

# Research on the Spatio-temporal Coupling Relationship Between Water Resources Utilization and Industrial Development in Beijing-Tianjin-Hebei Region

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## ABSTRACT

Clarifying the temporal and spatial coupling relationship between the utilization of water resources in the Beijing-Tianjin-Hebei region and industrial development plays an important supporting role in optimizing the allocation of water resources in the Beijing-Tianjin-Hebei region and improving the coordination between water resource utilization and economic development in the Beijing-Tianjin-Hebei region. At present, few literatures have adopted long-term series to study the spatio-temporal coupling relationship between water resources utilization and industrial development in the Beijing-Tianjin-Hebei region. To this end, firstly, the grey relational evaluation method is used to evaluate the correlation degree of water use for industrial development in the Beijing-Tianjin-Hebei region in different planning periods; secondly, the Tapio elastic coefficient method is used to evaluate the water elasticity coefficient for industrial development in the Beijing-Tianjin-Hebei region in different planning periods; then, using the driving effect decomposition method, the driving effect of industrial development water in the Beijing-Tianjin-Hebei region is decomposed into structural adjustment effect and technological progress effect. During the period from the Eighth Five-Year Plan to the Thirteenth Five-Year Plan period, the correlation between the primary industry and the utilization of water resources in the Beijing-Tianjin-Hebei region is at a relatively high level, and the correlation between the secondary and tertiary industries and the utilization of water resources has fluctuated downward; the water elasticity coefficients of the primary and secondary industries in Beijing-Tianjin-Hebei are generally negative, and the water elastic coefficients of the tertiary industry are generally positive; the effects of technological advancement of water use for the primary and secondary industries in the Beijing-Tianjin-Hebei region are relatively significant, and the effects of structural adjustment are gradually becoming prominent. The absolute value of the effects of technological advancement of water for the tertiary industry is always lower than the effect of structural adjustment.

**Keywords:** *Water resources, Industrial development, Correlation degree, Elasticity coefficient, Driving effect.*

## 1. INTRODUCTION

Water resources are a strategic resource for the sustainable economic and social development of the Beijing-Tianjin-Hebei region and provide an important guarantee for economic and industrial development, residents' lives, and environmental protection. The "14th Five-Year Plan" of the Beijing-Tianjin-Hebei region clearly proposes to strengthen the strategic reserve of water resources,

strengthen water pollution control and water resources protection, and improve the level of intensive and safe use of water resources. It points out the direction for accelerating the transformation and upgrading of the economic and industrial structure of the Beijing-Tianjin-Hebei region, strengthening the control of water resource utilization in the Beijing-Tianjin-Hebei region, and effectively improving the coordination of water resource utilization and economic development in

the Beijing-Tianjin-Hebei region. To this end, research on the spatio-temporal coupling relationship between water resource utilization and economic development in the Beijing-Tianjin-Hebei region is conducive to providing decision-making support for optimizing the allocation of water resources in the Beijing-Tianjin-Hebei region and improving the coordination of water resources utilization and economic development in the Beijing-Tianjin-Hebei region.

**2. LITERATURE REVIEW**

At present, scholars have carried out an analysis of the correlation between water resources utilization and economic development in the Beijing-Tianjin-Hebei region, and determined the law of temporal and spatial change laws and influencing factors of industrial water use in the Beijing-Tianjin-Hebei region [1-5]. At the same time, on the basis of constructing a coordinated evaluation index system[6-8] for water resources utilization and economic development, scholars used VAR model [9], regional Gini coefficient[10], coupling coordination degree model[11-12], decoupling evaluation model[13-20] and other models to evaluate the coordination degree of water resources utilization and economic development in the Beijing-Tianjin-Hebei region. And they paid much attention to the evaluation of the decoupling relationship between water resources utilization and economic development in the Beijing-Tianjin-Hebei region [13-20]. However at present, few literatures have adopted long-term series to study the spatio-temporal coupling relationship between water resources utilization and industrial development in the Beijing-Tianjin-Hebei region. To this end, firstly, the gray correlation evaluation

method is used to evaluate the correlation degree of industrial development water use in the Beijing-Tianjin-Hebei region in different planning periods; secondly, the Tapio elastic coefficient method is used to evaluate the water elasticity coefficient for industrial development in the Beijing-Tianjin-Hebei region in different planning periods; then, the driving effect decomposition method is used to decompose the driving effect of industrial development water in the Beijing-Tianjin-Hebei region into structural adjustment effects and technological progress effects; finally, the coordination degree evaluation model is used to evaluate the coordination degree of the industrial development water structure and industrial structure in the Beijing-Tianjin-Hebei region in different planning periods.

