Analysis of the Relevance Between Water Resources Utilization and Industrial Development in Beijing

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ABSTRACT
The authors analyze the evolution of Beijing's water resources utilization based on changes in Beijing's industrial water use, adjustment of water structure and changes in water efficiency. At the same time, combined with changes in Beijing's economic and industrial development, the authors use the method of industrial structure change coefficient to reveal the direction of Beijing's industrial structure change. On this basis, the grey correlation evaluation method is used to measure the correlation between water resources utilization and industrial structure in Beijing. And the Tapio elasticity coefficient method is used to determine the water elasticity coefficient for the three industries in Beijing. Studies have shown that during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period, Beijing's industrial and agricultural water consumption has fallen rapidly, and domestic water consumption has risen rapidly, changing from the largest proportion of agricultural water to the largest proportion of domestic water. The average value of the change coefficient of the primary and secondary industry structure in Beijing is always negative, and the average value of the change coefficient of the tertiary industry structure is always positive. The tertiary industry is showing a relatively stable expansion trend. Beijing's primary industry has the highest correlation with water resources utilization, followed by the secondary industry, and the tertiary industry is the lowest. The correlation between the three industries in Beijing and the utilization of water resources has shown a gradual decline. The water elasticity coefficients of the primary and secondary industries are generally negative, and the water elasticity coefficients of the tertiary industry are always positive.

Keywords: *Beijing, Water resources, Industrial structure, Relevance, Elasticity coefficient.*

1. INTRODUCTION

Water resources are a strategic resource for the sustainable development of Beijing's economy and society, providing an important guarantee for economic and industrial development, residents' lives, and environmental protection. At present, on the basis of analyzing the evolution of water resources characteristics such as the amount of water resources and water supply structure in Beijing [1], [2], [3], [4], [5], [6], [7], scholars have reasonably predicted the water demand of Beijing's economic and social development [8], [9], [10], carried out an analysis of the correlation between water resources utilization and economic development, and determined the temporal and spatial changes of Beijing's industrial water use and influencing factors[11], [12], [13], [14], [15]. Scholars have also focused on evaluating the decoupling relationship between water resource utilization efficiency, water resource utilization and economic development in Beijing [16], [17], [18], [19], [20], [21]. However, few scholars have

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adopted long-term sequences to analyze the correlation between water resources utilization and industrial development in Beijing during different planning periods. To this end, the industrial structure change coefficient method, the gray correlation evaluation method and the Tapio elastic coefficient method are used to study the correlation between Beijing's water resources and the industrial structure in different planning periods, and the water elasticity coefficient of Beijing's three industries.

2. THE EVOLUTION OF WATER RESOURCES UTILIZATION AND INDUSTRIAL STRUCTURE IN BEIJING

2.1 The Evolution of Water Resources Utilization

During the period from the "Eighth Five-Year Plan" to the "Thirteenth Five-Year Plan" period, the average value of Beijing's total water consumption showed a fluctuating downward trend, from 4.418 billion cubic meters to 3.983 billion cubic meters, as shown in "Table 1".

Table 1. Beijing water resources utilization changes during "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period

Planning period	Total water consumption	Agricultural water consumption	Industrial water consumption	Domestic water consumption
	Mean value/m^3	*Mean value/m^3*	*Mean value/m^3*	*Mean value/m^3*
The 8th Five-Year Plan	44.18	20.87	13.77	9.55
The 9th Five-Year Plan	40.76	18	10.96	11.8
The 10th Five-Year Plan	35.52	14.29	7.76	12.64
The 11th Five-Year Plan	34.98	11.47	5.48	15
The 12th Five-Year Plan	36.78	8.64	4.78	16.6
The 13th Five-Year Plan	39.83	4.75	3.48	18.30

a Note: The data is calculated by the author with reference to "China Statistical Yearbook 1990-2019" and "Beijing Water Resources Bulletin".

According to "Table 1", during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period, the mean value of agricultural water consumption declined rapidly, from 2.087 billion cubic meters to 475 million cubic meters, a decrease of more than 75%. The mean value of industrial water consumption dropped rapidly, from 1.377 billion cubic meters to 348 million cubic meters, a decrease of 75%. The mean value of domestic water consumption increased rapidly, from 955 million cubic meters to 1.830 billion cubic meters, an increase of nearly double. Among them, domestic water takes the first place in the water structure, followed by ecological water, and agricultural water takes the third place in the water structure. The adjustments of Beijing's water consumption structure and changes in water efficiency during "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period are shown in "Table 2".

