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An Evaluation of the Ecological Civilization Level of Typical Urban Agglomerations in China

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Abstract: In order to evaluate China's ecological civilization level, a set of indicators was established on the basis of the United Nations' 2030 Agenda for Sustainable Development and the goal of ecological civilization construction in China. Using the double-objective evolutionary method and taking a city as the evaluation unit, this study examines the ecological civilization levels of three typical urban agglomerations: Beijing-Tianjin-Hebei (Jingjinji), the Yangtze River Delta, and the Pearl River Delta. Results indicate that the ecological civilization level of the Pearl River Delta ranked the highest (69.95), and the ecological civilization level of Jingjinji ranked the lowest (59.04). The green environmental domain is the short board of the three urban agglomerations' ecological civilization (EC) levels. The score of urban EC level evaluation shows the short board of the EC and designates directions for improving the EC development level.

Keywords: ecological civilization development level; Beijing-Tianjin-Hebei (Jingjinji) urban agglomeration; Yangtze River Delta urban agglomeration; Pearl River Delta urban agglomeration; double-objective evolutionary method

1 Background of the research

Several index systems have been advanced in order to evaluate the development of ecological civilization (EC) in China. The authors of the *Green Development Index Report of China—Regional Comparison (2014)*, which takes into account green economic growth, resources and environment, and government policy, have proposed a green development index for the evaluation of sustainable development potential [1]. In the evaluation report on the *Annual Report on China's Provincial Eco-Civilization Index (ECI 2015)*, the authors have proposed a set of indices that aim to highlight the basic role of ecology and the coordinated development of economy, society, and the environment [2]. The *Green Development Index System* and the *Assessment Target of Ecological Civilization Construction* [3] proposed by the Chinese government represent evaluation tools. Due to the large differences in geography, economy, and social and cultural history, different regions exhibit different EC levels. It is important to evaluate the EC level on a city-level scale.

The Jingjinji, Yangtze River Delta, and Pearl River Delta urban agglomerations are typical urban agglomerations and the earliest and fastest developing cities in China; they represent an advanced level of urban development that began after the Chinese reforms and the opening up of the country to the outside world. In this study, we propose a set of indices that consider the goal of sustainable development for 2030 [4] and the goal of EC development in China [5]. We used the city as the research unit, evaluated the EC development level of the Jingjinji, Yangtze River Delta, and Pearl River Delta urban agglomerations, and provided decision-making references for regional policy formulation.

2 Methodology

2.1 Index system

This index system was applied in the evaluation of the cities, and it is different from the index system used for provincial evaluation (Table 1).

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2.2 Study area

The Jingjinji urban agglomeration consists of 10 cities located in the core area of the Bohai rim and northeast Asia. It includes the two province-level municipalities of Beijing and Tianjin and the cities of Baoding, Langfang, Tanshan, Qinhuangdao, Shijiazhuang, Zhangjiakou, Chende, and Cangzhou in the Hebei province.

The Yangtze River Delta urban agglomeration consists of 26 cities, including the province-level municipality of Shanghai and the cities of Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yancheng, Yangzhou, Zhenjiang, and Taizhou in the Jiangsu Province; Hanzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Jinhua, Zhoushan, and Taizhou in the Zhejiang province; and Hefei, Wuhu, Maanshan, Tongling, Anqing, Chuzhou, Chizhou, and Xuancheng in the Anhui province.

The Pearl River Delta urban agglomeration consists of 9 cities, including Guangzhou, Shenzhen, Zhuhai, Foshan, Dongguan, Zhongshan, Jiangmen, Zhaoqing, and Huizhou in the Guangdong province. Details of the three urban agglomerations are shown in Table 2.

2.3 Data sources

This research is based on statistical data from 2014 and includes data from the statistical yearbook, industry statistics, scientific research achievements, and other materials (Table 3). The statistical unit is the city area, except in the case of the "per

Table 1. Index system of China's EC.