**3. RESEARCH METHODS**

**3.1 Relevant Analysis Method of Industrial Development Water Use**

According to the evolution of industrial development and water resources utilization in the Beijing-Tianjin-Hebei region in different periods, the water consumption of the Beijing-Tianjin-Hebei region is used as the parent variable, and the industrial production value of the Beijing-Tianjin-Hebei region is used as the sub-variable, to carry out dimensionless treatment of the gross industrial production value and water consumption of the Beijing-Tianjin-Hebei region. Using the grey correlation evaluation method to calculate the correlation degree of industrial development water use in the Beijing-Tianjin-Hebei region, it can be expressed as

$$\begin{cases}
 C_{ij} = \frac{1}{T} \sum_{t=1}^T N_{ij}(t) \\
 N_{ij}(t) = \frac{\left[ \min_j \min_t |Y'_i(t) - X'_{ij}(t)| + \rho \max_j \max_t |Y'_i(t) - X'_{ij}(t)| \right]}{|Y'_i(t) - X'_{ij}(t)| + \rho \max_j \max_t |Y'_i(t) - X'_{ij}(t)|} \\
 Y'_i(t) = \frac{Y_i(t)}{Y_i(t_0)} \\
 X'_{ij}(t) = \frac{X_{ij}(t)}{X_{ij}(t_0)} \\
 Y_i(t) = \{Y_i(1), Y_i(2), \dots, Y_i(n)\} \\
 X_{ij}(t) = \{X_{ij}(1), X_{ij}(2), \dots, X_{ij}(n)\}
 \end{cases} \tag{1}$$

In formula (1),  $C_{ij}$  is the degree of relevance of  $j$  industrial water use in the  $i$  area ( $i = 1, 2, 3$  represents Beijing, Tianjin, and Hebei respectively;  $j = 1, 2, 3$  represents the primary industry, the secondary industry and the tertiary industry respectively).  $N_{ij}(t)$  is the gray correlation coefficient of the water resource utilization in the  $i$  area and the  $j$  industry in the  $i$  area during the  $t$  period.  $Y_i'(t)$  and  $Y_i(t)$  are the dimensionless values of  $Y_i(t)$  and  $X_{ij}(t)$  respectively.  $Y_i(t)$  and  $Y_i(t_0)$  are respectively the water consumption of the  $i$  area in the  $t$  period and the base period  $t_0$  period.  $X_{ij}(t)$  and  $X_{ij}(t_0)$  are respectively the gross production value of the  $j$  industry in the  $t$  period and the base period of  $t_0$  period in the  $i$  area.  $\rho$  is called the resolution coefficient, and the general value interval is  $[0, 1]$ . The smaller  $\rho$ , the greater the resolution, and  $\rho = 0.5$  is usually used.

$\min_j \min_t |Y_i'(t) - X_{ij}'(t)|$  represents the minimum difference between the two levels, where  $\min_t |Y_i'(t) - X_{ij}'(t)|$  and  $\min_j (\min_t |Y_i'(t) - X_{ij}'(t)|)$  are the minimum difference of the first level and the second level respectively;  $\max_j \max_t |Y_i'(t) - X_{ij}'(t)|$  represents the maximum difference between the two levels, and  $\max_t |Y_i'(t) - X_{ij}'(t)|$  and  $\max_j (\max_t |Y_i'(t) - X_{ij}'(t)|)$  are the maximum difference of the first level and the second level respectively.

### 3.2 Analysis Method of Water Elasticity for Industrial Development

According to the evolution of industrial development and water resources utilization in the Beijing-Tianjin-Hebei region in different periods, the Tapio elastic coefficient method is used to determine the water elasticity coefficient for industrial development in the Beijing-Tianjin-Hebei region, which can be expressed as

$$T_{ij}^h = \frac{\Delta W_{ij}^h / W_{ij}^{t_0}}{\Delta G_{ij}^h / G_{ij}^{t_0}} \quad (2)$$

In formula (2),  $T_{ij}^h$  represents the water elasticity coefficient of the  $j$  industry development in the  $i$  area of Beijing-Tianjin-Hebei during the  $t_1$  period. Among them,  $\Delta W_{ij}^h$  represents the increase in water consumption of the  $j$  industry in  $i$  area during the  $t_1$  period relative to the  $t_0$  period;  $W_{ij}^{t_0}$  represents the water consumption of the  $j$  industry in the  $i$  area during the  $t_0$  period;  $\Delta G_{ij}^h$  represents the change in the gross product value of the  $j$  industry in the  $i$  area in the  $t_1$  period compared to the  $t_0$  period;  $G_{ij}^{t_0}$  respectively represent the gross production value of the  $j$  industry in the  $i$  area during the  $t_0$  period.