Table 2. Beijing's water structure adjustment and water efficiency changes during "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period

Planning period	Percentage of water consumption structure/%			Changes in water consumption growth/100 million cubic meters			Water use efficiency change index	
	Agriculture	*Industry*	*Living*	*Agriculture*	*Industry*	*Living*	*Agriculture*	*Industry*
The 8th Five-Year Plan	47.34	31.11	21.54	-2.41	1.44	4.73	0.53	0.46
The 9th Five-Year Plan	44.15	26.90	28.95	-2.84	-3.26	1.62	0.79	0.48
The 10th Five-Year Plan	40.13	21.81	35.70	-3.82	-3.72	0.54	0.69	0.32
The 11th Five-Year Plan	32.80	15.69	42.87	-1.84	-1.74	1.37	0.61	0.46
The 12th Five-Year Plan	23.57	13.03	45.13	-4.43	-1.26	2.20	0.52	0.56
The 13th Five-Year Plan	11.98	8.74	45.97	-2.70	-0.50	1.20	0.71	0.76

According to "Table 2", during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period, first, from the perspective of industrial water use structure adjustment, the proportion of industrial and agricultural water structure continued to decline, and the proportion of domestic water structure continued to rise. By the "Thirteenth Five-Year Plan" period, the changes in the average proportions of agricultural, industrial, and domestic water consumption structures were -35.36%, -22.37%, and 24.43%, respectively, changing from the largest average proportion of agricultural water consumption (47.34%) to the largest average proportion of domestic water consumption (45.97%). Second, from the perspective of changes in industrial water consumption and water efficiency, both industrial and agricultural water consumption has a negative growth (only industrial water consumption during the "the Eighth Five-Year Plan" period), and the growth trend of domestic water consumption is an overall decline, from 473 million cubic meters to 120 million cubic meters. The industrial and agricultural water use efficiency change index is always less than 1, and the industrial and agricultural water use efficiency continues to improve, but the improvement space is gradually shrinking.

2.2 The Evolution Trend of Industrial Structure

The economic scale of Beijing has grown substantially, the economic growth rate has continued to decline, the service industry has developed rapidly, and the industrial structure has formed a "three-two-one" pattern, which has risen to the level of developed countries. During "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period, with the acceleration of Beijing's industrialization process, Beijing has accelerated the adjustment and transformation of its industrial structure. The proportion of the primary industry and the secondary industry's structure has steadily declined, and the proportion of the tertiary industry's structure has risen rapidly. Beijing's economic development has entered a post-industrial period, with the tertiary industry dominating. Among them, the average proportion of the primary industry and the secondary industry structure dropped from 6.28% and 46.57% to 0.38% and 17.36% respectively, and the average proportion of the tertiary industry structure rose from 47.16% to 82.25% (see "Figure 1").

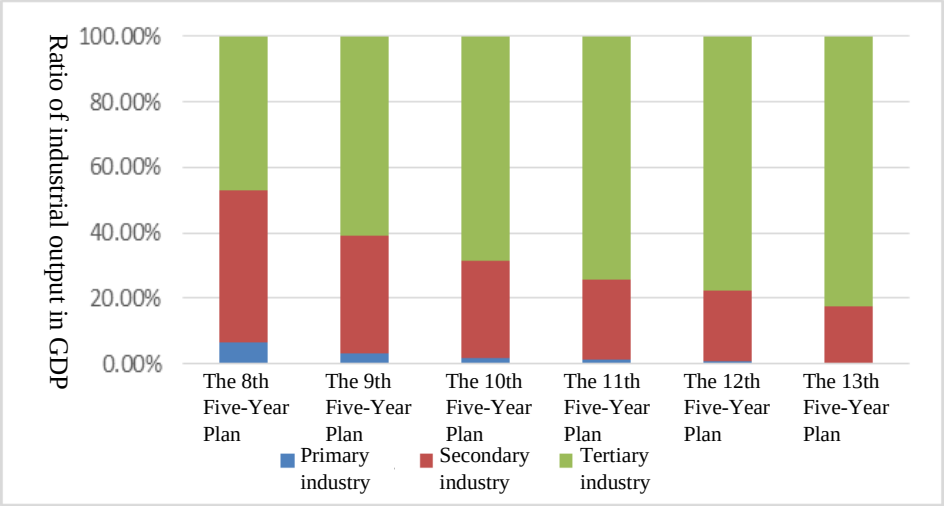

Figure 1 Trends of Beijing's industrial structure during "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period.