Domain	Index	Quota	Unit
Green environment (0.25)*	Ecological status index (0.4)*	Habitat quality index (1)*	%
	Environmental quality index (0.6)*	Air quality index (0.5)*	–
		Surface water quality index (0.5)*	–
Green production (0.35)*	Industry optimization index (0.6)*	Per capita GDP (0.5)*	yuan
		Proportion of the tertiary industry's added value (0.5)*	%
	Industry efficiency index (0.4)*	GDP per unit of built-up land (0.3)*	ten thousand yuan/km^2
		Water pollution intensity (0.2)*	kg/ten thousand yuan
		Air pollution intensity (0.2)*	kg/ten thousand yuan
		Fertilizer per crop acreage (0.3)*	t·hm^{-2}
Green life (0.2)*	Urban-rural coordination index (0.5)*	Urbanization (0.4)*	%
		Per capita disposable income of urban residents (0.3)*	yuan
		Income proportion of urban and rural residents (0.3)*	–
	Urban human settlements index (0.3)*	Per capita park green area (0.5)*	hm^2/ten thousand people
		Green coverage rate of built-up area (0.5)*	%
	Green consumption index (0.2)*	Per capita ecological footprint (1)*	global hectare
Green governance (0.2)*	Pollution control index (0.4)*	Urban sewage treatment rate (0.5)*	%
		Harmless treatment rate of urban solid waste (0.5)*	%
	Construction performance index (0.6)*	Natural reserve area ratio (0.5)*	%
		Decrease rate of unit GDP energy consumption (0.5)*	%
Deflating index		Demonstration of EC development	–
		Environmental risk events	–

* The data in parentheses represents weights.

Table 2. Information on the three typical urban agglomerations (2014).

Index	Jingjinji urban agglomeration	Yangtze River Delta urban agglomeration	Pearl River Delta urban agglomeration
Number of cities	10	26	9
Proportional area (%)	2.27	2.16	0.57
Population (100 million)	1.10	1.59	0.58
Per capita GDP (ten thousand yuan)	6.04	8.45	10.00
Urbanization (%)	57.34	63.59	80.03

capita park green area" and the "green coverage rate of built-up area," for which the municipal district is used as the unit. The air quality index (AQI), surface water quality index [5], water pollution intensity, air pollution intensity, and the environmental risk index (ERI) are based on industry statistical data.

The surface water quality index represents the city water quality index（CWQI）(Eq. (1))

$$\mathrm{CWQI_{city}}=\frac{\mathrm{CWQI_{river}}\times M+\mathrm{CWQI_{lake}}\times N}{(M+N)} \quad (1)$$

where $\mathrm{CWQI_{city}}$ is the water quality of the city, $\mathrm{CWQI_{river}}$ is the water quality of rivers, $\mathrm{CWQI_{lake}}$ is the water quality of lakes, M is the number of cross-sections of a river, and N is the number of lake monitoring points.

The water pollution intensity is the ratio of industrial chemical oxygen demand (COD), ammonia nitrogen, and gross domestic product (GDP). The air pollution intensity is the ratio of industrial SO_2, NO_x, ash, and GDP, and the environmental risk index is based on the *National Emergency Plan for Environmental Emergencies* [6] (Eq. (2)).

$$\mathrm{ERI}=-3\times A-2\times B-1\times C-0.5\times D \quad (2)$$

where ERI is the environmental risk index, and A, B, C, and D are the number of mega environmental events, the number of significant environmental events, the number of environmental events, and the number of general environmental events, respectively.

The habitat quality index (Eq. (3)) and the per capita ecological footprint [7] (Eq. (4)) originate from scientific research studies.

$$\mathrm{IE}=A_{\mathrm{bio}}\times(0.35\times A_{\mathrm{forest}}+0.21\times A_{\mathrm{grass}}+0.28\times A_{\mathrm{wet}}+0.11\times A_{\mathrm{crop}}+0.05\times A_{\mathrm{unused}})/S \quad (3)$$

where IE is the habitat quality index, A_{bio} is a constant of 511.26, A_{forest} is the area of forest, A_{grass} is the area of grassland, A_{wet} is the area of wetland, A_{crop} is the area of cropland, A_{unused} is the area of unused land, and S is the total area.

$$\mathrm{EF}=\sum_{i=1}^{n}\frac{C_i}{\mathrm{EP}_i}\mathrm{EQ}_i \quad (4)$$

where EF is the ecological footprint (ha), n is the population, EP_i is the global annual average ecological productivity ($\mathrm{kg\cdot ha^{-1}}$), C_i is the resource consumption, and EQ_i is equal to a quantization factor.

The remainder of the index data were obtained from the statistical yearbook.