According to the "China Statistical Yearbook", only the four major categories of water consumption and total water consumption in the Beijing-Tianjin-Hebei region are calculated for agriculture, industry, life, and ecology. Among them, domestic water consumption includes domestic water consumption, tertiary industry and construction industry water consumption. Regarding the "Water Bulletin" of the Beijing-Tianjin-Hebei region over the years, Beijing and Hebei did not separately list the water consumption of the primary, secondary and tertiary industries. Among them, the primary industry only counts agricultural water consumption data, the industrial water consumption does not include the construction industry water consumption data in the secondary industry, and the tertiary industry water consumption data is included in the domestic water consumption data. It is because that only the "Tianjin Water Resources Bulletin" from 2003 to 2017 made statistics on the water consumption of the three industries. Therefore, the researchers need to estimate the conversion coefficients of the primary industry and agricultural water consumption, the secondary industry and industrial water consumption, and the household and domestic water consumption based on the data of Tianjin's tertiary industry water consumption and residential water consumption, and to respectively derive and estimate the industrial water consumption and domestic water consumption of Beijing and Hebei, which can be expressed as

$$\begin{cases} FI_i(t) = FI_{12}(t) \cdot k_{1i} = FI_{12}(t) \cdot \frac{1}{T} \sum_{t=1}^T \frac{FI_{12}(t)}{A_{12}(t)} \cdot \frac{A_{1i}(t)}{A_{12}(t)} \\ SI_i(t) = SI_{22}(t) \cdot k_{2i} = SI_{22}(t) \cdot \frac{1}{T} \sum_{t=1}^T \frac{SI_{22}(t)}{I_{22}(t)} \cdot \frac{I_{2i}(t)}{I_{22}(t)} \\ PL_i(t) = L_i(t) \cdot k_i = L_i(t) \cdot \frac{1}{T} \sum_{t=1}^T \frac{PL_i(t)}{L_i(t)} \\ TI_i(t) = W_i(t) - FI_i(t) - SI_i(t) - PL_i(t) - EI_i(t) \end{cases}$$

In formula (3),  $FI_i(t)$ ,  $SI_i(t)$ ,  $PL_i(t)$ , and  $TI_i(t)$  are estimated value of the water consumption of the primary industry, the secondary industry, the domestic water consumption, and the tertiary industry, respectively, in the period o region;  $k_{1i}$ ,  $k_{2i}$ , and  $k_i$  ( $i=1,2,3$  are Beijing, Tianjin, Hebei respectively) are the conversion coefficients for the water consumption of the primary industry, the water consumption of the secondary industry, and the domestic water consumption in the region of  $i$ ;  $\frac{FI_{12}(t)}{A_{12}(t)}$  is the ratio of the water consumption of

Tianjin's primary industry to the water consumption of Tianjin's agriculture in the period of  $t$ ;  $\frac{A_{1i}(t)}{A_{12}(t)}$  is

the ratio of the agricultural water consumption in the area of  $i$  in the period of  $t$  to the agricultural water consumption in Tianjin;  $\frac{SI_{22}(t)}{I_{22}(t)}$  is the ratio

of the water consumption of Tianjin's secondary industry to the industrial water consumption of

$$\Delta W_{ij}^{t_1} = W_{ij}^{t_1} - W_{ij}^{t_0} = G_i^{t_1} \cdot \frac{G_{ij}^{t_1}}{G_i^{t_1}} \cdot WG_{ij}^{t_1} - G_i^{t_0} \cdot \frac{G_{ij}^{t_0}}{G_i^{t_0}} \cdot WG_{ij}^{t_0}$$

(4)

In formula (4),  $\Delta W_{ij}^{t_1}$  represents the increase in water consumption of the  $j$  industry in the  $i$  area during the  $t_1$  period relative to the  $t_0$  period;  $W_{ij}^{t_1}$  and  $W_{ij}^{t_0}$  respectively represent the water consumption of the  $j$  industry in  $i$  area in the  $t_1$  period and the  $t_0$  period;  $G_i^{t_1}$  and  $G_i^{t_0}$  respectively represent the total economic output value of the  $i$  area in the  $t_1$  period and the  $t_0$  period;  $G_{ij}^{t_1}$  and  $G_{ij}^{t_0}$  respectively represent the economic added value of the  $j$  industry in the  $i$  area in the  $t_1$  period and the  $t_0$  period;  $\frac{G_{ij}^{t_1}}{G_i^{t_1}}$  and  $\frac{G_{ij}^{t_0}}{G_i^{t_0}}$  respectively indicate the

