EVALUATION SYSTEM AND SPATIAL DISTRIBUTION PATTERN OF ECOLOGICAL CITY CONSTRUCTION – BASED ON DPSIR-TOPSIS MODEL

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Abstract. Ecological city construction plays a major role in achieving a sustainable and healthy city development. To facilitate the deep understanding of ecological city development condition and its construction process, the following studies were carried out in this paper: a comprehensive evaluation index system was firstly established based on DPSIR-TOPSIS model. The paper then went on to examine the spatial distribution status of ecological city construction according to the clustering results of coordination degree. Obstacle parameter analysis was conducted using obstacle degree model to study ecological construction level in 34 ecological cities. The result showed that: the ecological construction condition of a city in central and coastal area stayed at high level; Good coupling coordination degree among the five factors of DPSIR was found in The Pearl River Delta and The Yangtze River Delta; Driving force and Impact systems that highly affect city ecological construction in western and northern area, while ecological construction in cities like Lanzhou and Xining approached to the state of preliminary coordination. In general, ecological city construction in China is showing a constant improvement. However, cities of high-level coordination are still short-numbered.
Keywords: *ecological city, DPSIR-TOPSIS model, obstacle degree, coordinating degree, spatial pattern distribution*

Introduction

Since the opening up policy, urbanization has been greatly advanced by industrial agglomeration, urban expansion and population migration. In 2012, the urbanization rate reached over 50% for the first time and figure increased over 57.35% in 2016 (Xia et al., 2018). The urbanization has brought in the fast economic development, and at the same time resulted in many environmental and social problems. For instance, non-renewable resources are consumed in a fast speed, domestic and industrial water is massively discharged to the nature, resources and public facilities allocated to percapita is inefficient due to huge growth of population. These problems not only hinder the path of achieving a sustainable social and economic development, but also are against the main concept of building a "*wild China*". As the19th CPC National Congress has promoted the "*Ecological Civilization*" being the main body of China's economic development, "Wild China" becomes a cause of shared future of mankind. According to statistics, China urbanization rate in the coming ten decades will continue growing. Hence, how to pursue a steady approach to promote urbanization under the "ecological civilization" theme, integrate it into the whole process of urbanization, and achieve the coordinated development between ecological construction and economic & social

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development are the practical problems worth attention. This paper is to conduct the evaluation, regional disparity and obstacle degree over 34 cities on their ecological construction, hoping it could contribute to the cause of ecological city construction.

Literature review

Since the industrial revolution, ecological construction has been a common concern of most countries and international organizations. Scholars all over the world have actively carried out theoretical and practical research on this concept and introduced it into ecological cities, following the United Nations presented it in the report of the Man and the Biosphere Program. The earliest "ecology" refers to the living state of biomes in the biosphere (Ghiselin, 1974). Later, the British scholar Tansler (Huang and Zeng, 2015) proposed the "ecosystem", that is, the biological and ecological environment form a unity in nature. Foreign scholars have not stated the concept of eco-city clearly. However, in a broad sense, eco-city refers to the establishment of social relations based on ecological principles, including social harmony, economic development, and superior natural environment, so that the resource environment can be utilized and recyclable. The eco-city in the narrow sense refers to the design and planning of the city according to the ecology principle, to establish a harmonious, efficient and sustainable ecological society. In this regard, countries have made a lot of achievements in ecological environment construction, such as green politics in the United States, eco-industrial parks in Japan. Based on the current urban development, the meaning of eco-city is enriching constantly. Different countries have drawn up appropriate development routes for their own situations, approaching green cities, but they still have a certain distance from eco-cities. In contrast, domestic scholars have focused on the connotation of "ecological civilization" based on the macro environment and then implemented it into the construction dimension of specific eco-cities. Among them, the macroscopic view involves the relationship between ecological civilization and nature (Gu et al., 2013), the relationship between ecological civilization and modern civilization (Shen, 2013), the relationship between the construction of ecological civilization and the development of the times (Zeng, 2017). The concrete implementation includes the urban ecological environment construction, economic construction, system construction, science and technology construction. Marx (Yu, 2005) once proposed that the socialist society is a harmonious and unified society between man and nature, and ecological civilization is the product of the development of industrial civilization to a certain stage, as an important component of human civilization. Therefore, the construction of ecological civilization is inseparable from the sustainable development of economy and society, and the eco-city is a new vision of the future city.

In recent years, theories and practices of ecological city construction have been under constant development. At the end of 2013, the Central Economic Working Conference had made a clear policy of "fully inserting the concept and principal of ecologic civilization into the development of urbanization to pursue an ecologically characterized urbanization cause", making the ecological construction a significant policy for the cause of urbanization (Bi et al., 2017). Ecological city construction therefore, will be the important development direction in future urbanization. Yanitsky (1982) pointed out that the basic character of ecological city should be a city of: prosperous economic status, civilized, environmentally beautiful, technology and nature in great harmonious. Kline et al. (2009) indicated that ecological city is a city of economic safety, where

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human and nature are harmoniously combined, people's living standard in high level and governments highly responsible to their people etc. In 1992, Rio Declaration promoted that humankind possesses the right of living a naturally coordinated, healthy and rich life. And this is in consistent with the top goal of ecological city construction, i.e. meeting people's basic life requirement and improving their living standard. The development bodies therefore, shall pursuit a human-oriented development concept though city development. Public participation plays a critical role in ecological city construction (Mi and Peng, 2014), and it shall be guaranteed by government policies (Zhao and Wang, 2015). A well management system, the economic, social and cultural innovation are key factors for ecological city construction (Zhang, 2015). It cannot develop well without a complete management system and co-effort of multiple parties on all aspects (Li, 2008). In 2015, President Xi Jinping initiated a series of city environmental improving polices based on the actual development condition of the country. In 2016, measures and policies on pursuing a sustainable and healthy city development were brought out on the basis of "Five Development Concepts". With China's address on ecological civilization and judging from scholar's in-depth studies, it becomes clear that it is not efficient if only focus the study on policy making, party participation etc., it is also important to formulate an appropriate evaluation index system to identify the existing problems and regional disparity. An et al. (2017) conducted such study by describing fragile factors influencing ecological city construction by means of fragility measurement; Zhang and Zhang (2015) built up an evaluation index system based on ecological city connotations, while Cheng and Ning (2014) built up the system from social-ecologic view suggested by experts. Ren et al., (2016) formulated a 3D model of ecological city planning, where the author used measuring method to make comparison to analyze the ecological cities of better development property.

