

Research on Water Resources Development and Utilization Based on Linear Regression and Multiple Nonlinear Regression

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Abstract. With the further development of industrialization and urbanization, China's water resources will be more severe. In order to study the synergy of the three red line targets, we predicted the total water consumption in 2030 by establishing the total water consumption model and using the linear regression prediction method. It is assumed that the water consumption of 10,000 yuan of industrial added value and the effective utilization coefficient of agricultural irrigation water all reached the red line value in 2030. Next, a multivariate nonlinear regression model of total water consumption is established, and the indirect substitution method is used to obtain the function of the internal relationship among the water consumption of 10,000 yuan GDP, the actual water consumption per mu of cultivated land for irrigation, and the water consumption of 10,000 yuan industrial added value, which includes time variables, and then the sensitivity analysis of the above functions are carried out. The following conclusions are drawn: China's overall water resources development and utilization should adopt the policy of improving the effective utilization coefficient of farmland irrigation water and reducing the industrial added value water consumption of 10,000 yuan as a supplement.

Keywords: Linear regression, indirect substitution method, multiple nonlinear regression.

1. Introduction

Water is the source of life, the key of production, and the foundation of ecology. Since the founding of the People's Republic of China, especially since the reform and opening-up, China's water resources development, utilization, allocation, conservation, protection, and management have made remarkable achievements and made outstanding contributions to economic and social development and people's living and working in peace and contentment. [1] However, many people and little water, uneven distribution of water resources in time and space are China's basic national conditions and hydrological conditions, and water shortage, severe water pollution, deterioration of water ecology, and other problems are very prominent, which have become the main bottlenecks restricting sustainable economic and social development. [2] With the development of industrialization and urbanization, the demand for water resources will continue to grow for a long period. The contradiction between the supply and demand of water resources will become more acute, and the situation facing China's water resources will become more severe. [3]

2. Prediction Model of Total Water Consumption Based on Linear Regression

In January 2012, the State Council issued the Opinions on Implementing the Strictest Water Resources Management System, which established the "three red lines" of water resources development and utilization control, water use efficiency control, and pollution control in water functional areas: [4]

First, establish the red control line of water resources development and utilization, and control the total water consumption in China within 700 billion m³ by 2030.

The second is to establish the red line of water use efficiency control. By 2030, the water use efficiency will reach or approach the advanced level in the world, the water consumption per 10,000

yuan of industrial added value will be reduced to below 40m³, and the effective utilization coefficient of farmland irrigation water will be increased above 0.6.

Third, establish the red line of the water function area to limit pollution. By 2030, the total amount of major pollutants entering rivers and lakes will be controlled within the range of the water function area's pollution-bearing capacity, and the water quality compliance rate of the water function area will be increased to over 95%. [5]

According to the bulletin of water resources, the total water consumption in China in 2017 was 604.34 billion m³, slightly higher than that of the previous year of 6040.2m³, which was equivalent to 86.33% of the red line target value of 700 billion m³ proposed by the state in 2030, and the annual increase in the future should be controlled within 1.13%. In 2017, the water consumption per 10,000 yuan of industrial added value in China was 45.6m³, which was 13.64% lower than the previous year's 52.8m³, equivalent to 114% of the red line target value of 40m³ proposed by the state in 2030, and the annual decline in the future should be controlled at more than 1.02%. [6] In 2016, the effective utilization coefficient of farmland irrigation water in China was 0.548, which was 1.11% higher than the previous year's 0.542, which was equivalent to 91.33% of the red line target value of 0.6 proposed by the state in 2030, and the annual increase in the future should be controlled above 0.7%. [7]

In order to ensure that the development and utilization of water resources and water use efficiency do not exceed the red control line, the water consumption per 10,000 yuan of industrial added value is in a downward trend, and the effective utilization coefficient of farmland irrigation water is increased to above 0.6. First, we construct the total water consumption function as follows:

$$Q = Q_1 + Q_2 + Q_3 + Q_4 \quad (1)$$

According to Eq.1, the total water consumption (Q) consists of industrial water consumption (Q_1), agricultural water consumption (Q_2), domestic water consumption (Q_3) and the total amount of ecological environment water supplement (Q_4). In order to measure the consistency of the three national water red line targets in 2030, Eq.1 should be decomposed as follows: [8]