According to "Figure 1", the coefficient of change in Beijing's industrial structure during "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period can be further measured. The coefficient of industrial structure change is mainly to reveal the direction of industrial structure change through the comparison of the proportion of the current output value of the three industries and the proportion of the base period output value. From the perspective of the change coefficient of Beijing's industrial structure, first, during the period from "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan", the mean value of the change coefficient of Beijing's primary industry structure was always negative, and the primary industry showed a rapid contraction. Among them, during the period from "the Eighth Five-Year Plan" to "the Tenth Five-Year Plan", the absolute value of the mean value of the coefficient of variation of the primary industry reached more than 10%. During the period from "the Eleventh Five-Year Plan" to "the Twelfth Five-Year Plan", the absolute value of the mean value of the coefficient of variation of the primary industry was close to 7%. By "the thirteenth Five-Year Plan" period, the absolute value of the mean value of the coefficient of variation of the primary industry exceeded 13%. Second, during the period from "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period, the mean value of the coefficient of variation of Beijing's secondary industry structure was always negative, and the secondary industry showed a gradual contraction trend. The absolute value of the mean value of the coefficient of variation of the secondary industry fluctuatedly increased from 3.92% to 4.21%. Third, during the period from "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period, the mean value of the coefficient of variation of Beijing's tertiary industry structure was always positive, and the tertiary industry showed a relatively stable expansion trend. However, the mean value of the coefficient of variation of the tertiary industry structure continued to drop from 6.18% to 1.04% during "the Thirteenth Five-Year Plan" period (see "Figure 2").

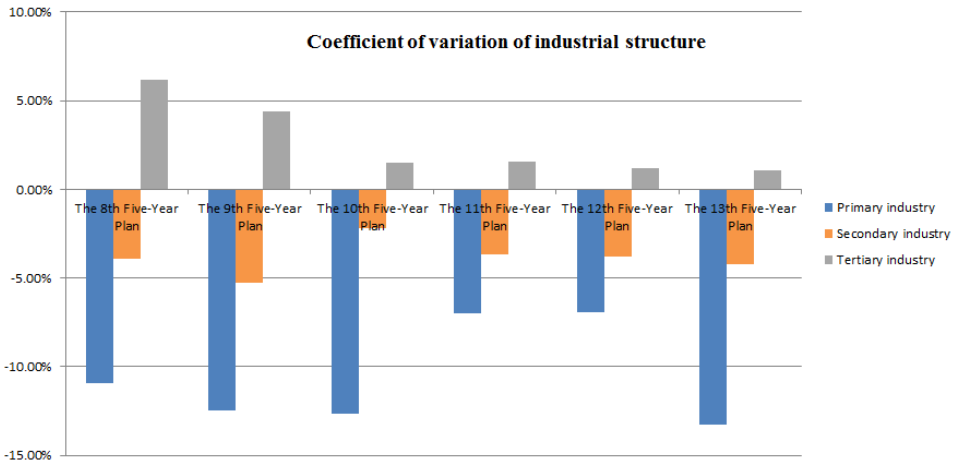

Figure 2 The coefficient of variation of Beijing's industrial structure during "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period.

3. CALCULATION OF CORRELATION BETWEEN WATER RESOURCES UTILIZATION AND INDUSTRIAL STRUCTURE IN BEIJING

According to the evolution of Beijing's water resources utilization and industrial structure in different periods, the grey relational evaluation method is used to measure the correlation between Beijing's water resources and industrial structure. Taking Beijing's water resource utilization in different periods as the parent variable and Beijing's industrial structure in different periods as the sub-variables, the water resources utilization variables and industrial structure variables of Beijing are processed in a dimensionless manner to determine Beijing's water resource utilization and industrial structure. The degree of relevance between can be expressed as

$$\begin{cases} C_k = \dfrac{1}{T}\sum_{t=1}^{T} N_k(t) \\ N_k(t) = \dfrac{\left[\min\limits_k \min\limits_t \left|Y'(t) - X_k'(t)\right| + \rho \max\limits_k \max\limits_t \left|Y'(t) - X_k'(t)\right|\right]}{\left|Y'(t) - X_k'(t)\right| + \rho \max\limits_k \max\limits_t \left|Y'(t) - X_k'(t)\right|} \\ Y'(t) = \dfrac{Y(t)}{Y(t_0)} \\ X_k'(t) = \dfrac{X_k(t)}{X_k(t_0)} \\ Y(t) = \{Y(1), Y(2), \cdots, Y(n)\} \\ X_k(t) = \{X_k(1), X_k(2), \cdots, X_k(n)\} \end{cases} \tag{1}$$