Theoretical and practical studies have been broadly taken by scholars' home and abroad and great achievements have been made. As the previous studies mainly focused on micro body participation in macro policy making, the evaluation index system thus formulated are subjective and the vision is somewhat narrowed. In this paper, and evaluation index system were established based on DPSIR concept model, with TOSPIS method as the evaluation method. Obstacle factors of each city were described using the obstacle degree model. The results and suggestions were then given as reference, hoping it could be the helpful material in sustainable city development and wild China cause.

Ecological city construction evaluation index system based on DPSIR-TOPSIS model

DPSIR model

This paper introduced DPSIR model to evaluate different level of ecological city construction. DPSIR model is developed from the PSR model from Organization for Economic Co-operation and Development (OECD) of European Environment Agency (EEA). It refers to five factors influencing the ecological city construction, i.e. Driving force, Pressure, State, Impact and Response, reflection the causation of "What, why and how". In DPSIR model, Driving force is a dynamic factor for ecological city construction; Pressure refers to human activities affecting the ecological environment, a direct pressure factor affecting the ecological environment; State means the condition of

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ecological environment under the above pressure, i.e. the ecological construction level; Impact refers to the ecological construction requirement under a certain system and its impact; Response means the effective measures and policies adopted for ecological development. DPSIR is a causal framework for describing the interactions between humankind and ecological city construction. This framework, due to its clear, hierarchy and objective structure, lays a theoretic foundation for establishing ecological city evaluation system.

Determination of evaluation indexes

Evaluation indexes are selected mainly on the basis of DPSIR-TOPSIS model. It follows a principal of scientific, independent, operational and subjectively & objectively combined. The system is demonstrated in three-layer structures: criteria, key elements, and index (see table 1).

Table 1. *Evaluation index system*

Criteria	Index	Code	Property	Weight
Driving force 0. 2224	GDP growth rate (%)	C1	positive	0. 0556
	GDP per capita (yuan)	C2	positive	0. 0556
	Urban per capita disposable income (yuan)	C3	positive	0. 0557
	Added value of the tertiary industry (%)	C4	positive	0. 0555
Pressure 0. 2777	Energy consumption per unit GDP (ton of standard coal/million yuan)	C5	negative	0. 0555
	Water Consumption per unit GDP (ton/million yuan)	C6	negative	0. 0556
	Generation of industrial solid waste per unit GDP (ton/million yuan)	C7	negative	0. 0555
	Industrial waste water emission per unit GDP (ton/million yuan)	C8	negative	0. 0555
	CO_2 emissions per unit GDP (ton/ million yuan)	C9	negative	0. 0556
States 0. 1665	Park/green space area per capita (m^2)	C10	positive	0. 0556
	Greening coverage in built-up area (%)	C11	positive	0. 0554
	Government fiscal expenditure on environment (%)	C12	positive	0. 0555
Impact 0. 1666	The Engel’s coefficient for urban residents (%)	C13	negative	0. 0555
	Rate of good ambient air quality (%)	C14	negative	0. 0555
	Regional environmental noise registration (dB)	C15	negative	0. 0556
Response 0.1668	Comprehensive utilization of industrial solid waste (%)	C16	positive	0. 0556
	Treatment rate of domestic sewage (%)	C17	positive	0. 0556
	Sewage treated & household refuse (%)	C18	positive	0. 0557

Determination of index weights

Dimensionless method

As each index data differs in nature and measurement units, an entropy method is applied to obtain the objective weights, the formula is shown below:

To be applied when the index is positive (*Eq. 1*):

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$$X_{ij} = \frac{X_{ij} - X_j^{min}}{X_j^{max} - X_j^{min}} \quad \text{(Eq.1)}$$

To be applied when the index is negative (*Eq. 2*):

$$X_{ij} = \frac{X_j^{max} - X_{ij}}{X_j^{max} - X_j^{min}} \quad \text{(Eq.2)}$$

To be applied when the index is moderate (*Eq. 3*):

$$X_{ij} = 1 - \frac{\left|X_{ij} - d_i\right|}{\max\left|X_{ij} - d_i\right|} \quad \text{(Eq.3)}$$

where di is the fixed standard value.

Determination of entropy weights

Entropy weight is an objective weight method. The weight of each index is firstly calculated according to information entropy, among which the irrational weights will be modified though entropy method, thus obtaining a considerably objective index weights. The specific steps are shown below:

(1) Certain indexes are translated after standardization (*Eq. 4*):

$$X_{ij} = H + X_{ij} \quad \text{(Eq.4)}$$

H in normal cases is 1.