Total industrial water consumption: (industrial added value×10,000-yuan industrial added value water consumption)/10,000, recorded as:

$$Q_1 = \frac{D_1 \times h}{10000} \quad (2)$$

Total agricultural water consumption: average actual irrigation water consumption per mu of cultivated land×actual irrigation mu of cultivated land.

$$Q_2 = m \times A \quad (3)$$

Among them, the actual irrigation water consumption per mu m of cultivated land can be expressed as the actual irrigation water absorption per mu of cultivated land (M)/ the effective coefficient of farmland irrigation water (k), which is recorded as:

$$Q_2 = \frac{M}{k} \times A \quad (4)$$

Total ecological water replenishment: the ratio of total ecological water replenishment to total water consumption (x)×total water consumption (Q)

$$Q_4 = x \times Q \quad (5)$$

To sum up, we can see:

$$Q = \frac{\frac{D_1 \times h}{10000} + \frac{M}{k} \times A + Q_3}{1 - x} \quad (6)$$

We can know from Eq.6 that the total water consumption is determined by variables such as industrial added value, water consumption of 10,000-yuan industrial added value, average water

absorption per mu of cultivated land for irrigation, effective coefficient of farmland irrigation water, actually irrigated mu of cultivated land, total domestic water consumption, the proportion of ecological environment water supplement, etc. [9]

Assuming that in 2030, the industrial added-value water consumption of 10,000 yuan and the effective utilization coefficient of agricultural irrigation water both reach the red line value, that is, 40m³ and 0.6 respectively, the total water consumption in 2030 is calculated through the regression prediction analysis of other variables mentioned above.

First, forecast the industrial water consumption. From the above formula, we know that industrial water consumption comprises industrial added value and water consumption of 10,000 yuan of industrial added value. By analyzing the data of national industrial added value over the years, the industrial added value is fitted by linear regression, and the results are as follows:

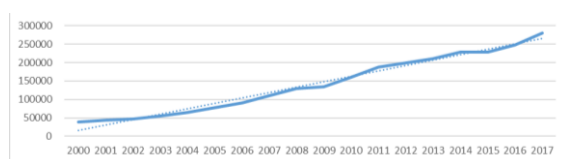


Figure 1. National industrial added value over the years

The national industrial added value function is as follows:

$$f(x) = 13898x - 12694 (R^2: 0.9655) \quad (7)$$

It is known that the linear fitting equation has a high degree of fitting, and it can be predicted that the national industrial added value in 2030 will be about 41,814.4 billion yuan. Combined with the assumed water consumption of 10,000-yuan industrial added value of 40m³ in 2030, it is concluded that the industrial water consumption in 2030 is 167.258 billion m³.

Secondly, forecast the agricultural water consumption. Because the agricultural water consumption depends on three factors, namely, the actual irrigation water absorption per mu of cultivated land, the effective utilization coefficient of farmland irrigation water, and the actual irrigation mu of cultivated land, the data over the years show that the actual irrigation water absorption per mu of cultivated land is relatively stable, with an average of 210.79m³. Based on the data analysis of the actual irrigated acreage of cultivated land in China over the years, the linear regression fitting of the actual irrigated acreage of cultivated land with regress function is carried out with MATLAB, and the results are as follows:

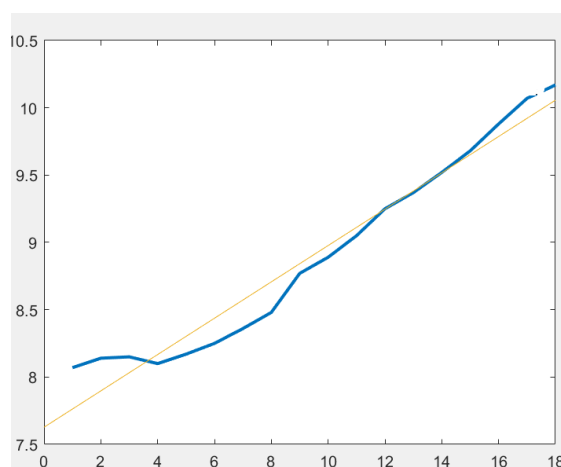


Figure 2. The actual irrigated acres of cultivated land in China over the years

The function of actual irrigation effective area in China is as follows:

$$f(x) = 0.13x + 7.63 (R^2: 0.9585) \quad (8)$$

It can be known that the linear fitting equation has a high degree of fitting, and it can be predicted that the actual effective irrigation area in China in 2030 will be about 1.181 billion mu. The effective

utilization coefficient of farmland irrigation water in China in 2030 is assumed to be 0.6. It can be obtained from Eq.4 that the total agricultural water consumption in 2030 is about 415.034 billion m³.

Thirdly, forecast and analyze the domestic water consumption. Through the analysis of the national domestic water consumption over the years, it can be seen that the national domestic water consumption shows a linear trend. The domestic water consumption is linearly fitted by the least square method with MATLAB, and the results are as follows:

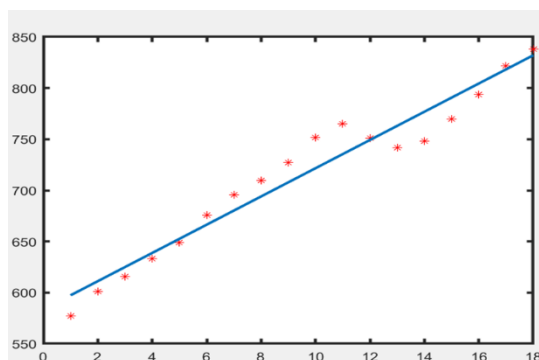


Figure 3. Total domestic water consumption in China over the years

The functional relationship between the total domestic water consumption in China and the time variable is as follows:

$$f(x) = 13.81x + 583.58 (R^2: 0.9467) \quad (9)$$

From this, it can be known that the linear fitting equation has a high degree of fitting, and the national domestic water consumption in 2030 is 101.154 billion m³.

Finally, the data analysis of ecological environment water supplement amount is carried out. Based on the data analysis of the national eco-environmental water supply over the years, it is found that it accounts for a relatively small proportion of the total water consumption in China, and it increases year by year with the total water consumption. For the convenience of calculation, it can be expressed as $x = 1.9\%$ by taking its annual average of 1.9%.

Through the above analysis and prediction of the total industrial water consumption, agricultural water consumption, domestic water consumption, and environmental and ecological water supplement, it can be concluded that the total water consumption in 2030 is about 696.683 billion m³, which is less than the target of 700 billion m³ proposed by the national red line.

Thus, it is concluded that according to the industrial added value of 10,000 yuan, the water consumption decreases at the rate of 1.95% per year, and the effective utilization coefficient of farmland irrigation water increases at the rate of 0.52% per year, which can ensure that the three red line indexes of water resources proposed by the state in 2030 can be realized simultaneously.

3. Water resources development and utilization model based on multiple nonlinear regression

In order to analyze and study the inherent laws of water consumption per m³ of 10,000 yuan GDP, average water consumption per mu of cultivated land for irrigation, and average water consumption per m³ of 10,000 yuan industrial added value, we can find the nonlinear relationship among them by analyzing the national water consumption per 10,000 yuan GDP, average water consumption per mu of cultivated land for irrigation and average water consumption per 10,000 yuan industrial added value over the years. [10] Therefore, a multivariate nonlinear regression prediction model is established.

$$Q = Q_1 + Q_2 + Q_3 + Q_4 \quad (10)$$

$$Q = d \times D \quad (11)$$

$$Q_1 = \frac{D_1 \times h}{10000} \quad (12)$$

$$Q_2 = m \times A \quad (13)$$

$$Q_4 = x \times Q \quad (14)$$

To sum up, we can get the following formula:

$$d \times D = \frac{D_1 \times h}{10000} + m \times A + Q_3 + x \times Q \quad (15)$$