In formula (1), the C_k is the correlation between Beijing's k industry and the utilization of water resources ($k = 1, 2, 3$ represents the primary industry, the secondary industry, and the tertiary industry respectively). The $N_k(t)$ is the gray correlation coefficient of the water resources utilization and the k industry during the period of t. $Y'(t)$ and $X_k'(t)$ are the dimensionless values of $Y(t)$ and $X_k(t)$ respectively. $Y(t)$ and $Y(t_0)$ are respectively the water resources utilization in the period of t and the base period t_0 period. $X_k(t)$ and $X_k(t_0)$ are the economic added value of k industry in the t period and the

base period t_0 period. ρ is called the resolution coefficient, and the general value interval is $[0,1]$. The smaller the ρ, the greater the resolution, and $\rho = 0.5$ is usually used. The $\min_k \min_t \left|Y'(t) - X_k'(t)\right|$ represents the minimum difference between the two levels, where $\min_t \left|Y'(t) - X_k'(t)\right|$ is the minimum difference of the first level, and $\min_k \left(\min_t \left|Y'(t) - X_k'(t)\right|\right)$ is the minimum difference of the second level; $\max_k \max_t \left|Y'(t) - X_k'(t)\right|$ represents the maximum difference between the two levels, where $\max_t \left|Y'(t) - X_k'(t)\right|$ is the maximum difference of the first level, and $\max_k \left(\max_t \left|Y'(t) - X_k'(t)\right|\right)$ is the maximum difference of the second level.

According to formula (1), the correlation between water resource utilization and industrial structure in Beijing is calculated, as shown in "Table 3".

Table 3. Correlation degree between Beijing's water resources utilization and industrial structure during the period from "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan"

Planning period	Correlation degree between primary industry and water resources	Correlation degree between secondary industry and water resources	Correlation degree between tertiary industry and water resources	Correlation degree between agriculture and water resources	Correlation degree between industry and water resources
The 8th Five-Year Plan	0.997	0.991	0.982	0.975	0.941
The 9th Five-Year Plan	0.989	0.969	0.914	0.923	0.812
The 10th Five-Year Plan	0.985	0.933	0.803	0.897	0.655
The 11th Five-Year Plan	0.977	0.881	0.632	0.851	0.503
The 12th Five-Year Plan	0.966	0.822	0.478	0.786	0.384
The 13th Five-Year Plan	0.975	0.783	0.358	0.834	0.339
1990-2019	0.982	0.904	0.716	0.883	0.628

a Note: The data is calculated by the authors with reference to "China Statistical Yearbook 1990-2019".

According to "Table 3", during "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period, firstly, from the perspective of the correlation between the three industries in Beijing and the utilization of water resources, the primary industry has the highest correlation with the utilization of water resources, followed by the secondary industry, and the tertiary industry is the lowest. The correlation between the three industries and the utilization of water resources has shown a gradual decline. The mean value of the correlation between primary industry, secondary industry, tertiary industry and water resource utilization decreased from 0.997, 0.991, 0.982 to 0.975, 0.783, and 0.358, respectively. The primary industry is strongly dependent on the use of water resources. Secondly, from the perspective of the correlation between industry and agriculture and water resource utilization in Beijing, the correlation between agriculture and water resource utilization is declining in a fluctuating manner, and industry and water resource utilization are declining rapidly. The mean value of the correlation between agriculture, industry and water resource utilization decreased from 0.975 and 0.941 to 0.834 and 0.339, respectively. Agriculture has a strong dependence on the use of water resources. On the whole, from 1990 to 2019, the mean value of the correlation between the primary industry, the secondary industry, and the tertiary industry and the utilization of water resources was 0.982, 0.904, and 0.716, respectively. The mean values of the correlation between agriculture, industry and water resource utilization are 0.883 and 0.628 respectively.

4. MEASUREMENT AND CALCULATION OF BEIJING'S INDUSTRIAL WATER ELASTICITY COEFFICIENT

Combining the evolution of water resources utilization and industrial structure in Beijing, the Tapio elasticity coefficient method is used to

measure the water elasticity coefficient of the three industries in Beijing, which can be expressed as

$$\begin{cases} T^{t_1} = \dfrac{\Delta W^{t_1} / W^{t_0}}{\Delta G^{t_1} / G^{t_0}} \\ T_j^{t_1} = \dfrac{\Delta W_j^{t_1} / W_j^{t_0}}{\Delta G_j^{t_1} / G_j^{t_0}} \end{cases} \quad (2)$$

