Study on the Coupling Coordination Degree between Metropolitan Economic System and Water Environmental System - Taking Beijing as an Example

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Abstract. The generation of metropolis is the inevitable outcome of the development of urbanization to a certain stage. The economy and society of metropolis are in the rapid development, but this process brings great pressure to the ecological environment, especially the water resources environment at the same time. In this paper, the relationship between metropolitan economic system and water environmental system is deeply studied, and the concept of "coupling" is introduced. Based on the framework of "pressure-state-response" (PSR), 12 detailed indexes, such as total population and water consumption per ten thousand Yuan GDP, were selected to construct four subsystems. The coordination degree measurement model has been used to calculate the degree of coupling between the economic system and water environmental system. On this basis, the following conclusions are drawn through the example of Beijing city: (1) In the process of metropolitan development, the economic system and the water environmental system are interrelated and there exist a complex coupling mechanism. (2) With the adjustment of economic structure and the progress of technology, the coupling index between the metropolitan economic system and the water environmental system has been increasing, and this process shows an upward trend

Keywords. Metropolis, economic system, water environmental system, coupling.

1 Introduction

In recent years, the number and the population of large cities continues to increase because of China's rapid economic development. As of the end of 2014, China has 16 mega-cities, in the forefront of the world. Urbanization was initially led by agglomeration development in order to achieve economies of scale. When the scale of urban development to a certain stage, it began to spread out from the center of the city, radiated surrounding areas and re-stage, eventually formed city or metropolitan area. As China's opening up efforts to expand the internal structure of the economy continue to optimize the transition, China's economic development situation is good. The economic and social situation of Beijing, Shanghai and other cities is highly developed. However, with the rapid development of the economy, the extensive economic industry

still occupies a considerable proportion of the energy consumption, which causes the corresponding water environment system of the region to bear too much pressure. The water pollution of these cities is serious, and the water quality self-recovery ability is poor [1].

Beijing is the capital of China, at the same time it is a typical representative of China's metropolis. Beijing is in the north of China and is located in the northern part of the North China Plain. And Beijing is the largest city in northern China, it has jurisdiction over 18 counties, with a total area of 16410.54km^2 and total population of 2151.6 million. Beijing's winter is cold, summer is hot and humid. It is a typical temperate continental climate, with an average annual rainfall of about 600mm, precipitation distribution is extremely uneven, 80% concentrated in 6,7,8 three months. Beijing's economic and social development is relatively advanced, but the corresponding water resources environment is relatively scarce, it belongs to the typical water shortage city. The economic development brought greater pressure to the water supply system. It discharges a large amount of waste water, causing great pollution to water resources. However the corresponding water environment system in Beijing due to limited supply capacity, can not meet the Beijing daily Production and life requirements of the necessary water supply requirements. Its corresponding water resources carrying capacity is relatively limited, their own digestion, their ability to digest sewage is relatively inadequate.

2 Research methods

2.1 Construction of index system

Based on the three principles of scientific, representative and feasible, 12 indicators were selected according to the "Pressure-State-Response (PSR)" framework to construct four subsystems. These four subsystems include social population subsystem, economic development subsystem, water environment supply subsystem and water environment carrying subsystem. Among them, pressure indicators reflect a range of factors caused by human activity to the system, status indicators show the current status of the system, and the response indicators reflect human's positive efforts to further improve the system. Three types of indicators have differences and relations, jointly push forward the development of the system (see Figure.1)

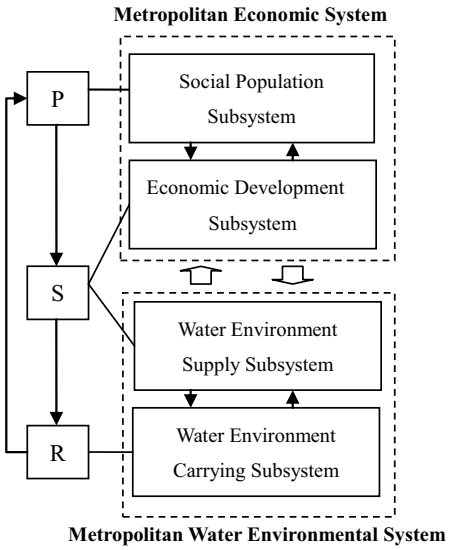

Fig.1. PSR running mechanism and coupling relationship diagram.

