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# Analysis of Water Quality Change and its Influencing Factors in Beijing

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## Abstract

**According to the water quality data of Beijing National Control Monitoring Station from 2004 to 2018, the water quality index is synthesized, and the trend of water quality in Beijing is analyzed from three aspects: average change of water quality, extreme value change, and volatility change. Mainly adopt the method of combining principal component analysis and linear regression, select the factors that affect water quality from three aspects of economic and industrial development, resource utilization, and nature, and establish an index system and multi-factor analysis. The results show that the industrial structure, per capita water consumption, and precipitation are the main factors affecting Beijing's water quality changes. Therefore, optimizing the industrial structure, improving the efficiency of water use, and protecting the natural environment are important measures to improve surface water quality.**

## Keywords

**Water Quality; Principal Component Analysis; Influencing Factors.**

## 1. Introduction

There are five major water systems in Beijing, including Yongding River, Daqing River, North Canal, Chaobai River, and Ji Canal. As the capital of China, Beijing's rivers carry 21.54 million permanent residents and 16,410 square kilometers of land. With economic development and population growth, the demand for water resources and water quality is increasing. Beijing's water quality is facing huge challenges and the water environment is very fragile. This paper uses the water quality index data of the state-controlled section monitoring stations to comprehensively analyze the lack of water quality changes in Beijing in recent years, and explore its influencing factors. This is of great significance to the environmental protection and sustainable development of Beijing.

## 2. Characteristics of Water Quality Changes in Beijing

We selected the water quality indicators of the two state-controlled cross-section water quality monitoring points in Beijing from 2004 to 2018 and the river water quality index method published by the Ministry of Ecology and Environment to construct a single factor index and a comprehensive water quality index system. We comprehensively explore the development status of the water environment in the Beijing-Tianjin-Hebei region from the three research perspectives of annual water quality index average analysis, volatility analysis, and extreme value analysis.

There are mainly two state-controlled monitoring sections in Beijing, which are located in Miyun District and Mentougou District, Beijing. See Table 1 for specific section information.

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**Table 1.** Name and location information of monitoring section

| Section name | River | Section location | Latitude and longitude |
|---|---|---|---|
| Beijing Miyun Gubeikou | Hongru River | Chao River (Entrance of Miyun Reservoir) | (117° 17'00" W, 40° 47'00" N) |
| Beijing Mentougou Riverside City | Wan River | Yongding River (Outlet of Guanting Reservoir) | (115° 42'55" W, 40° 04'10" N) |

## 2.1. Analysis Method

At present, the construction of water quality index is relatively diverse, and each has its own advantages and disadvantages. We build a comprehensive water quality index and a single-factor water quality index system based on the river water quality index method announced by the Ministry of Ecology and Environment in May 2019. The construction method of the water quality index is as follows:

1)Single factor water quality index

Divide the concentration value of each individual index by the corresponding surface water type III standard limit of the index to obtain the single factor water quality index:

$$\mathrm{CWQI(i)} = \frac{C(i)}{C_s(i)}$$

Where C(i) is the concentration value of the i-th water quality index; $\mathrm{C_s}(i)$ is the level III standard limit for surface water of the i-th water quality index; CWQI(i) is the water quality index of the i-th water quality index.

In addition, the calculation method of the dissolved oxygen water quality index is as follows:

$$\mathrm{CWQI(DO)} = \frac{\mathrm{C_s}(DO)}{C(DO)}$$

Where C(DO) is the concentration value of dissolved oxygen; $\mathrm{C_s}(DO)$ is the Class III standard limit for surface water of dissolved oxygen; CWQI(DO) is the water quality index of dissolved oxygen.

The calculation method of pH value is as follows: if pH≤7, the calculation formula is:

$$\mathrm{CWQI(pH)} = \frac{7.0 - \mathrm{pH}}{7.0 - pH_{sd}}$$

If pH>7, the calculation formula is:

$$\mathrm{CWQI(pH)} = \frac{\mathrm{pH} - 7.0}{pH_{su} - 7.0}$$

Where $\mathrm{pH_{sd}}$ is the lower limit of pH in GB3838-2002; $\mathrm{pH_{su}}$ is the upper limit of pH in GB3838-2002; CWQI (pH) is the water quality index of pH.