(3)

Tianjin during the period of  $t$ ;  $\frac{I_{2it}}{I_{22t}}$  is the ratio of

the industrial water consumption in the area of  $i$  in the period of  $t$  to the industrial water consumption in Tianjin;  $\frac{PL_i(t)}{L_i(t)}$  is the ratio of the residential

water consumption to the domestic water consumption in the area of  $i$  during the period of  $t$ ;  $W_i(t)$  is the total water consumption of the area in the period of  $t$ ;  $EI_i(t)$  is the ecological water consumption in the area of  $i$  in the period of  $t$ .

### 3.3 Analysis Method of Driving Effect of Industrial Development Water

According to the evolution of industrial development and water resources utilization in the Beijing-Tianjin-Hebei region in different periods, the industrial decomposition of the growth and changes in water consumption for industrial development in the Beijing-Tianjin-Hebei region can be expressed as

proportion of the gross output value of the  $j$  industry in the total economic output value (that is, the proportion of the industrial structure) in the  $i$  area in the  $t_1$  period and the  $t_0$  period;  $WG_{ij}^{t_1}$  and  $WG_{ij}^{t_0}$  respectively represent the 10,000 yuan value-added water consumption of the  $j$  industry in the  $i$  area in the  $t_1$  period and the  $t_0$  period.

According to formula (4), it can be seen that the changes in water consumption for industrial development in the Beijing-Tianjin-Hebei region are mainly affected by changes in industrial GDP, industrial structure and water efficiency. That is, the driving effect of water for industrial development in the Beijing-Tianjin-Hebei region

can be decomposed into structural adjustment effect and technological progress effect. To this end, the structural adjustment and technological progress effect of the water use for the development of the  $j$

$$\Delta W_{ij}^{t_1} = \Delta W_{ijs}^{t_1} + \Delta W_{ije}^{t_1}$$

$$\left\{ \begin{aligned} \Delta W_{ijs}^{t_1} &= WG_{ij}^{t_0} \left( G_i^{t_1} \cdot \frac{G_{ij}^{t_1}}{G_i^{t_1}} - G_i^{t_0} \cdot \frac{G_{ij}^{t_0}}{G_i^{t_0}} \right) + \frac{1}{2} (WG_{ij}^{t_1} - WG_{ij}^{t_0}) \left( G_i^{t_1} \cdot \frac{G_{ij}^{t_1}}{G_i^{t_1}} - G_i^{t_0} \cdot \frac{G_{ij}^{t_0}}{G_i^{t_0}} \right) \\ \Delta W_{ije}^{t_1} &= G_i^{t_0} \cdot \frac{G_{ij}^{t_0}}{G_i^{t_0}} (WG_{ij}^{t_1} - WG_{ij}^{t_0}) + \frac{1}{2} (WG_{ij}^{t_1} - WG_{ij}^{t_0}) \left( G_i^{t_1} \cdot \frac{G_{ij}^{t_1}}{G_i^{t_1}} - G_i^{t_0} \cdot \frac{G_{ij}^{t_0}}{G_i^{t_0}} \right) \end{aligned} \right. \quad (5)$$

In formula (5),  $\Delta W_{ijs}^{t_1}$  expresses the structural adjustment effect of the change in water consumption for industrial development in the  $i$  area in the  $t_1$  period compared with the  $t_0$  period, that is, the change in water consumption caused by the adjustment of the industrial structure;  $\Delta W_{ije}^{t_0}$  represents the technological progress effect of the change in industrial water consumption of the  $i$  area in the  $t_1$  period compared to the  $t_0$  period, that is, the change in water consumption caused by the change in water efficiency caused by industrial technological progress.

#### 4. EMPIRICAL RESEARCH

During the "8th Five-Year Plan" period to the "13th Five-Year Plan" period, with the acceleration of China's urbanization and industrialization process, the Beijing-Tianjin-Hebei region has accelerated the adjustment and transformation of industrial structure, the proportion of the primary and secondary industry structure has steadily declined, and the proportion of the tertiary industry 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%, 46.57% to 0.41%, 17.74%, and the average proportion of the tertiary industry structure rose from 47.16% to 81.85%. The economic development of Tianjin has moved from the late industrialization period to the post-industrialization period. The tertiary industry has gradually become the leading industry, but the secondary industry structure still accounts for a relatively high proportion. Among them, the average proportion of the primary and secondary industrial structure

industry in  $i$  area of the Beijing-Tianjin-Hebei region, which can be expressed as