2.2 Data Sources

This paper takes Beijing as one of the most representative metropolises in China. All the data are obtained from "Beijing Statistical Yearbook 1997-2013" and relevant water resources bulletins.

2.3 Data Processing

2.3.1 Data preprocessing

Since units of the index in evaluation system are different, we must first carry out data preprocessing in order to compare between different indicators and determine the weights, i.e. for each data dimensionless normalized. This paper uses the maximum difference normalization method for further data processing. There are two types of evaluation, efficiency index and cost -based index. Efficiency index refers that the attribute values show a positive correlation with coordination degree of economy and environment, the greater its value, the better. While the cost-based indicators, by contrast, refers to the negative correlation between its attribute values and coordination degree of economy and environment [2-3].

$$\text{efficiency index} \quad X'_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} \tag{1}$$

$$\text{cost -based index} \quad X'_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)} \tag{2}$$

In this formula, X_{ij} means the original value of index j in year i, X'_{ij} is the normalized value, $\max(X_j)$ and $\min(X_j)$ refer to the maximum and minimum value of index j.

2.3.2 Mean square difference method to determine the index weight

In this paper, an objective mean square difference method is used to determine the index weights. And in order to eliminate the impact of different indicators means, the concept of variation coefficient is introduced.

$$CV_j = \frac{\sigma_j}{\bar{X}_j} \tag{3}$$

$$W_j = \frac{CV_j}{\sum_{j=1}^{n} CV_j} \tag{4}$$

In this formula, CV_j represents a variation coefficient of index j, σ_j says the average variance of index j (i.e., standard deviation), and $\bar{X}_j$, W_j respectively refer to their mean value and weight value.

2.3.3 Metropolitan economy and metropolitan water environment comprehensive index calculation

Multiply the standardized values of each index by the corresponding weights and come to the comprehensive index of metropolitan economy f(x) and the comprehensive index of metropolitan water environment g (y).They respectively refer to the Metropolitan comprehensive development of economic systems and water environmental systems.

$$f(x) = \sum_{i=1}^{m} X'_{ij} W_x \tag{5}$$

$$g(y) = \sum_{i=1}^{n} Y'_{ij} W_y \tag{6}$$

2.3.4 Coordination degree analysis

Coordinate degree is a quantitative indicator used to reflect the degree of harmony between systems in the process of development. Comprehensive evaluation index is a measure of the overall function and benefits of the parent system. But in some cases there will be two parent system, such as A and B, whose coordinate degrees are the same while comprehensive evaluation indexes are different from each other. In this case, even if they have the same coordination degree, it is also difficult to show that their coordinated development situations are consistent.

$$C = \left\{ \frac{f(x) \times g(y)}{\left[\frac{f(x)+g(y)}{2} \right]^2} \right\}^k \tag{7}$$

$$T = \alpha f(x) + \beta g(y) \tag{8}$$

$$D = \sqrt{C \times T} \tag{9}$$

In this formula, C is coordination degree, K means the adjustment coefficient (the k=2),T is the comprehensive evaluation index of urban economy and the environment system, α and β coefficients to be determined. In this paper the development of metropolitan economy and Metropolitan water environmental protection are equally important, so take α = β = 0.5. D refers to the coordinated development coefficient [4-7].

3 Results and analysis

According to the above steps , the data processing results can be obtained in Table 1 .f(x) means comprehensive index of economic system, g(y) means comprehensive index of water environmental system and D means coordinated development coefficient.

Table 1. The results of the coordinated development of economic and water environmental systems in Beijing (1997-2013).