2)Comprehensive water quality index

According to the CWQI of each individual index, the sum of the values is the comprehensive CWQI. The calculation formula is as follows:

$$\mathrm{CWQI} = \sum_{i=1}^{n} CWQI(i)$$

The larger the value of the comprehensive water quality index of each single factor index, the larger the multiple of exceeding the standard, and the worse the water quality.

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The original index construction method included 21 indicators, but due to the unavailability of data, this paper can only select 4 indicators for research. First, convert the monitored concentrations of the PH, COMDn, NH3-N, and DO indicators for each week from 2004 to 2018 into PH, COMDn, NH3-N, and DO, and then add them to get a comprehensive water quality index. Then, the weekly average value is synthesized to analyze the annual average value of the water quality index.

Since water quality is greatly affected by natural factors, especially precipitation factors, water quality will fluctuate to varying degrees in months and years. It is generally believed that the smaller the fluctuation of water quality, the more stable the water quality environment. Therefore, this study analyzes the volatility of water quality in the Beijing-Tianjin-Hebei region by calculating the monthly variance of the multi-year average of water quality.

The "Beijing-Tianjin-Hebei Water Pollution Emergency Joint Prevention and Control Mechanism Cooperation Agreement" issued in October 2014 strengthened the management of water quality emergencies and extreme situations. Therefore, it is necessary not only to analyze the average trend of water quality but also to pay attention to water quality emergencies. And extreme situations. Based on this, this study uses the 90% quantile of the annual water quality index as the critical point and describes the 90% quantile and maximum value of Beijing, Tianjin, and Hebei in the figure. The lower limit of the histogram is the 90% quantile. The upper limit is the maximum value. Observe the frequency changes of the three provinces (cities) on the extreme values of each index.2.2 Analysis results

## 2.2. Analysis of the Average Change of the Comprehensive Water Quality Index

According to the monitoring data obtained by the data center of the Ministry of Environmental Protection, the weekly data is averaged to obtain the annual data, and the single factor index (DO index, CODMn index, PH index and NH3-N index) of the section is solved according to the calculation method of each index, and then The comprehensive water quality index is obtained, and the water quality index change diagram of each section is shown in Figure 1.

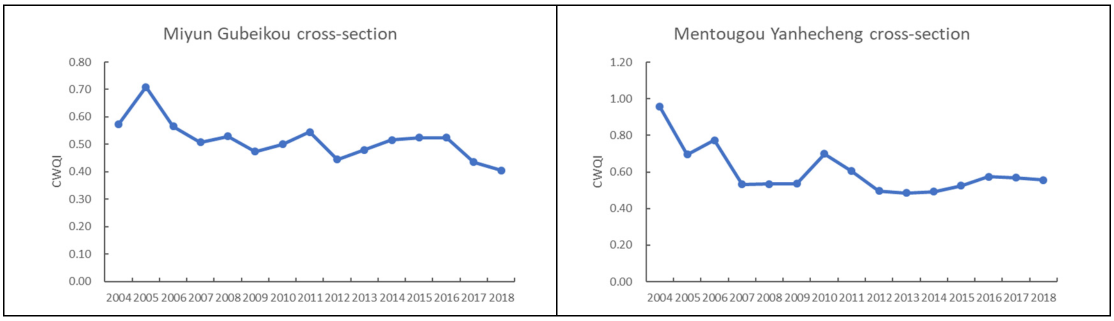


**Figure 1.** Average change of water quality index

By observing Figure 1, it can be seen that the comprehensive water quality index of the Gubeikou section of Miyun, Beijing has shown a slow downward trend, from 0.7 in 2005 to 0.4 in 2018. The comprehensive water quality index of Beijing Mentougou Yanhecheng section showed a trend of first decline and then rise. The comprehensive water quality index declined significantly from 2004 to 2009, from 0.95 to 0.49, and from 2010 to 2018 there was a slow upward trend, from 0.48 to 0.56. In general, the comprehensive water quality index dropped significantly from 2004 to 2009, and the water quality became better