2.4 Standardization and evaluation

The benchmark values of each index were determined based on the national standards, the relevant planning requirements, the international class ratio, and statistical analysis characteristics. The double-objective evolutionary method was used to quantify the indices based on the following formula:

$$A_{ij}=(X_{ij}-S_{C(X_{ij})})\times\frac{(S_A-S_C)}{(S_{A(X_{ij})}-S_{C(X_{ij})})}+S_C \quad (5)$$

where A_{ij} is the evaluation of the indicators based on the benchmarks, X_{ij} is the index data, $S_{A(Xij)}$ is the excellent value, $S_{C(Xij)}$ is the passing value, and S_A and S_C are the constants 90 and 60, respectively. When $A_{ij}<0$, the value is 0; when $A_{ij}>100$, the value is 100.

2.5 Weight and comprehensive evaluation

The analytic hierarchy process (AHP) method was used to determine the weight of the index system (Table 1). The synthetic weighted method was used to estimate the EC level, which was classified into four grades (Table 3).

Table 3. Gradation of the EC level.

Grade	A	B	C	D
Scores（K）	$K\leq 80$	$70\leq K<80$	$60\leq K<70$	$K<60$

The formula for calculating a comprehensive score K is as follows:

$$K=\sum_{i=1}^{n}W_i\cdot A_i \quad (6)$$

3 Results and discussions

The Pearl River Delta urban agglomeration had the highest EC score (mean=69.95, grade B), followed by the Yangtze River Delta urban agglomeration (mean=67.61, grade C) and the Jingjinji urban agglomeration (mean=59.04, grade D). The Pearl River Delta urban agglomeration achieved the highest scores for the green environment, green production, and green lifestyle domains, while the Yangtze River Delta urban agglomeration achieved the highest score for the green government domain. The Jingjinji urban agglomeration had the lowest score for green environment, far behind the other agglomerations, and the lowest scores for green production, green lifestyle, and green government (Table 4). To sum, the ecological environment is the short board of the ecological civilization development level of the three typical urban groups. This ecological civilization development comprises two main aspects: industrial optimization and efficiency (Fig. 1).

The development level of the Jingjinji urban agglomeration has been far lower than that of the other two urban agglomerations. The development levels of the Yangtze River Delta and the Pearl River Delta showed little difference in the green environment, green industry, and green governance areas; the development of various fields and indices of the Pearl River Delta was generally better, but the low score on the green consumption index was a short board for its ecological civilization development. It can be seen that the ecological environment was the short board of the ecological civilization development level

Table 4. Average percentages of the EC indices for the urban agglomerations.

	EC	Green environment	Green production	Green lifestyle	Green governance
Jingjinji urban agglomeration	59.04	39.08	68.82	63.18	64.98
Yangtze River Delta urban agglomeration	67.61	56.17	76.23	68.23	67.92
Pearl River Delta urban agglomeration	69.95	59.07	78.79	73.11	65.90

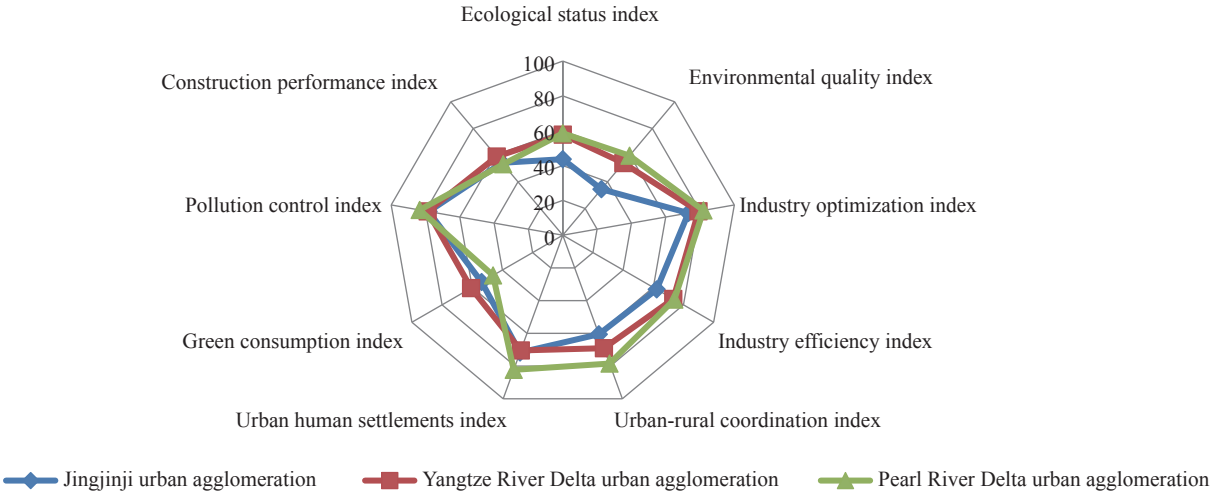

Fig. 1. The EC levels of the three typical urban agglomerations.

of the three typical urban agglomerations, and the ecological civilization development was the best aspect of industrial optimization and efficiency.