Year	f(x)	g(y)	D
1997	0.1177	0.2268	0.0072
1998	0.1196	0.2185	0.0071
1999	0.1625	0.2331	0.0120
2000	0.1966	0.3357	0.0239
2001	0.1861	0.4104	0.0277
2002	0.2379	0.5014	0.0504
2003	0.2168	0.5069	0.0444
2004	0.3532	0.5891	0.1102
2005	0.3797	0.6968	0.1501
2006	0.4336	0.7053	0.1859
2007	0.6539	0.7400	0.3649
2008	0.6603	0.7370	0.3685
2009	0.7057	0.7607	0.4231
2010	0.6723	0.7610	0.3937
2011	0.8801	0.7607	0.5894
2012	0.9094	0.7684	0.6266
2013	0.9829	0.7657	0.7011

3.1 The comprehensive index analysis of economic system in Beijing

From the above results, we can see that the economic performance of Beijing in 1997 to 2013 shows a stable growth trend (see Figure 2). The economic system composite index increased from 0.1177 in 1997 to the highest Value of 0.9829 in 2013.

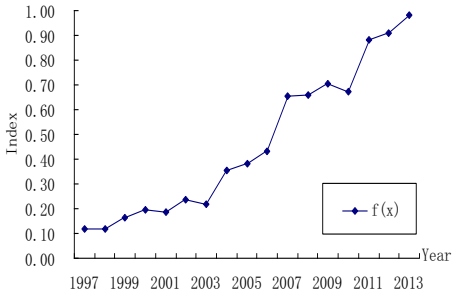

Fig.2. The comprehensive index trend chart of economic system in Beijing (1997-2013).

3.2 The comprehensive index analysis of water environmental system in Beijing

The data of the water environment system from 1997 to 2013 in Beijing were processed, and the water environmental system comprehensive index also showed a simple overall upward trend (see Figure 3). The lowest value of water environment index appeared in 1998, the index value was 0.2185, while the highest value appeared in 2012, the index value was 0.7684.

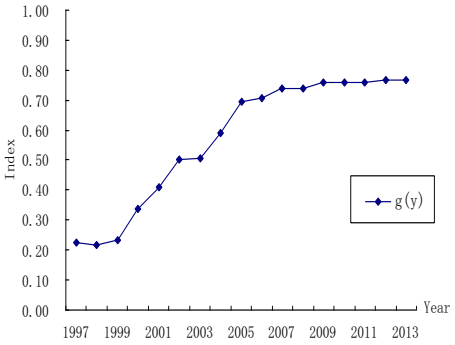

Fig.3. The comprehensive index trend chart of water environmental system in Beijing (1997-2013).

3.3 Coordination degree analysis between economic system and water environmental system in Beijing

According to the results of data processing in Table 2, the trend of the coordinated development coefficient of economic and water environmental systems in Beijing is plotted (see Figure 4). It can be seen from the figure that during 1997 to 2013, the relationship between Beijing's socio-economic and its protection of the coordinated development of water environment was good. The degree of coordination between them showed an overall upward trend, and the degree of coupling continuous optimization. The coefficient of coordinated development of economic system and water environmental system in Beijing increased from the lowest value of 0.0071 in 1998 to the highest value of 0.7011 in 2013.

On the basis of summarizing the existing research results, this paper divides the coupling states into 5 different stages from the serious uncoordinated stage to the high quality coordinated stage (see Table 2).

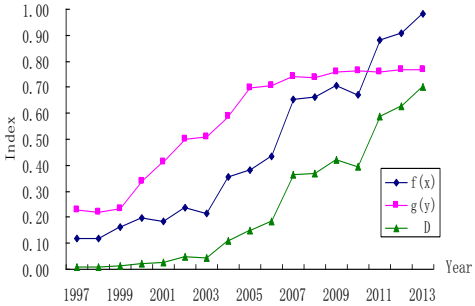

Fig.4. The coordinated development coefficient of economic system and water environmental system in Beijing (1997-2013).

Table 2. The classification standard of coordinated development coefficient.