## 2.3. Analysis of Water Quality Volatility

Due to natural factors such as temperature and precipitation, as well as man-made influences such as pollution emissions, various water quality testing indicators often show volatility. This section analyzes the multi-year average monthly concentration changes of CODMn, DO, NH3-N and PH indicators of each monitoring section. , And calculate the multi-year variance to evaluate the volatility of water quality changes. The box diagram of the average change of each index over the years is shown in Figure 2.

Analyzing the volatility of the CODMn index of the section, January, February, July, August, and September in the Beijing Miyun Gubeikou section are the months with relatively large fluctuations in the CODMn index. The variance statistics table shows that the average variance of these five months is Above 0.8, April and May at the Yanhecheng section of Mentougou, Beijing are the months when the CODMn indicator fluctuates greatly. The variance statistics table shows that the variance of these two months both exceeded 4.0.

Analyzing the volatility of the DO indicator of the section, February, November, and December at the Gubeikou section of Miyun, Beijing are the months with relatively large fluctuations in the DO indicator. The variance statistics table shows that the variance of these three months has exceeded 2.5. Beijing Mentougou In the Yanhecheng section, January, February, and December are the months when the DO indicator fluctuates greatly. According to the variance statistics table, the variance of these three months all exceeds 3.0.

Analyzing the volatility of the NH3-N index of the section, the NH3-N index of Beijing Miyun Gubeikou section fluctuates very little. According to the variance statistics table, the variance of all months is close to 0.01, and the NH3-N index of Beijing Mentougou Yanhecheng section fluctuates relatively small. , Through the variance statistics table, we can see that the variance of all months is less than 0.6.

Analyzing the volatility of the PH indicator of the section, May and June in the Beijing Miyun Gubeikou section are the months with relatively large fluctuations in the PH indicator. According to the variance statistics table, the variance of these two months is more than 0.2. Beijing Mentougou Yanhecheng In the section, January, August, and November are the months with relatively large fluctuations in the PH indicator. The variance statistics table shows that the variances of these three months all exceed 0.3.

In general, the most severe volatility of the CODMn indicator in Beijing was in July and August, the most volatile of the DO indicator was in December and January, and the most volatile of the NH3-N indicator was in February. The volatility of the PH indicator was the most severe. The worst sex is in June.

## 2.4. Analysis of Extreme Value Changes

The frequency and frequency of extreme values are another analysis aspect of water quality fluctuations. In this section, we take the 90% quantile of the months of many years as the critical point, and the quantile with the value between 90%-100% as the extreme value. The frequency of extreme points in each month.

Analyzing the frequency of the extreme values of the CODMn index in each month shows that the extreme values of the Gubeikou section of Miyun in Beijing mainly appeared in July, August, and September, with the frequency of 16.4%, 24.7%, and 16.4% respectively. The frequency of extreme values of the Yanhecheng section in Mentougou, Beijing is relatively uniform, the highest in August, at 24.7%, and the lowest in November, at 1.4%; the extreme values of DO index of the Beijing Miyun Gubeikou section mainly appeared in December, at 28.8% , Concentrated in the first quarter, the second and third quarters were less than 5%. The extreme value of DO index of Beijing Mentougou Yanhecheng section mainly appeared in February, which was 31.9%, concentrated in the first quarter.