None of the cities' EC levels achieved grade A. Most cities in the Pearl River Delta urban agglomeration obtained a B grade (66.67%), and 33.33% of the cities achieved a C grade. Most cities in the Yangtze River Delta urban agglomeration obtained a C grade (57.69%), 38.46% of the cities achieved a B grade, and 3.85% of the cities achieved a D grade. Most cities in the Jingjinji urban agglomeration achieved a D grade, and 40% of the cities achieved a C grade (Table 5).

3.1 Jingjinji urban agglomeration

In the Jingjinji urban agglomeration, Beijing's EC level was highest, followed by Tianjin and Chengde. Zhangjiakou and Chengde achieved the highest scores for the green environment domain, while Beijing and Tianjin achieved the lowest scores. Beijing and Tianjin achieved the highest scores for green production. Tianjin and Qinhuangdao achieved the highest scores for green governance (Fig. 2).

3.2 Yangtze River Delta urban agglomeration

The Yangtze River Delta urban agglomeration's EC level was found to be the most advanced in the whole country. Among the 26 cities in the Yangtze River Delta urban agglomeration, Hangzhou ranked first in terms of ecological civilization development level (Fig. 3). With regard to the various domain levels, Taizhou, Chizhou, Hangzhou, Yizhou, and Anqing achieved the top ranks in terms of the green environment domain, and Jiaxing and Zhenjiang were ranked last. Shanghai, Hangzhou, Wuxi, and Suzhou scored the highest in the green production fields. Zhoushan, Ningbo, Zhenjiang, and Tongling achieved the top ranks. Ranking last were Shanghai, Xuancheng, and Chuzhou. The overall level of green governance was high, and Chuzhou and Taizhou achieved relatively low scores.

3.3 Pearl River Delta urban agglomeration

The ecological civilization development level of the Pearl River Delta urban agglomeration was the highest in the whole country. Among its cities, the ecological civilization development level of Zhuhai was the highest, followed by Guangzhou and Shenzhen (Fig. 4). With regard to the various domain levels, Zhaoqing, Huizhou, and Jiangmen achieved the top ranks in terms of the green environment domain, and Shenzhen and Dongguan were ranked at the bottom. The green production domain ranks differed, with Zhaoqing City being ranked as relatively backward. There was no obvious difference in the domain of green life, and Zhaoqing and Huizhou achieved relatively low ranks; green treatment was also relatively low. Zhuhai and Huizhou achieved top ranks in the green governance area, followed by Zhaoqing, Dongguan, and Guangzhou.

Table 5. Proportion of EC levels for the urban agglomerations. %

Level	Jingjinji urban agglomeration	Yangtze River Delta urban agglomeration	Pearl River Delta urban agglomeration
A	0	0	0
B	0	38.46	66.67
C	40	57.69	33.33
D	60	3.85	0

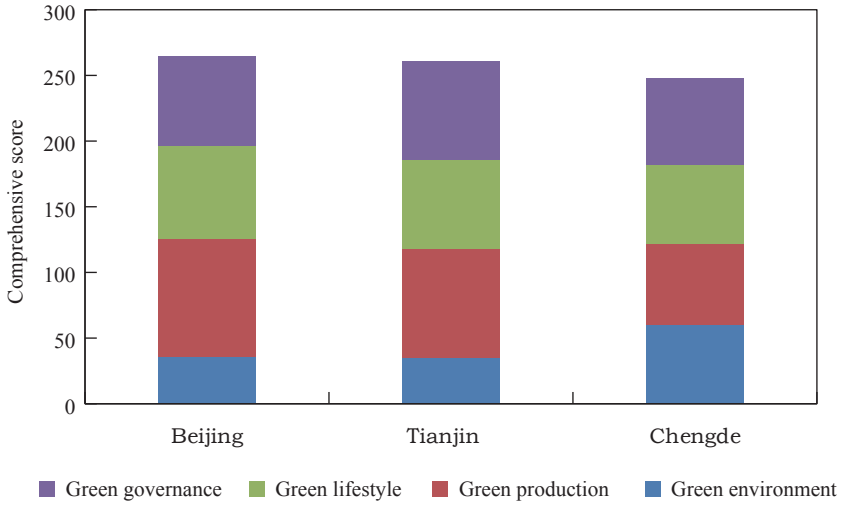

Fig. 2. EC levels for the Jingjinji urban agglomeration.