Coordinated development coefficient（D）	**Standard**
0≤D≤0.1	Serious uncoordinated stage
0.1<D≤0.3	Uncoordinated stage
0.3<D≤0.5	Basic coordinated stage
0.5<D≤0.7	Good coordinated stage
0.7<D≤1	High quality coordinated stage

According to the classification criteria, the coordinated development coefficient of economic system and water environmental system in Beijing from 1997 to 2013 is divided into the following stages [8]:

(1)Serious uncoordinated stage (1997-2003)

In the past, the development of water conservancy in Beijing has been neglected due to the high attention paid to economic growth and urbanization by the state and the Beijing municipal government. Serious water pollution happened caused by the weak sewage treatment ability of Beijing. So the coordinated development coefficient of economic system and water environmental system in Beijing was so poor in a very long period of time, it was in the serious uncoordinated stage.

(2) Uncoordinated stage (2004-2006)

In 2004, with the success of China's accession to the WTO and the accelerated adjustment of the national economic structure, Beijing's economic development also ushered in a new opportunity to optimize the economic structure. It eliminated high water consumption and high pollution industries. At the same time Beijing increased investment in water pollution control, its water pollution treatment capacity also increased to a certain extent. However, due to the lack of investment in water resources, sewage discharge still increased. The coordinated development coefficient of economic system and water environmental system in Beijing was in the uncoordinated stage

(3) Basic coordinated stage (2007-2010)

After 2007, with the Beijing Olympic Games approaching, the environmental protection of Beijing was imminent. The investment in the field of water environmental protection increased significantly, and the adjustment of industrial structure was also further accelerated. Beijing has introduced a large number of advanced sewage treatment technology, the daily sewage treatment capacity and sewage treatment rate improved significantly. During this period, the coordinated

development coefficient of economic system and water environmental system in Beijing was in the basic coordinated stage.

(4) Good coordinated stage (2011-2012)

From 2011 to 2012, the construction of energy-saving economy in Beijing was increasingly perfect. During this period, Beijing's per capita GDP continued to increase, investment in water supply increased significantly, while the industrial water consumption and domestic water consumption remained basically unchanged. The degree of coordination between the Beijing economic system and the water environmental system was further improved, and it was in a good coordination stage.

(5) High quality coordinated stage (2013)

In 2013, the scientific concept of development has been subjected to more attention by all walks of life. Beijing's economic level of urbanization, per capita GDP and many other indicators reached the maximum in recent years. At the same time, Beijing's water pollution treatment capacity continued to improve, industrial water, domestic water demand was stable. The coordination degree between the Beijing economic system and the water environmental system reached the optimal state and was in the stage of high quality coordination.

4 Conclusions

(1) In the process of metropolitan development, the economic system and the water environmental system are interrelated and there exist a complex coupling mechanism.

The economic system and the water environment system are two basic systems which constitute the metropolitan system, and there exist a complex coupling mechanisms. Metropolitan economic system consists of two subsystems: population society subsystem and economic development subsystem. Metropolitan water environment system consists of water environment supply subsystem and water environment carrying subsystem. There is a "pressure-state-response (P-S-R)" relationship among the four subsystems. The operation of metropolitan economic system transports a large number of industrial and domestic wastewater to the water environment system, and also has brought greater pressure to it. At the same time, the metropolitan water environment system provides the necessary water resources for the further development of the economic system, and provides the water environment feedback to the metropolitan economic system [9].

(2) With the adjustment of economic structure and the progress of technology, the coupling index between the metropolitan economic system and the water environmental system has been increasing, and this process shows an upward trend

China's economic and social development presents a typical dual structure. Metropolis, as a priority area for economic and social development in China, enjoys all kinds of policy dividends and makes full use of all kinds of resources, so it develops rapidly. But it the early time, due to the Government's one-sided emphasis on economic construction, environment especially the water environment suffered serious pollution. The coordinated development coefficient of economic system and water environmental system in was in the uncoordinated stage. With the optimization and adjustment of China's economic structure, the whole society has increased investment in water pollution control. Metropolis enhanced the sewage treatment technology, and reduced water consumption. In this period, the coordination degree between the metropolitan economic system and the water environmental system is gradually increasing, and a rising trend appears.

Acknowledgments

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