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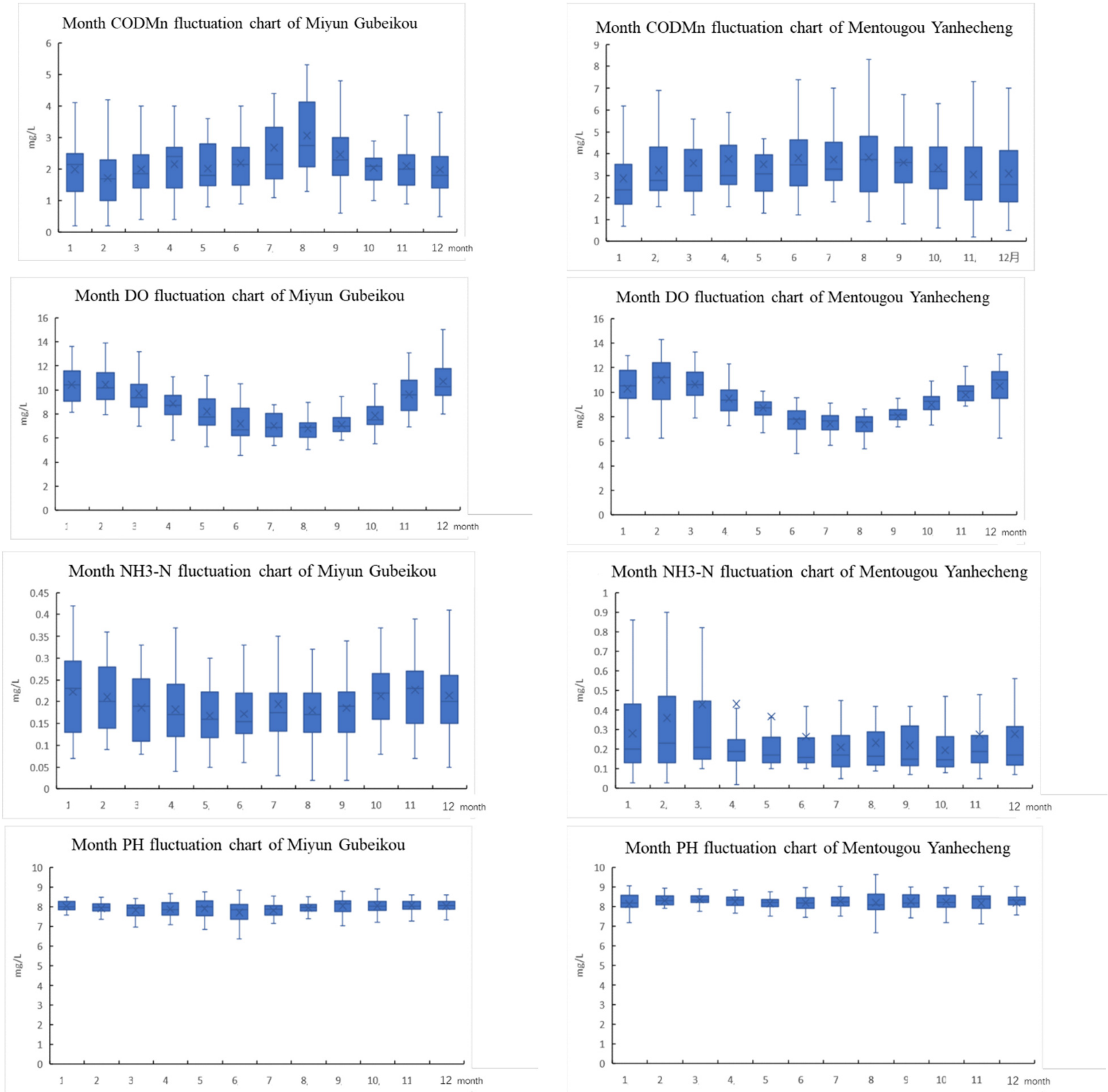


**Figure 2.** Monthly volatility changes of water quality index

The frequency of the extreme values in each month of the second and third quarters was less than 5%; Beijing Miyun Gubeikou The extreme values of the NH3-N index of the section mainly appeared in December and January, with the frequency of 16.4% and 15.1% respectively. The extreme value of the NH3-N index of the Beijing Mentougou Yanhecheng section mainly appeared in the first quarter, and less in the third and fourth quarters; the extreme value of the PH of the Beijing Miyun Gubeikou section mainly appeared in the second and fourth quarters. The most frequent occurrence in October. It was 15.1%, with the lowest frequency in March, at 1.4%. The extreme values of PH at the Yanhecheng section of Mentougou, Beijing mainly appeared in March and September, with frequencies of 13.9% and 16.7%, respectively. The frequency of occurrence was lower in the second quarter. Therefore, Beijing's water quality has an obvious monthly fluctuation trend, in which the seasonal fluctuations of different indicators are not completely consistent.