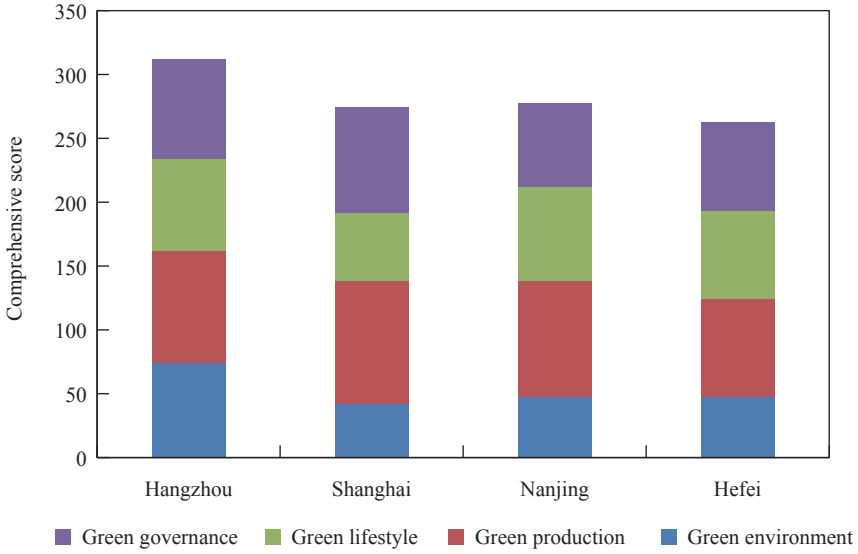

Fig. 3. The EC levels of the Yangtze River Delta urban agglomeration.

4 Conclusions and suggestions

Beijing, Tianjin, and Hebei, the Yangtze River Delta, and the Pearl River Delta are located in the northern coastal, eastern coastal, and southern coastal areas, respectively. These areas do not only represent the pioneering force of China's urban development since the reform and opening up of the country but also reflect the diversity and difference in China's urban development to a certain extent. Generally speaking, the overall level of China's typical urban agglomerations is relatively low, and the eco-environmental quality is a short board for China's ecological civilization development.

Because of the lack of data, our study does not reflect the energy utilization efficiency index and the soil environment quality index. Moreover, we also lack the related natural resources assets indices, which cannot reflect the energy structure optimization,

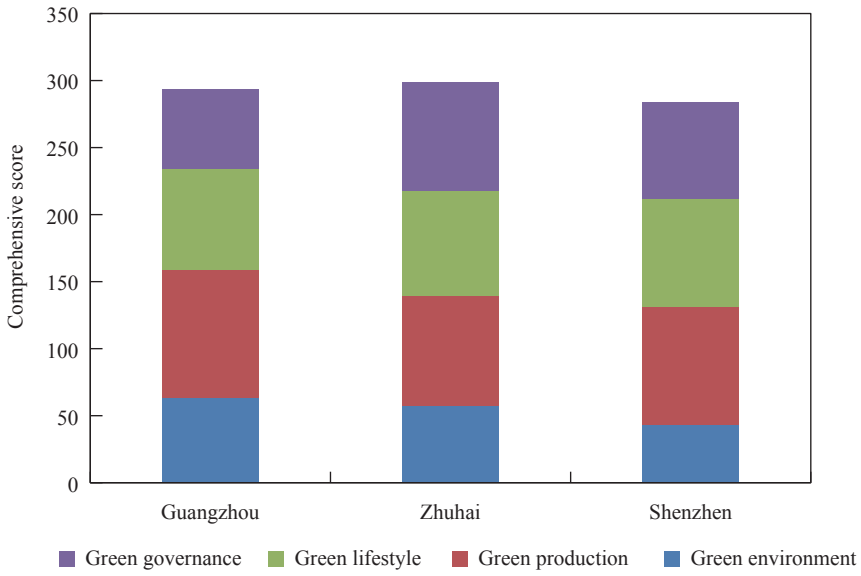

Fig. 4. The EC levels of the Pearl River Delta urban agglomeration.

overall environmental quality optimization, and ecological quality optimization; thus, the ecological civilization development level of the whole area cannot be fully improved. Therefore, it is important to promote the construction of ecological civilization in China by strengthening the statistics of relevant ecological civilization indicators and the accounting of ecological assets.

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