In formula (2), T^{t_1} represents the water elasticity coefficient of Beijing in the period of t_1. Among them, ΔW^{t_1} represents the increase in total water consumption in Beijing during the period of t_1 relative to the period of t_0; W^{t_0} represents the total water consumption of Beijing during the period of t_0; ΔG^{t_1} represents the change in the economic output value of Beijing in the period of t_1 relative to the period of t_0; G^{t_0} represents the total economic output value of i region of the Beijing-Tianjin-Hebei area during t_0. $T_j^{t_1}$ represents the elastic coefficient of decoupling of j industrial water consumption during the t_1 period ($j = 1, 2, 3$ represents the primary industry, the secondary industry, and the tertiary industry). Among them, $\Delta W_j^{t_1}$ represents the increase in water consumption of j industry during t_1 period compared to t_0 period; $W_j^{t_0}$ represents the water consumption of j industry during t_0 period; $\Delta G_j^{t_1}$ represents the change in the economic added value of j industry during t_1 period relative to t_0 period; $G_j^{t_0}$ respectively represents the economic added value of j industry during t_0 period.

According to formula (2), the water elasticity coefficient of the three industries in Beijing during "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period is calculated, as shown in "Table 4".

Table 4. Beijing's three industries water elastic coefficient during the period from "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan"

Planning period	Total elastic coefficient of water consumption	Elastic coefficient of water consumption of primary industry	Elastic coefficient of water consumption of secondary industry	Elasticity coefficient of water consumption of tertiary industry
The 8th Five-Year Plan	0.045	-0.164	0.080	0.274
The 9th Five-Year Plan	-0.091	-1.878	-0.394	0.120
The 10th Five-Year Plan	-0.121	-1.947	-0.368	0.056
The 11th Five-Year Plan	0.020	-0.361	-0.381	0.169
The 12th Five-Year Plan	0.135	-3.209	-0.731	0.233
The 13th Five-Year Plan	0.171	2.230	-0.510	0.105

a Note: The data is calculated by the author with reference to the "China Statistical Yearbook 1990-2019". The water elasticity coefficient is the ratio of the increase in water consumption to the increase in the corresponding industrial output value.

According to "Table 4", during the period from "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan", the total water consumption in Beijing fluctuated and declined slightly. However, the total elastic coefficient of water consumption is generally positive. Among them, during the period from "the Eighth Five-Year Plan" to "the Twelfth Five-Year Plan", the primary industry's water consumption elasticity coefficient was negative. By "the Thirteenth Five-Year Plan" period, although the water consumption of the primary industry continues to decline, the added value of the primary industry has declined, causing the elasticity of the primary industry to turn positive. During "the Ninth Five-Year Plan" period to "the Thirteenth Five-Year Plan" period, the secondary industry's water consumption was effectively controlled, and the secondary industry's water elasticity coefficient was always negative. During "the Eighth Five-Year Plan" period to "the Thirteenth Five-Year Plan" period, the water consumption of the tertiary industry continued to grow, the water elasticity coefficient of the tertiary industry was always positive, and the growth rate of the water consumption of the tertiary industry slowed down.

5. CONCLUSION

During "the Eighth Five-Year Plan" to "the Thirteenth Five-Year Plan" period, Beijing's total

water consumption showed a fluctuating downward trend. Industrial and agricultural water consumption was rapidly declining, and domestic water consumption was rising sharply, changing from the largest proportion of agricultural water to the largest proportion of domestic water. However, the growth and change trend of domestic water consumption is an overall decline, and the efficiency of industrial, agricultural and domestic water use in Beijing has continued to improve. The primary industry has the highest correlation with water resources utilization, followed by the secondary industry, and the tertiary industry is the lowest. The correlation between the three industries and the utilization of water resources has shown a gradual decline. The correlation between agriculture and water resource utilization is declining in a fluctuating manner, and industry and water resource utilization are declining rapidly. The water elasticity coefficients of the primary and secondary industries are generally negative, and the water elasticity coefficients of the tertiary industry are always positive. The direction of Beijing's water resources optimization is to appropriately reduce the use of water resources in the primary and secondary industries and increase the use of water in the tertiary industry under the premise of ensuring the safety of food production. That is, through industrial and agricultural water-saving technologies and other measures, it is important to give priority to controlling the water consumption of the primary industry, strictly controlling the water consumption of the secondary industry, and rationally increasing the water consumption of the tertiary industry, so as to effectively improve the comprehensive output of water resources under the rigid constraints of Beijing's water resources.

AUTHORS' CONTRIBUTIONS

Dan Wu is responsible for experimental design and writing the manuscript, Renxing Yang, Yue Li, Yanlai Jin are responsible for analyzing data and writing the manuscript.

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