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**Table 2.** Multi-year average monthly variance statistics of various indicators

| Month | CODMn | | DO | | NH3-N | | PH | |
|---|---|---|---|---|---|---|---|---|
| | Miyun Gubeikou Section | Section of Yanhe City, Mentougou | Miyun Gubeikou Section | Section of Yanhe City, Mentougou | Miyun Gubeikou Section | Section of Yanhe City, Mentougou | Miyun Gubeikou Section | Section of Yanhe City, Mentougou |
| Sample size | 730 | 716 | 730 | 716 | 729 | 715 | 730 | 716 |
| Number of extremes | 73 | 72 | 73 | 72 | 73 | 71 | 73 | 72 |
| January | 13 | 11 | 13 | 11 | 11 | 11 | 3 | 4 |
| February | 13 | 23 | 13 | 23 | 7 | 12 | 4 | 7 |
| March | 13 | 15 | 13 | 15 | 4 | 13 | 1 | 10 |
| April | 2 | 2 | 2 | 2 | 6 | 8 | 9 | 3 |
| May | 2 | 1 | 2 | 1 | 0 | 4 | 9 | 1 |
| June | 0 | 0 | 0 | 0 | 3 | 5 | 6 | 3 |
| July | 0 | 0 | 0 | 0 | 7 | 1 | 2 | 5 |
| August | 0 | 0 | 0 | 0 | 5 | 3 | 3 | 7 |
| September | 0 | 0 | 0 | 0 | 3 | 2 | 10 | 12 |
| October | 0 | 0 | 0 | 0 | 6 | 1 | 11 | 9 |
| November | 9 | 4 | 9 | 4 | 9 | 3 | 9 | 8 |
| December | 21 | 16 | 21 | 16 | 12 | 8 | 6 | 3 |

## 3. Analysis Methods and Results of Water Quality Influencing Factors

### 3.1. Analysis Method

There are many factors affecting environmental quality, including socio-economic development, industrial structure, resource utilization, etc. The impact of these factors on environmental quality is often interrelated, positive or negative. In order to study the impact of social, economic, and technological development on environmental quality, this article transforms it into a mathematical problem to analyze the relationship between the water quality index CWQI and various factors C. Based on the statistical data of Beijing from 2004 to 2018, the method of combining principal component analysis and linear regression was used to find out the key factors affecting the water environmental quality of major rivers in Beijing.

General ideas and steps: (1) Prepare data: determine the CWQI as the environmental quality indicatory, and select a group of variables that are closely related to it (such as a proportion of industry to total GDP, resident population, etc.) x1, x2,...and find the data of these variables over the years. (2) Fill in the data: due to the absence of data, the missing value was filled by the linear trend method. (3) Standardization: the filled data will be standardized, making it so that all data will be a series of no dimensionless number with mean values of zero and variance of one. (4) Principal component dimension reduction: using the method of principal component analysis to reduce dimension of variables, get several unrelated principal component unrelated and which can represent more than 85% of the original data information through linear combination of the original data. Supposing extracted n principal components are extracted, the coefficient of the variable xi to the principal component $f_j$ is $a_{ij}$ .(5) Linear regression: using linear regression method to find the relationship between the variable y and the extracted n principal components: $y = b_1 f_1 + b_2 f_2 + \cdots b_n f_n + b_0$ (6) Calculated the final coefficient:

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$w_i = b_1 a_{i1} + b_2 a_{i2} + \cdots b_n a_{in}$ as the function coefficient of the variable xi for environmental indicatory.