(2) The variation coefficient of index j (*Eq. 5*):

$$g_i = 1 - e_i \quad \text{(Eq.5)}$$

(3) The index weight of item j (*Eq. 6*):

$$W_i = \frac{g_i}{\sum_{i=1}^{p} g_i} \quad \text{(Eq.6)}$$

Evaluation method

TOPSIS model

TOPSIS model was firstly brought out by Hwang and Yoon in 1981. It is a technique for order preference by similarity to ideal solution among the limited evaluation subjects. The order preference is carried out by calculating the optimal value and the worst value of the subjects. The result of the evaluated subject more close to the optimal value and farthest to the worst value is considered the optimal subject, vice versa. This method can best utilize the original data and is applicable for analyzing data of large quantity and extensive distribution. The specific steps are as follows:

(1) Positive ideal solution (*Eq. 7*):

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$$Y^{+} = (y_j^{+}) = y(\max) \qquad \text{(Eq.7)}$$

Negative ideal solution (*Eq. 8*):

$$Y^{-} = (y_j^{-}) = y(\min) \qquad \text{(Eq.8)}$$

(2) Calculate respectively the distance between different evaluation index vectors and positive S1 and negative S2 (*Eq. 9*):

$$S^{+} = \sqrt{\sum_{j=1}^{30} (y_{1j} + y_j)^2} S^{-} = \sqrt{\sum_{j=1}^{30} y_{1j} - y_j)^2} \qquad \text{(Eq.9)}$$

(3) Calculate the similarity of different indexes (*Eq. 10*):

$$C_1 = \frac{S_1^{-}}{S_1^{-} + S_1^{+}} \qquad \text{(Eq.10)}$$

Similarly, calculate the relative similarity of each year and each sub-system. The lower the S^{+} value, the closer the evaluation index to the ideal situation, the better the ecological development state it demonstrates; The lower the S^{-}, the closer the index to the negative ideal situation, the lower the ecologic development level; The bigger the C_j, the higher level of ecological city construction in the year of j. Based on practical situation of 34 cities, this paper classified the development level of these cities into four category using equal apace method and in accordance with similarity value of C_j. The four categories are: excellent (0.6-0.7); well (0.5-0.6); normal (0.4-0.5); worse (below 0.4).

Obstacle degree model

After measuring the construction level of 34 eco-cities in China from 2011 to 2015, this paper used time series as the standard to select two endpoints on the time axis, 2011 and 2015 as the research object. Then the status of China's eco-city construction at two extreme time points was compared, with a further analysis of each indicator. We introduced a contribution value D_{ij}, deviation degree E_{ij}, obstacle degree to identify the obstacle factors.

The specific steps are (*Eqs.11* and *12*):

$$D_{ij} = W_{ij} \times W_i E_{ij} = 1 - X_{ij} \qquad \text{(Eq.11)}$$

$$P_{ij} = \frac{D_{ij} \times E_{ij}}{\sum_{i=1}^{m} (D_{ij} \times E_{ij})} \qquad \text{(Eq.12)}$$

where, W_{ij} is the index weight j in criteria layer i, W_i is the index weight of criteria i where the index j is located. X_{ij} is the standardized value of individual index, obstacle degree ($P_{ij}P_{ij}$) is the value of obstacle degree of classified and individual index of year j.

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Coupling coordination model

Coupling is a physics concept which refers to two or more systems or motion modes join up by various interactions. The coupling reaches high level when the factors of each system are in positive interaction, vice versa. The specific steps are:

(1) Calculate the evaluation index by linearity weighted method (*Eq. 13*):

$$U = \sum_{i=1}^{m} W_{ij},\quad U = (B_i, D_i, E_i, H_i, G_i) \tag{Eq.13}$$

where, B_i, D_i, E_i, H_i, G_i are the comprehensive indexes of driving force sub-system, pressure sub-system, state sub-system, impact and response sub-system.

(2) Through coupling coordination model, the coupling formula for ecological city construction is (*Eq. 14*):

$$C = \left\{ \frac{S_1 \times S_2 \times S_3 \times S_4 \times S_5}{\left[\frac{S_1 + S_2 + S_3 + S_4 + S_5}{5} \right]} \right\} \tag{Eq.14}$$

where, C is coupling. If c = 1, it comes to the optimal coupling state. Factors within the system develops randomly if c = 0.

Coupling coordination reflects the coordination condition among different systems, which is the in-depth analysis of coupling, the formula is (*Eq. 15*):

$$D = \sqrt{C \times T} \tag{Eq.15}$$

where, D is the coupling coordination and T is the comprehensive coordination index.

Ecological city construction evaluation and spatial pattern evolution based on DPSIR-TOPSI

Data source

The paper studies in 2011 and 2015, and its statistical data come from China Statistical Yearbook, China City Statistical Yearbook, and etc. Specific research methods using entropy method, TOPSIS method, the introduction of obstacle degree and coupling degree model, and through clustering method and ARGIS to carry on the spatial pattern distribution of the results.

Eco-construction evaluation analysis based on DPSIR-TOPSIS model

Evaluation results and analysis of ecological city construction (see Table 2)

Evaluation analysis

It is shown from table 1 that the ecological construction level of each city showed an uprising trend. Judging from the change trend, the sub-system of driving force in 2015 went closely to the ideal solution compared with the year of 2011. Specifically, the sub-system of driving force in cities of higher economic level, such as Beijing and Shanghai, approached to the ideal value. In regards to the Pressure change trend, sub-

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system of Pressure in Beijing and Shanghai in 2015 decreased by 0.16% and 0.14% respectively compared with the year 2011, showing an increase in environmental pressure. Judging from S+ value of State sub-system and Impact subsystem, the change trend showed that northwest cities had better performance in this two aspects. For instance, Nanjing and Beijing had better performance in sub-system of Impact while other cities are in poor condition. Change trend of Impact sub-system value S- showed the same result as the trend of S+, that is, almost reach the ideal solution. Comprehensively, the result showed as follows: sub-system of Pressure > sub-system of Response > sub-system of Driving force > sub-system of Impact > sub-system of State (see *Fig. 1*).