dropped from 7.07% and 56.73% to 1.19% and 38.67%, respectively, and the average proportion of the tertiary industry structure continued to rise from 36.20% to 60.14%. Hebei's economic development has moved from the period of industrialization to the latter period of industrialization, with the secondary industry as the mainstay, and the secondary and tertiary industries have developed simultaneously. Among them, the average proportion of the primary industry structure continued to drop from 20.57% to 10.10%, and the average proportion of the secondary industry structure first continued to rise from 46.49% in the "8th Five-Year Plan" period to 53.01% in the "11th Five-Year Plan" period, and then declined to 43.15% of the 13th Five-Year Plan. The average proportion of the tertiary industry structure rose from 32.94% to 46.75%. By the "13th Five-Year Plan" period, the average proportion of the tertiary industry structure has exceeded that of the secondary industry. The leading industries in the Beijing-Tianjin-Hebei region have undergone an evolution from "primary industry → second industry → tertiary industry". The water resources of Beijing-Tianjin-Hebei region will also be re-allocated among different industries with the adjustment of industrial structure to realize the optimal allocation and utilization of water resources among the development needs of different industries.

##### 4.1 Water Relevance for Industrial Development in the Beijing-Tianjin-Hebei Region

According to formula (1), the correlation degree of water use for industrial development in the Beijing-Tianjin-Hebei region during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period can be calculated, as shown in "Figure 1".

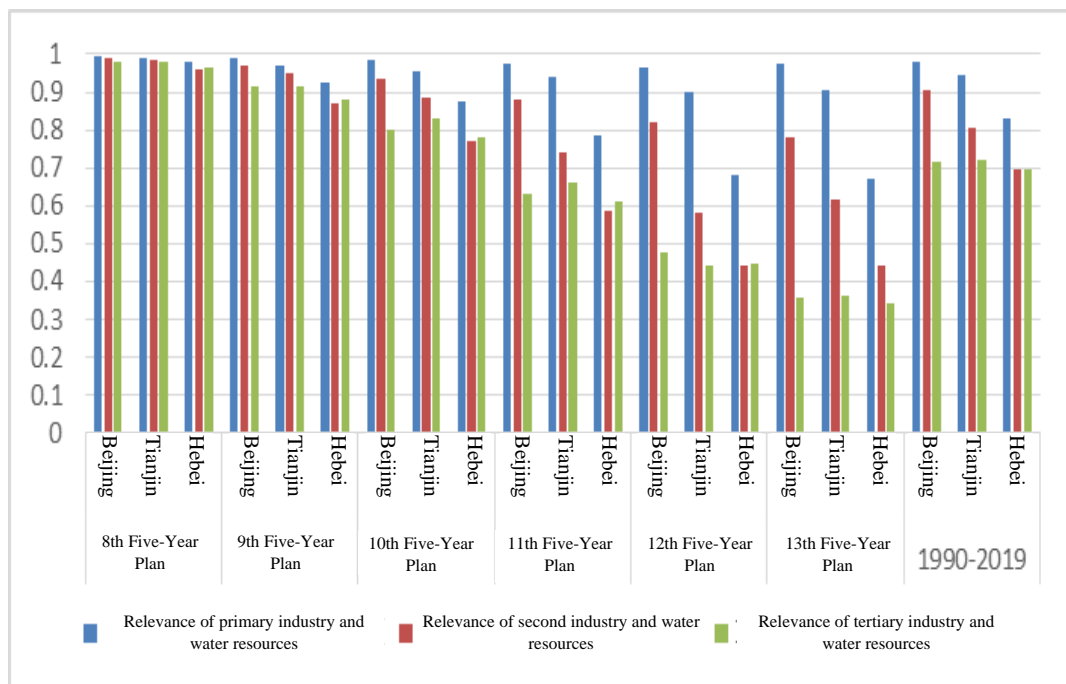


Figure 1 Correlation degree of water use for industrial development in the Beijing-Tianjin-Hebei region during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period.

a Note: The indicator data is calculated by the author with reference to the "China Statistical Yearbook 1990-2019". The "13th Five-Year Plan" period only includes 2016-2019 (the same below).

