cities:

Different functional cities equipped with different compactness. Laying its foundation on the study on city functions classification in China by Xu Feng [23], sample cities in this paper will be divided into 4 types: comprehensive city, industrial city, mining city and city with tourism, commerce and other services as its main business. Compactness of different functional cities varies, and results as table 3, figure 2-4:

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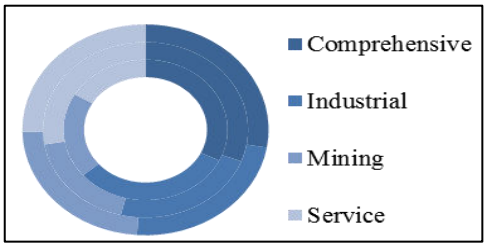

Figure 2. *Compactness features of different functional cities in 2002*

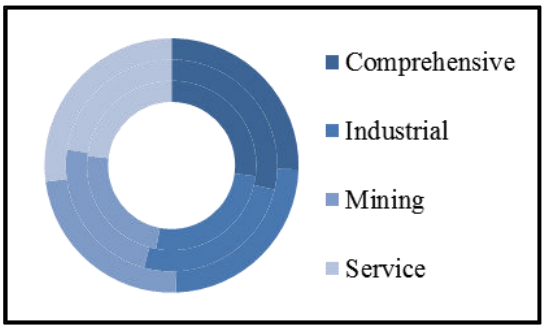

Figure 3. *Compactness features of different functional cities in 2007*

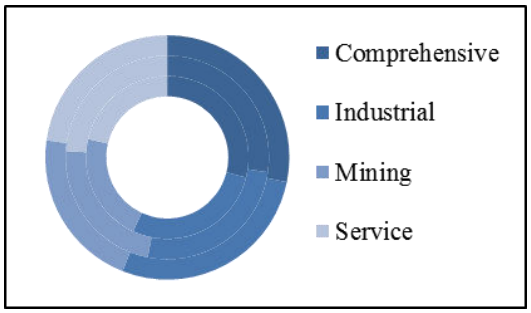

Figure 4. *Compactness features of different functional cities in 2012*

Analyzing individual compactness, economic and social compactness of comprehensive cities show an increasing trend, resources and environment compactness however falls down from 25.34% in 2002 to 22.18% in 20i12 which thus should be given more concentration. Social compactness of industrial

and mining cities whose weight proportion goes up from 52.11% and 51.08% to 56.29% and 59.71%, indicating that transitional industrial and mining cities have already made progress. However, the downward of their economic and resources and environment compactness need to be adjusted while developing. All compactness weight proportions of service cities increase to some extent, showing that those cities enjoy a greater balance on their compactness.

4. Conclusion:

In order to deal with the issues in the process of rapid urbanization in China, concept of city compactness is introduced in this paper to improve the efficiency of urban space and urban intensive development, optimize the city function and protect the resources and environment. Discuss the economic, social and resources and environment development of large cities in China from the perspective of sustainable development.

With sustainable development theory, comprehensive evaluation index system of city compactness is built on economic development compactness (EDC), social development compactness (SDC), resources and environment compactness (REC) the three aspects. Entropy weight method and comprehensive evaluation are adopted to determine and evaluate indexes weights and city compactness.

In this paper, city compactness evaluation mainly targets on internal function compactness of cities on a macro level, but micro elements such as life quality of urban residents, subjective feeling are excluded. There is still room for index selection and weights determination. In addition, city cultural and history as well as development wills and values of the government have close relationship with city compactness, which should be well-concerned in the study on city compactness in the future. Limited by data acquisition, only 52 cities are selected for compactness features study on 3 time sections. A wider range of sample cities is a necessity for the deeper study on the change characteristics of city compactness in China and should also be empirically tested in a longer time scale.

5. Conflict of interest:

The author confirms that this article content has no conflict of interest.

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