Table 2. *Topsis evaluate value*

	2011 Years							2015 Years						
City	**Driving**	**Pressure**	**State**	**Impact**	**Response**	**E-V**	**Ranks**	**Driving**	**Pressure**	**State**	**Impact**	**Response**	**E-V**	**Ranks**
Shenzhen	0.520	0.954	0.498	0.570	0.966	0.623	6	0.804	0.972	0.294	0.571	0.998	0.661	1
Beijing	0.654	0.983	0.534	0.759	0.694	0.641	3	0.820	0.86	0.374	0.711	0.932	0.652	2
Guangzhou	0.785	0.913	0.422	0.847	0.875	0.660	1	0.844	0.982	0.179	0.601	0.997	0.650	3
Nanjing	0.613	0.713	0.452	0.724	0.778	0.582	11	0.733	0.887	0.253	0.699	0.987	0.637	4
Zhuhai	0.468	0.768	0.936	0.741	0.937	0.645	2	0.575	0.804	0.384	0.672	0.994	0.610	5
Xiamen	0.694	0.705	0.260	0.690	0.968	0.598	10	0.467	0.815	0.483	0.634	0.988	0.607	6
Hangzhou	0.541	0.883	0.141	0.365	0.983	0.568	16	0.780	0.946	0.136	0.221	0.982	0.598	7
Harbin	0.187	0.949	0.165	0.624	0.365	0.51	26	0.199	0.995	0.408	0.491	0.996	0.595	8
Jinan	0.414	0.926	0.191	0.89	0.942	0.616	8	0.472	0.969	0.098	0.517	0.997	0.595	9
Shanghai	0.579	0.703	0.123	0.733	0.998	0.580	12	0.746	0.473	0.034	0.598	0.982	0.532	10
Changsha	0.497	0.932	0.089	0.889	0.992	0.620	7	0.528	0.941	0.034	0.716	0.984	0.591	11
Hohhot	0.576	0.756	0.519	0.906	0.364	0.569	15	0.640	0.887	0.225	0.826	0.616	0.585	12
Shenyang	0.32	0.973	0.356	0.918	0.928	0.633	4	0.168	0.989	0.673	0.185	0.981	0.584	13
Haikou	0.357	0.795	0.406	0.481	0.919	0.565	18	0.405	0.845	0.144	0.616	0.990	0.583	14
Changchun	0.203	0.914	0.13	0.985	0.729	0.566	17	0.111	0.900	0.485	0.580	0.997	0.580	15
Chongqing	0.277	0.755	0.567	0.641	0.910	0.551	19	0.275	0.919	0.347	0.641	0.972	0.578	16
Urumchi	0.350	0.369	0.524	0.551	0.412	0.465	32	0.568	0.836	0.066	0.557	0.961	0.567	17
Chengdu	0.418	0.967	0.328	0.749	0.972	0.626	5	0.277	0.961	0.122	0.366	0.995	0.565	18
Hefei	0.315	0.929	0.403	0.354	0.593	0.534	21	0.309	0.931	0.149	0.453	0.981	0.565	19
Fuzhou	0.323	0.907	0.257	0.534	0.984	0.578	13	0.35	0.888	0.108	0.576	0.969	0.564	20
Nanchang	0.174	0.811	0.209	0.913	0.987	0.571	14	0.263	0.898	0.056	0.74	0.999	0.562	21
Zhengzhou	0.254	0.830	0.065	0.660	0.743	0.508	28	0.329	0.931	0.371	0.316	0.949	0.558	22
Xian	0.396	0.924	0.076	0.687	0.741	0.547	20	0.182	0.973	0.095	0.482	0.983	0.558	23
Wuhan	0.363	0.718	0.134	0.306	0.887	0.509	27	0.455	0.905	0.051	0.272	0.995	0.555	24
Tianjin	0.667	0.898	0.141	0.710	0.948	0.613	9	0.475	0.855	0.025	0.445	0.982	0.551	25
Shijiazhuang	0.107	0.406	0.563	0.798	0.995	0.529	22	0.108	0.568	0.600	0.755	0.994	0.550	26
Lanzhou	0.244	0.345	0.08	0.082	0.719	0.396	34	0.244	0.829	0.601	0.56	0.587	0.536	27
Lanning	0.195	0.618	0.321	0.890	0.293	0.479	31	0.179	0.756	0.223	0.586	0.932	0.536	28
Kunming	0.268	0.541	0.495	0.890	0.462	0.516	24	0.271	0.648	0.225	0.904	0.641	0.530	29
Guiyang	0.400	0.450	0.267	0.534	0.704	0.484	30	0.447	0.772	0.158	0.481	0.745	0.525	30
Shantou	0.074	0.780	0.380	0.437	0.963	0.514	25	0.096	0.844	0.307	0.395	0.976	0.518	31
Taiyuan	0.142	0.686	0.202	0.865	0.505	0.496	29	0.32	0.823	0.132	0.641	0.439	0.501	32
Yinchuan	0.128	0.325	0.534	0.887	0.948	0.517	23	0.166	0.538	0.383	0.714	0.711	0.496	33
Xining	0.203	0.401	0.279	0.579	0.642	0.451	33	0.256	0.423	0.377	0.546	0.848	0.488	34