According to "Figure 1", from 1990 to 2019, Beijing and Tianjin's primary industry had the highest correlation with water resources utilization, followed by the secondary industry, and the tertiary industry was the lowest. The mean value of correlation between Beijing's primary industry, secondary industry, tertiary industry and water resource utilization is 0.982, 0.904, and 0.716, respectively. The mean value of correlation between Tianjin's primary industry, secondary industry, tertiary industry and water resource utilization is 0.947, 0.805, and 0.720, respectively. From the "Eighth Five-Year" period to the "Thirteenth Five-Year" period, the change trend of the correlation between the three industries in Beijing and Tianjin and the utilization of water resources is the same as that of Beijing-Tianjin-Hebei as a whole, showing a declining trend. The average value of correlation between Beijing's primary, secondary, tertiary industry and water resource utilization decreased from 0.997, 0.991, 0.982 to 0.975, 0.783, and 0.358, respectively. The average value of the correlation between Tianjin's primary industry, secondary industry, tertiary industry and water resource utilization decreased from 0.992, 0.985, and 0.980 to 0.904, 0.616, and 0.303, respectively. The correlation between the three industries in Beijing and the utilization of

water resources is higher than that in Tianjin. The primary industries in Beijing and Tianjin are strongly dependent on the use of water resources. The dependence of the three industries in Beijing and Tianjin on the use of water resources has gradually weakened.

From 1990 to 2019, Hebei's primary industry had the highest correlation with water resources utilization, followed by the tertiary industry, and the secondary industry was the lowest. The mean value of the correlation between Hebei's primary industry, secondary industry, tertiary industry and water resources utilization is 0.830, 0.697, and 0.694, respectively. During the "Eighth Five-Year" period to the "Thirteenth Five-Year" period, the correlation between Hebei's three industries and water resources utilization also showed a decreasing trend. The average value of the correlation between Hebei's primary industry, secondary industry, tertiary industry and water resources utilization decreased from 0.978, 0.960, 0.963 to 0.672, 0.441, and 0.344, respectively. The correlation between Hebei's three industries and water resources utilization is lower than that of Beijing and Tianjin. The degree of correlation between Hebei's primary industry and water resources utilization is significantly lower than that

of Beijing and Tianjin. This is closely related to the internal structure of Hebei's agriculture, which is dominated by drought-tolerant crops such as wheat, corn and potatoes. In addition, unlike Beijing and Tianjin, during the "Eighth Five-Year Plan" period to the "Thirteenth Five-Year Plan" period, Hebei's tertiary industry has a higher correlation with water resources utilization than the secondary industry. During the "13th Five-Year Plan" period, the correlation between Hebei's tertiary industry and water resources utilization was lower than that of the secondary industry.

#### 4.2 Water Elasticity Coefficient for Industrial Development in the Beijing-Tianjin-Hebei Region

According to formula (3), the water consumption for industrial development in the Beijing-Tianjin-Hebei region during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period can be determined, as shown in "Figure 2".

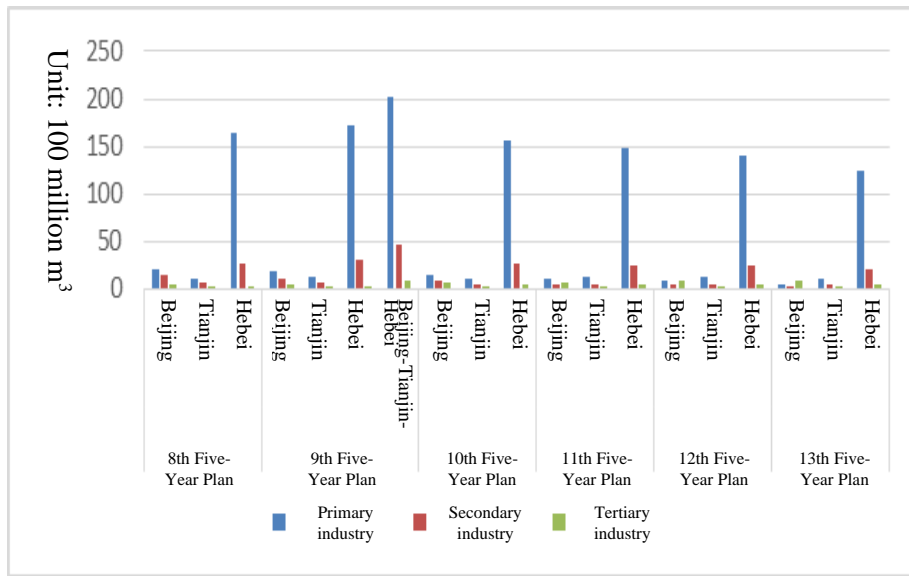


Figure 2 Water consumption for industrial development in the Beijing-Tianjin-Hebei region during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period.

According to formula (2) and the data in "Figure 2", the water elasticity coefficient for industrial development in the Beijing-Tianjin-Hebei region during the "Eighth Five-Year Plan"- "Thirteenth Five-Year Plan" period is determined, as shown in "Table 1".