## 3.2. Influencing Factors

Selected 28 representative indicators from 7 aspects such as economic development, social development, resource utilization, pollution control, and natural factors, established influencing factors analysis index system (Table 3), and conducted an analysis of influence factors. The results of the analysis are shown in Figure 3.

**Table 3.** Influencing factors index system of water environmental quality.

| Category | No | Index |
|---|---|---|
| Environmental indicators | C1 | Water resources |
| | C2 | Precipitation |
| Economic development indicators | C3 | GDP per capita |
| | C4 | TDN (night light index) |
| | C5 | TDN2 |
| | C6 | The proportion of fixed asset investment in GDP |
| | C7 | City power consumption |
| Social development | C8 | permanent residents |
| | C9 | The population density |
| | C10 | Urbanization rate |
| | C11 | Construction land area |
| | C12 | Green area per capita |
| | C13 | Road area per capita |
| Industrial structure | C14 | Proportion of industrial output value |
| | C15 | Agricultural output value |
| | C16 | Proportion of tertiary industry output value |
| Agricultural activities | C17 | Fertilizer application rate |
| | C18 | Sown area of crops |
| | C19 | Grain production |
| Resource utilization indicators | C20 | Freshwater aquaculture area |
| | C21 | Daily water consumption per capita |
| | C22 | Industrial water consumption |
| | C23 | Water consumption per 10,000 yuan of industrial added value |
| | C24 | Water consumption per 10,000 yuan of agricultural added value |
| Pollution control | C25 | Industrial wastewater discharge |
| | C26 | Urban sewage discharge |
| | C27 | Sewage treatment capacity |
| | C28 | Total sewage treatment |

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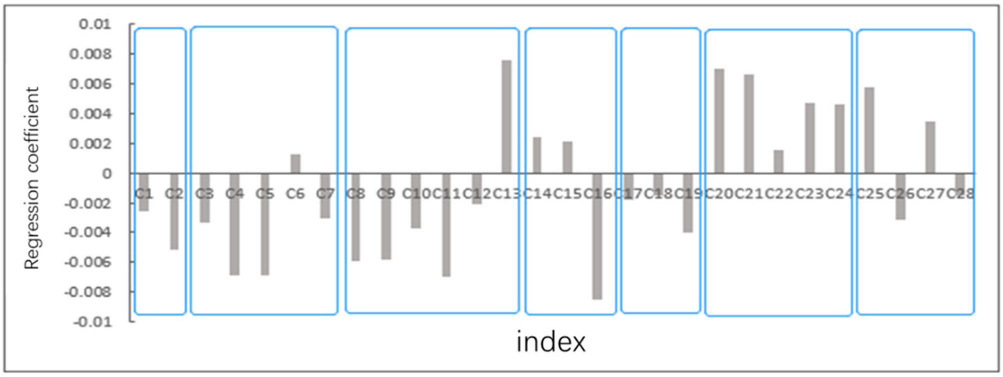


**Figure 3.** The multi influence factors analysis result on the CWQI

## 4. Result Analysis

According to Figure 4, the top ten influencing factors of the comprehensive water quality index are: the proportion of tertiary industry output value (C16), per capita road area (C13), freshwater aquaculture area (C20), construction land area (C11), lighting index TDN (C4), the square of the light index (C5), per capita daily water consumption (C21), permanent population (C8), population density (C9), industrial wastewater discharge (C25), its distribution reached 5 aspects. (C4 and C5 belong to economic development; C13, C11, C18, and C9 belong to social development; C16 belongs to industrial structure; C20 and C21 belong to resource utilization; C25 belongs to pollution control).

Based on the actual situation, the factors affecting the comprehensive water quality of Beijing can be mainly classified into the following aspects:

(1) Economic development and industrial structure.