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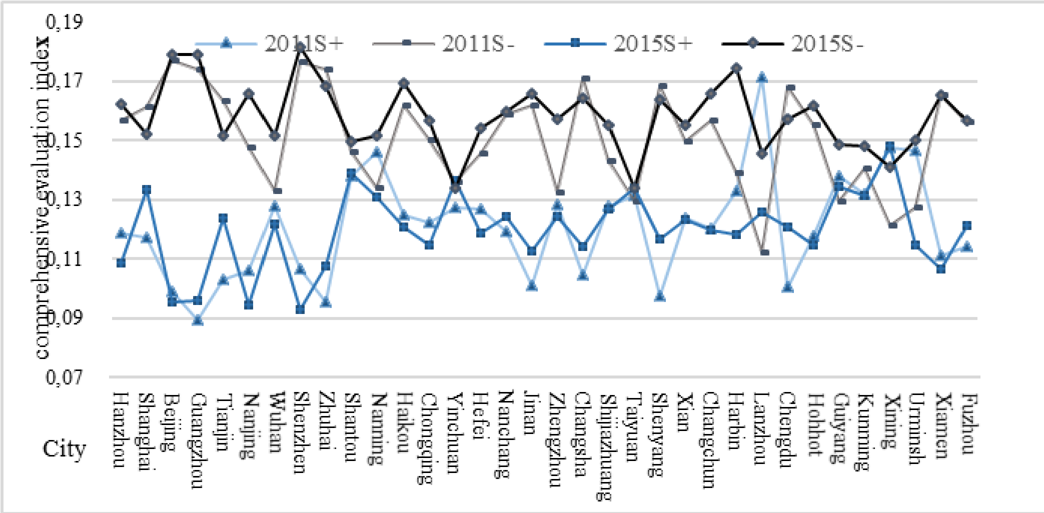

Figure 1. *Changes of evaluation index approaching the ideal solution*

Eco-environmental carrying capacity of each DPSIR sub-system

Compared with the year 2011, sub-system performance of DPSIR in 2015 were shown as follows (see *Fig. 2*):

The sub-system of driving force of each city in 2015 showed an uprising trend in general. Cities of high economic level like Shanghai, Beijing, Nanjing and Shenzhen shared bigger proportion, among which Beijing yielded a 23.9% year-on-year growth. On the other hand, subsystem of driving force in northern cities like Shenyang, Xi'an, Changchun experienced a downward trend, among which Xi'an experienced a year-on-year decrease of 21%. Sub-system of pressure in 2015 was in a stage of fluctuation. Beijing, Shanghai and Tianjin went downward by 12.26%, 23.1% and 4.24% respectively, whose performance is still better than low-level economic cities in northwest and southwest regions. Lanzhou and Guiyang showed a significant growth. Lanzhou experienced a year-on-year growth of 48.42% but was still lower than average level judging from its place in the ranking list. Sub-system of pressure in Xiamen increased by 11.2%. The figures suggested that, during ecological construction, super-huge cities still have a lot of work to do in coping with problems like environmental pressure, sustainability issue on their pursuit of the fast economic growth. The State sub-system of each city in year 2015 showed a downward trend, among which Guangzhou decreased by 24.32%. Beijing, Guangzhou, Nanjing and other cities with high economic development showed an excessive encroachment of green land, the maintenance work was unattended and the planning is not in a reasonable condition. Hohhot, Taiyuan and other cities, due to their self-condition and slow economic growth, had a slow pace in green city construction. In 2015, the sub-system of Impact showed more of growth than decrease among cities. Large increase was still mainly shown in northeast cities and cities in Yangtze River Delta. In recent years, although China has been addressing the issue of keeping a good ambient air quality rate, treatment on issues like air pollution, noise control is still less effective. The sub-system of Response in 2015 showed a pleasant trend in general. However, there are also a decrease found in cities like Yinchuan, Lanzhou and Taiyuan with figure reaching over 20%. Due to low awareness of comprehensive utilization of wastes, defective ecologic mechanism and

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low-level technological competence, the comprehensive utilization rate of solid waste is hard to reach its best performance in northwest cities.

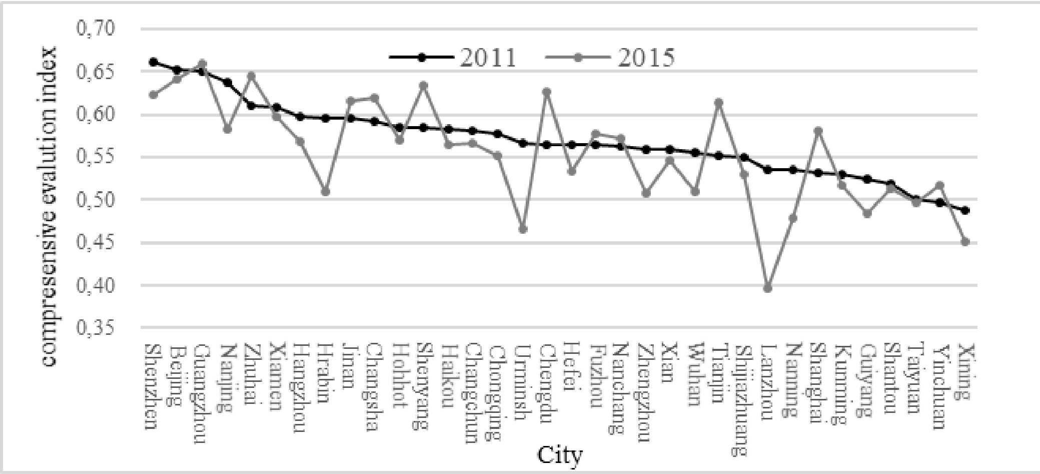
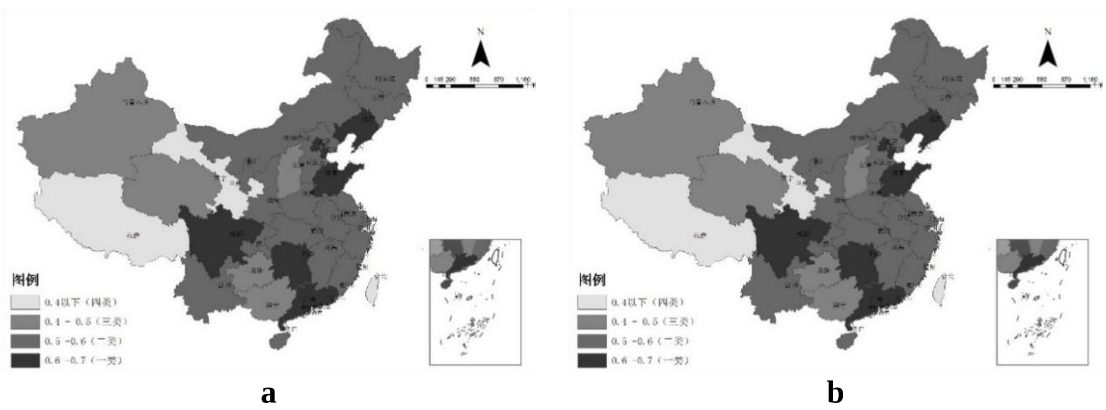