According to "Table 1", during the "Eighth Five-Year Plan" to "Twelfth Five-Year Plan" period, the water elasticity coefficient of Beijing's primary industry was negative. The value added has declined, causing the water elasticity coefficient of the primary industry to become positive. During the "Ninth Five-Year Plan" period to the "Thirteenth Five-Year Plan" period, Beijing's secondary industry 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, Beijing's tertiary industry water consumption continued to

grow, and the water elasticity coefficient of the tertiary industry was always positive.

According to "Table 1", during the "Eighth Five-Year Plan" to "Twelfth Five-Year Plan" period, the water elasticity coefficient of Beijing's primary industry was negative. The value added has declined, causing the water elasticity coefficient of the primary industry to become positive. During the "Ninth Five-Year Plan" period to the "Thirteenth Five-Year Plan" period, Beijing's secondary industry 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, Beijing's tertiary industry water consumption continued to grow, and the water elasticity coefficient of the tertiary industry was always positive.

Third, during the "Eighth Five-Year Plan" to "Twelfth Five-Year Plan" period, the water elasticity coefficients of Hebei's primary and secondary industries were negative (only the secondary industry during the "Eighth Five-Year Plan" period and the primary industry during the "Ninth Five-Year Plan" period have a positive water use elasticity coefficient). By the "13th Five-Year Plan" period, the water elasticity coefficient of Hebei's primary industry was still negative. At the

same time, as the water consumption of the primary industry further declined, while the added value of the secondary industry has declined, causing the water elasticity coefficient of the secondary industry to be positive. In addition, during the "Eighth Five-Year Plan" period to the "Thirteenth Five-Year Plan" period, the water consumption of the tertiary industry continued to grow, and the water elasticity coefficient of the tertiary industry was positive.

Table 1. The elastic coefficient of water use for industrial development in the Beijing-Tianjin-Hebei region during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period

Planning period	Region	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	Beijing	-0.164	0.080	0.274
	Tianjin	0.009	0.065	0.020
	Hebei	-0.046	0.120	0.508
The 9th Five-Year Plan	Beijing	-1.878	-0.394	0.120
	Tianjin	0.720	-0.417	0.278
	Hebei	0.035	-0.067	0.593
The 10th Five-Year Plan	Beijing	-1.947	-0.368	0.056
	Tianjin	0.246	-0.106	-0.126
	Hebei	-0.102	-0.056	0.100
The 11th Five-Year Plan	Beijing	-0.361	-0.381	0.169
	Tianjin	-0.634	0.056	0.216
	Hebei	-0.052	-0.098	0.057
The 12th Five-Year Plan	Beijing	-3.209	-0.731	0.233
	Tianjin	0.273	0.164	-0.288
	Hebei	-0.172	-0.071	0.077
The 13th Five-Year Plan	Beijing	2.230	-0.510	0.105
	Tianjin	2.337	-0.106	15.733
	Hebei	-6.758	2.996	0.526

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

### **4.3 The Driving Effect of Water for Industrial Development in the Beijing-Tianjin-Hebei Region**

According to formula (4)-formula (5), the driving effect of industrial development in the Beijing-Tianjin-Hebei region during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period is determined, as shown in "Table 2".



Table 2. The driving effect of industrial water use in the Beijing-Tianjin-Hebei region during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period

Planning period	Region	Primary industry		Secondary industry		Tertiary industry	
		Structural adjustment effect	Technological progress effect	Structural adjustment effect	Technological progress effect	Structural adjustment effect	Technological progress effect
The 8th Five-Year Plan	Beijing	11.35	-13.79	13.72	-12.21	6.76	-4.21
	Tianjin	9.33	-9.21	8.93	-8.09	1.81	-1.75
	Hebei	207.52	-221.91	38.37	-31.68	2.21	-0.86
The 9th Five-Year Plan	Beijing	1.37	-4.24	6.39	-9.81	6.52	-5.45
	Tianjin	2.19	-0.57	3.69	-5.84	1.12	-0.73
	Hebei	43.89	-42.14	20.05	-21.84	2.10	-0.72
The 10th Five-Year Plan	Beijing	1.67	-5.53	7.04	-10.93	6.63	-6.12
	Tianjin	5.58	-4.00	5.52	-6.39	1.28	-1.51
	Hebei	88.23	-99.87	22.20	-23.92	2.95	-2.57
The 11th Five-Year Plan	Beijing	4.15	-6.00	3.46	-5.28	6.43	-5.54
	Tianjin	3.31	-5.89	4.40	-4.07	1.56	-1.21
	Hebei	96.00	-102.51	19.53	-22.19	3.67	-3.39
The 12th Five-Year Plan	Beijing	1.06	-5.54	1.41	-2.73	4.93	-3.56
	Tianjin	4.33	-3.00	2.53	-2.04	1.18	-1.69
	Hebei	42.27	-50.83	7.00	-7.57	2.55	-2.31
The 13th Five-Year Plan	Beijing	-1.05	-1.68	0.87	-1.39	4.79	-4.18
	Tianjin	-1.30	-1.93	-2.57	2.78	0.06	0.65
	Hebei	2.87	-24.09	-1.19	-2.60	2.24	-0.96