The analysis results show that economic development and industrial structure have a greater impact on Beijing's water environment. The proportion of Beijing's tertiary industry output value is inversely proportional to the comprehensive water quality index, which means that the higher the output value of the tertiary industry, the lower the comprehensive water quality index and the better the water quality. According to data from the Beijing Municipal Bureau of Commerce, Beijing's service industry accounted for 83.5% of GDP in 2019, which is 30 points higher than the national average of 53.9%. From the perspective of global GDP, the service industry accounts for 70% of the world's total economy, and the proportion in some advanced economies is even closer to 80%. Therefore, the proportion of Beijing's service industry in GDP is the level of advanced cities in the world.

The economic development represented by the lighting index is inversely proportional to the comprehensive water quality index, which means that the larger the lighting index, the better the economic development, and the smaller the comprehensive water quality index, the better the water quality. Analyzing the scatter diagram of the light index and the comprehensive water quality index (Figure 4-6) shows that using linear fitting and quadratic curve fitting, the goodness of fit is not much different, and both are greater than 0.5, and the fit is good. Combining with Krueger's (1991) conclusion that "environment and economy develop into an'inverted U shape'", it can be seen that the relationship between economic development and water quality in Beijing has passed the turning point and entered the second stage.

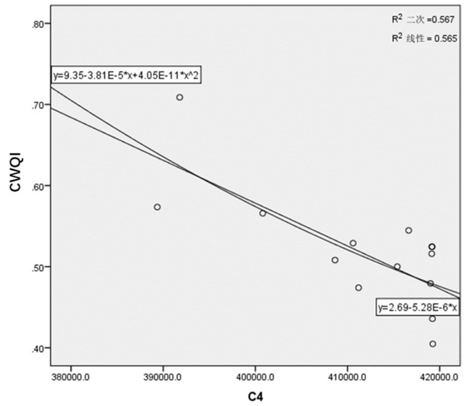


**Figure 4.** Fitting diagram of comprehensive water quality index and light index

(2) Resource utilization and pollution control

Figure 4 shows that the coefficients of per capita daily water consumption (C21), industrial water consumption (C22), industrial value-added water consumption per 10,000 yuan (C23), agricultural value-added water consumption per 10,000 yuan (C24) and the comprehensive water quality index are positive Value, that is, the more water you use, the greater the water quality index and the worse the water quality. Combining Beijing's water efficiency data from 2004 to 2018 shows that Beijing's per capita daily water consumption (C21), industrial water consumption (C22), water consumption per 10,000 yuan of industrial added value (C23), and water consumption per 10,000 yuan of agricultural value added (C24) are showing a downward trend. Among them, industrial water consumption fell the most, from 4.89 billion cubic meters in 2004 to 740 million cubic meters in 2018, with a rate of decrease of 84.9%. Combining the industrial wastewater discharge (C25) and sewage treatment capacity (C27) data in sewage control, it can be seen that Beijing has done a very good job in pollution control. In 2018, Beijing's sewage treatment capacity reached 7,007,800 cubic meters per day. Reached 1.848 billion cubic meters. The increase in water use efficiency and sewage treatment capacity in Beijing has continuously improved water quality.

(3) Natural factors

Both the amount of water resources and the amount of precipitation are negatively correlated with the comprehensive water quality index, that is, the more water resources, the more precipitation, and the smaller the water quality index, the better the water quality. Under natural conditions with sufficient surface water resources, the water environment has a self-purifying effect. The amount of surface water resources is brought by natural runoff and natural precipitation. Therefore, the more precipitation, the indicator concentration in the river can be diluted. Due to climate change and the development of urbanization, the precipitation in Beijing has shown an inverted U-shaped change: precipitation continued to increase from 2004 to 2013, and precipitation continued to decrease from 2013 to 2018.

## 5. Conclusion

In summary, Beijing's water quality is slowly improving, but the water quality fluctuates greatly, and extreme values are also prone to occur in summer and winter. Factors such as economic development, industrial structure, per capita water consumption, sewage treatment rate, and precipitation represented by lighting data all affect Beijing's water quality. It can be seen that optimizing industrial structure, transforming development methods, improving sewage treatment capacity, and increasing ecological water use in multiple ways are important measures to improve water quality.

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