Figure 2. *Similarity status among cities in 2011 and 2015*

Table 2 and *Figure 2* revealed a rank change in 2015 compared with 2011. The rank in some cities like Beijing, Nanjing, Xiamen, Hangzhou went upward, whose rank in 2011 was shown better than central and western cities. Kunming, Shantou, Xining, Yinchuan, Taiyuan and some other northwest cities in 2015 went downward, ranking lower in both 2011 and 2015 and showing a slow ecological construction pace. *Fig. 3a* suggested a four ecological city construction type. The first type were the cities with best ecological city construction. Examples were Guangzhou, Shenzhen Jinan. The second type was vastly distributed. Bad performance was found in northwest cities like Urumchi, Lanzhou, Xining, clustering into the third and the fourth type. *Fig. 3b* showed a city rank change in 2015. Among them, Guangdong had three cities listed in the first type. Xiamen and Nanjing upgraded into the first type. Beijing showed no change in the rank. Shenyang, Jinan with other cities clustered into the second type-cities of good ecological construction performance. Yinchuan stationed into the third type in 2015, while Urumchi, Taiyuan, Lanzhou experienced a certain growth in ecological city construction and went up to the second type from the third and the fourth type. In general, ecological construction in each city showed a steady step forward (see *Fig. 3*).



a **b**

Figure 3. *Cluster result of similarity in **a** 2011 and **b** 2015*

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Obstacle degree analysis

Judging from the frequency of the obstacle factors, 8 indexes are frequently occurred as obstacle factors in 2011 and 2015(see table 3). Among these, the added value of the tertiary industry and GDP per capita were two main factors affecting many cities. Rate of good ambient air quality, industrial waste, water emission per unit GDP and park/green space area per capita appeared in cities of good economic performance like Shanghai, Hangzhou and Shenzhen. The respective responding criteria layer of the 8 factors are Driving force sub-system, Pressure sub-system and State sub-system, among which the obstacle factor of State sub-system showed the highest frequency. The eastern and central ecological city was influenced most by this system.

Table 3. *Times of index in cities*

Index	City						
Rate of good ambient air quality	Hangzhou	Shenzhen					
Added value of the tertiary industry	Hangzhou Tianjin Shanghai	Shanghai Nanjing	Wuhan Zhuhai	Chengdu	Hefei Zhengzhou	Changsha Shenyang	Changchun Xiamen	Shijiazhuang
Generation of industrial solid waste per unit GDP	Shanghai	Xiamen						
Park/green space area per capita	Shanghai	Xian						
Water Consumption per unit GDP	Nanjing	Zhuhai	Nanning	Nanchang	Shijiazhuang			
GDP per capita	Shantou Nanning	Haikou Hefei	Xian Chengdu	Guiyang Kunming	Xian	Harbin		
Greening coverage in built-up area	Hohhot	Guangzhou	Shenzhen	Jinan				
Government fiscal expenditure on environment	Guangzhou	Wuhan	Changsha	Chengdu	Fuzhou			

It indicated the changes of obstacle degree of each sub-system among cities in sample period (see *Fig. 4*). The values and changes showed that, in general, the sub-system of State and Impact experienced a downward trend. The sub-system of Driving force, Response and Pressure on the other hand went upward during fluctuation. Compared with 2011, changes in 2015 were: Higher obstacle degree was found in the sub-system of Driving force and Pressure; obstacle degree of Pressure sub-system experienced a large increase in cities like Hangzhou, Shanghai, Beijing, Guangzhou and Tianjin. The increase of obstacle degree of response sub-system, such as in Xiamen, Fuzhou and Shanghai, was insignificant. The State sub-system was lower than the Impact subsystem but was still the main obstacle factor both in 2011 and 2015.

In general, the obstacle degree of Response and Impact sub-system were relatively insignificant. The ranking order is shown below: Judging from the rank, in the year of 2011: Driving force sub-system> State sub-system>Pressure sub-system>Impact sub-system > Response sub-system. In the year of 2015: Pressure sub-system > Driving force sub-system > State sub-system > Impact sub-system > Response sub-system.