According to "Table 2", firstly, the structural adjustment effect of Beijing's primary and secondary industries has declined overall. During the "Ninth Five-Year Plan" to "Twelfth Five-Year Plan" period, the absolute value of the technological progress effect of the primary industry and the secondary industry's water use significantly exceeded the structural adjustment effect. By the "13th Five-Year Plan" period, the structural adjustment effect of the primary industry's water use has been significant, and its technological progress has achieved negative growth. The absolute value of the technological progress effect of the secondary industry's water consumption obviously exceeds the structural adjustment effect. The gap between the absolute value of the technical progress effect of the tertiary industry's water use and the structural adjustment effect is gradually narrowing. However, the absolute value of the technical progress effect of the tertiary industry water is still lower than the structural adjustment effect.

Secondly, during the "Eighth Five-Year Plan" to "Twelfth Five-Year Plan" period, the structural adjustment effects of Tianjin's primary and secondary industries' water use fluctuated downward. However, the structural adjustment effect of the primary industry and the secondary industry's water use is generally greater than the absolute value of the technological progress effect. At the same time, the structural adjustment effect of the tertiary industry's water use has gradually declined, and the gap between the absolute value of the structural adjustment effect and the technological progress effect has shown an expanding trend. By the "Thirteenth Five-Year Plan" period, the structural adjustment effect of the primary industry and the secondary industry's water use has been significant, and both have achieved negative growth. At the same time, the effect of technological progress on water use in the secondary and tertiary industries is not significant, and neither has achieved negative growth.

Thirdly, during the "Eighth Five-Year Plan" to "Twelfth Five-Year Plan" period, the structural

adjustment effect of water use for the primary and secondary industries in Hebei declined fluctuatingly, and the absolute value of the technological progress effect of water use for the primary and secondary industries significantly exceeded the structural adjustment effect. By the "13th Five-Year Plan" period, the absolute value of the technological progress effect of the primary industry's water use still exceeds the structural adjustment effect. At the same time, the structural adjustment effect of the secondary industry's water consumption is significant, achieving negative growth. However, during the "Eighth Five-Year Plan" to "Thirteenth Five-Year Plan" period, the absolute value of the technical progress effect of the tertiary industry's water use has always been lower than the structural adjustment effect.

## 5. CONCLUSION

This paper used the grey relational evaluation method to evaluate the correlation degree of water use for industrial development in the Beijing-Tianjin-Hebei region in different planning periods; it also used the Tapio elastic coefficient method to evaluate the water elasticity coefficient for industrial development in the Beijing-Tianjin-Hebei region in different planning periods; this paper used the driving effect decomposition method as well, to determine the structural adjustment effect and technological progress effect of industrial development water in the Beijing-Tianjin-Hebei region. Studies have shown that the direction of water resource optimization in the Beijing-Tianjin-Hebei region is to appropriately reduce the use of water resources in the primary and secondary industries, and increase the use of water resources in the tertiary industry, so as to realize the effective improvement of the comprehensive output benefit level of the Beijing-Tianjin-Hebei water resources. under the premise of ensuring the safety of food production. Among them, the basic direction of the optimization of water resources in the Beijing-Tianjin area is that: through industrial and agricultural water-saving technologies and other measures, priority should be given to controlling the water consumption of the primary industry, the water consumption of the secondary industry should be strictly controlled, and the water consumption of the tertiary industry should be reasonably increased. In the process of water resource optimization, water consumption and utilization of Beijing's primary industry need to be controlled. At the same time, since the correlation between Hebei's primary industry and water

resources is significantly lower than that of the Beijing-Tianjin area, Hebei's primary industry can be the largest source of water resources. Under the premise of ensuring food security, the utilization of water resources in Hebei's primary industry should be appropriately transferred to other regions and other industries.

## AUTHORS' CONTRIBUTIONS

Dan Wu is responsible for experimental design and writing the manuscript, Xiaoqian Xiang responsible for analysed data and writing the manuscript.

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