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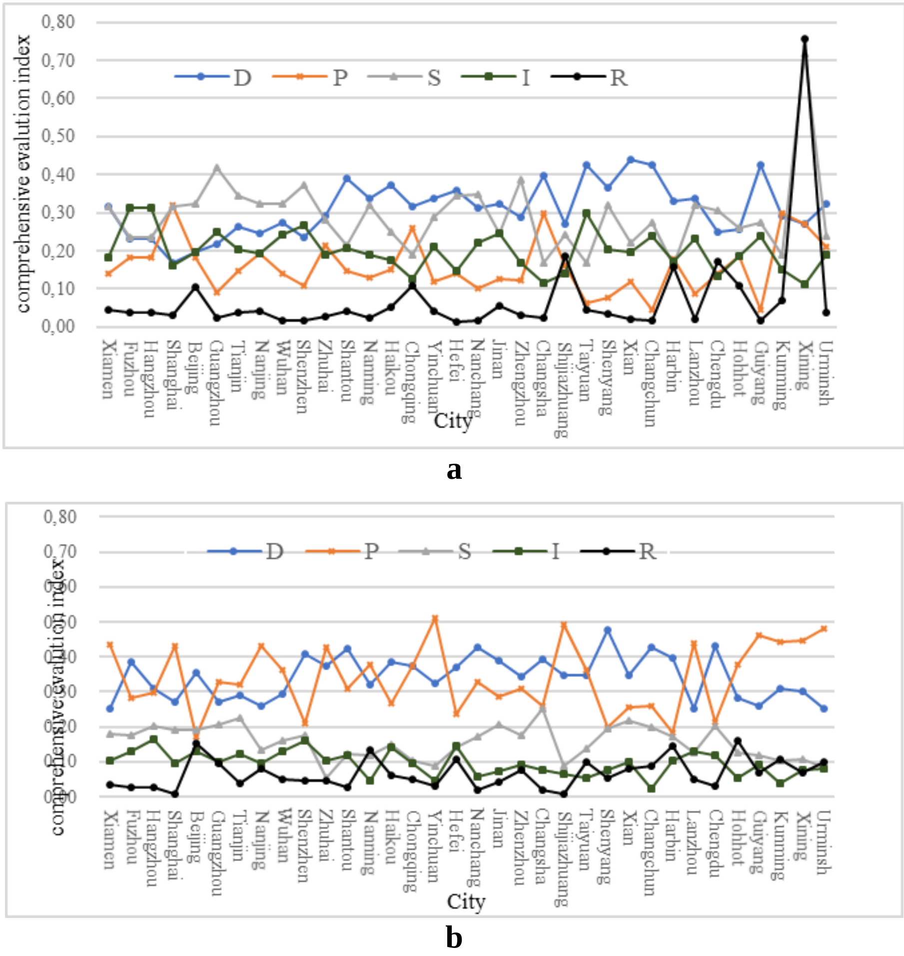

Figure 4. *Changes in obstacle degree of each sub-system in* ***a*** *2011 and* ***b*** *2015*

Spatial change of coupling coordination distribution

From these changes it can be seen that: high level coupling coordination are stably distributed in provinces of Pearl River Delta and Yangtze River Delta area. In 2011, Beijing, Guangzhou, Zhuhai and Shenzhen ranked the highest in coupling coordination, followed by Xiamen and Nanjing. Beijing, Guangzhou and Shenzhen took the lead in ecological construction by driving force and pressure sector, while Xiamen and Nanjing had State and Impact sub-system as their leading points. Cities with low coupling coordination were found in Lanzhou, Xining, Urumchi, and Guiyang-- mainly those cities in central and western provinces. These cities were commonly found lack of distinct system and are general in low-level performance. The construction of each system in northeast provinces showed a medium level performance and high degree of coordination. During the Five-year economic construction period, cities in eastern China region, such as Hangzhou and Nanjing, made a great achievement on sub-system of Driving force and State, developing faster than other regions. The State sub-system however, was relatively backward. Under the fast economic development background, western China region in general showed a medium-level coupling dis-coordination in 2011 due to their weak self-condition and slow economic development. Generally, the coupling coordination in central and western region under the “economic new normal” went upward in 2015 (see *Figs. 5* and *6*).

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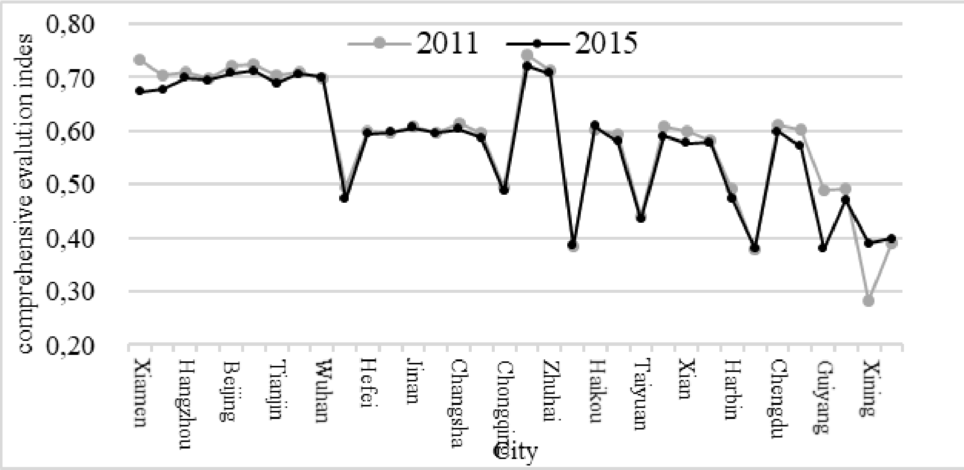
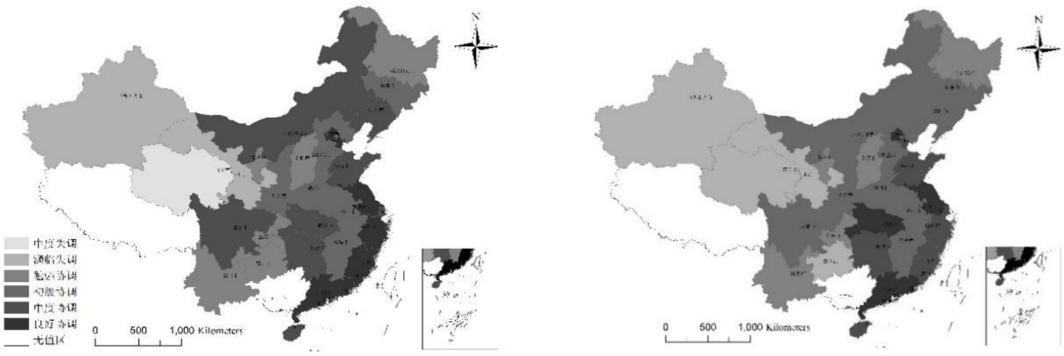


Figure 5. *Coupling coordination in 2011 and 2015*



a **b**

Figure 6. *Coupling coordination status in **a** 2011 and **b** 2015*

Revolution of ecological city construction pattern

This paper adopted a cluster analyzing method to evaluate the coordination scores of each sub-system in 2011 and 2015. The result showed that: cities of the first category in 2011 were represented by Hefei, Xi’an, Shijiazhuang; some cities showed a more distinct score in State and Impact sub-system but low score in coordination, which was represented by Haikou; cities in the second category, represented by Shanghai, Shenzhen, revealed higher scores in Driving force sub-system and coordination but lower score in Pressure sub-system. Cities in the third category represented by Shantou, Urumchi and Lanzhou revealed low score in all five sub-systems and poor coordination; Yinchuan, Chongqing, Harbin and Kunming were in the fourth category and Xining was the only city in the fifth category.

The cluster classification went through certain minor changes in 2015: the first four categories remained in the same condition; Xining from the fifth category went up to the third category, showing a relief in bad coordination. Coordination status in some cities like Fuzhou and Hangzhou changed from medium coordinated to lightly coordinated, showing a decrease in coordination. Shenzhen, Zhuhai and Guangzhou remained the medium coordination. No big change occurred in other cities (see *Fig. 7*).

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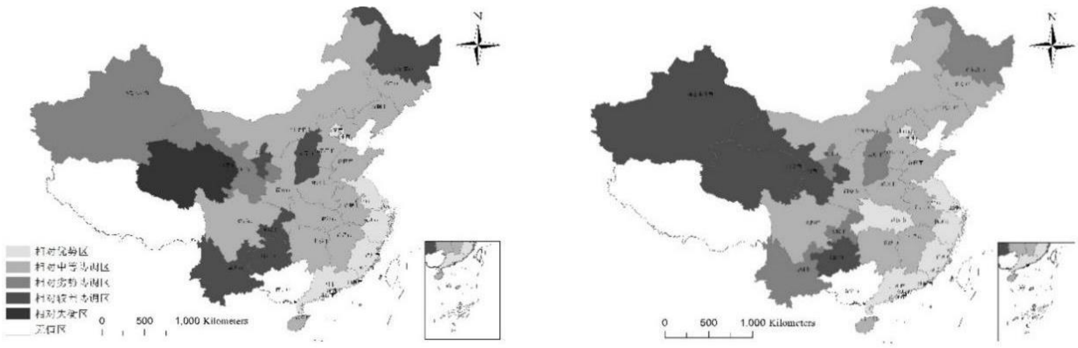

a b

Figure 7. *Cluster results in **a** 2011 and **b** 2015*

Conclusion and outlook

At the macro level, the construction of China’s eco-city has begun to take shape, constructing a localized eco-city model from multiple dimensions such as politics, economy and ecology gradually under the background of the global ecological movement. From the perspective of self-construction, there is still a big gap in the goal of China's eco-city construction from a high level of coordinated development. In comparison, cities with higher economic development have better ecological construction like Beijing, Shanghai, Nanjing, Guangzhou, from the comprehensive evaluation index under the DPSIR model, and vice versa. This is mainly due to the fact that many cities in the initial stage of construction give priority to developing the economy, ignoring ecological damage and environmental pollution. As the economy evolves to a considerable level, it will focus on environmental problems again. They improve their ecological environment by increasing technical and financial resources to rebuild ecological cities. Hence, the central and western regions with poor economic development are still in the game stage of economic development and ecological construction.

The ecological city construction in China still has far way to go in achieving a high-level coordinated development. In regional development, addresses shall be made to develop the strong sub-systems based on practical condition and at the same time paying attention to the other sub-system construction. In general, the statistics revealed a low-pace development of State and Impact sub-system. State sub-system construction in central and eastern region showed a particular weakness waiting to be highly addressed. Northwest regions, on the other hand, shall develop their sub-system of Driving force and at the same time paying attention to issues like resource and environmental pressure and green space per capita etc, so that the effective coordination with sub-system of Response can be achieved. The comprehensive evaluation results showed a general upward rise in each city’s ecological construction, reflecting that the condition was getting good. The similarity value among cities showed the good performance of Driving force sub-system and Pressure sub-system in cities with better economic development but bad performance in cities with low economic development. The changes of obstacle degree showed that driving force sub-system and pressure sub-system were the main obstacles hindering the ecological city construction in western and northern region, while State sub-system remained as the main obstacle in central and eastern region. From the statistical changes of the applied model, it can be seen that ecological city construction in southeast coastal area showed a better performance, while low construction level was found in cities of northwest, southwest and northeast region.

By establishing an evaluation index system based on DPSIR conceptual model, and by carrying out an empirical study using the method of similarity analysis, obstacle degree study and coupling coordination degree model, a relatively comprehensive analysis on city ecological construction level and spatial distribution pattern in China was accomplished. However, further studies are still expected. For instance, although indexes of the evaluation system are carefully selected and it is proved to be representative, mathematical approach and model construction can be further improved. In addition, this study mainly conducted a time-span evaluation on the overall changes and changes of each individual factor concerning ecological city construction, discussions around future development, management approach, inter-province cross-sectional study under the same time scale shall be further conducted. Moreover, studies on ecological city governance shall be fully carried out based on solid knowledge background of ecological city construction process.

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