According to Eq.14, in addition to the three variables that we need to study, such as the water consumption of 10,000 yuan GDP, the actual water consumption per mu of cultivated land for irrigation, and the water consumption of 10,000 yuan industrial added value, the above formula also has five other variables, such as industrial added value (D1), the actual irrigated mu of cultivated land (A), the total domestic water consumption (Q3), the proportion of total ecological and environmental water replenishment (X) and the gross domestic product (D) to simplify the model for reducing variables.

$$D_1 = 13898 \times t - 12694 \quad (16)$$

$$A = 0.13 \times t + 7.63 \quad (17)$$

$$Q_3 = 13.81 \times t + 583.58 \quad (18)$$

$$x = 1.9\% \quad (19)$$

The national gross domestic product (GDP) over the years is fitted by nonlinear regression, and the results are as follows:

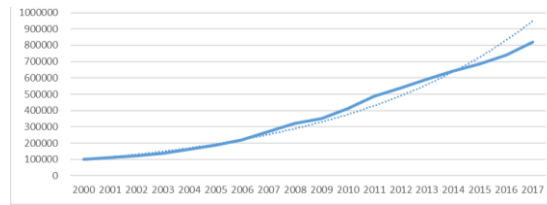


Figure 4. Gross domestic product over the years

The GDP function is as follows:

$$f(x) = 87874e^{0.13x} (R^2: 0.9872) \quad (20)$$

namely

$$D = 87874e^{0.13t} \quad (21)$$

From $R^2=0.9872$, it can be known that the exponential function has a high degree of fitting, and thus the nonlinear functional relationship between GDP and time can be obtained.

$$d = \frac{(1.39t - 1.27)h + (0.13t + 7.63)m + (13.81t + 58.83)}{87874e^{0.13t}} \quad (22)$$

From Eq.21, a multivariate nonlinear regression model with the dependent variable of water consumption per 10,000 yuan of GDP, actual water consumption per mu of cultivated land for irrigation, water consumption per 10,000 yuan of industrial added value, and time as independent variables is obtained, so the inherent laws of water consumption per m³ of 10,000 yuan of GDP, actual water consumption per mu of cultivated land for irrigation and water consumption per m³ of industrial added value per 10,000 yuan are obtained.

To analyze the influence of variable change on independent variables, we derive from Eq.21 to get:

$$\frac{\partial d}{\partial m} \frac{\partial h}{\partial d} = \frac{0.13t + 7.63}{1.39t - 1.27} \quad (23)$$

When the time is 2030, the value obtained by the above formula is 0.28. The above results show that the change of water consumption per mu of cultivated land caused by the change of water consumption per mu is lower than that of industrial added value. It is caused by the change of water consumption per mu of cultivated land, indicating that the decline rate of water consumption per mu of agricultural cultivated land irrigation needs to be further increased.

Because of the large proportion of agricultural water consumption, the total water consumption is positively correlated with the water consumption of 10,000 yuan of industrial added value and negatively correlated with the effective utilization coefficient of farmland irrigation water. In order to ensure the realization of the national total water consumption target in 2030, the development and utilization of China's overall water resources should adopt the policy of mainly improving the effective utilization coefficient of farmland irrigation water, supplemented by reducing the water consumption by 10,000 yuan of industrial added value.

4. Conclusion

According to the data of China's water resources bulletin information over the years, this paper constructs relevant mathematical models to use water resources effectively. Firstly, the mathematical model of total water consumption is obtained by establishing the functions of agricultural water consumption, industrial water consumption, and ecological environment water supplement. Secondly, it is assumed that the industrial added-value water consumption of 10,000 yuan and the effective utilization coefficient of agricultural irrigation water all reach the red line value in 2030. It is confirmed whether the total water consumption in 2030 is within the red line by linear regression prediction of national industrial added value, national actual irrigation effective area, and national domestic water consumption. Next, a multivariate nonlinear regression model of total water consumption is established, and an indirect substitution method is used. The related variables in the model are simplified into functions of time variables after linear or nonlinear regression prediction and then substituted into the model to obtain the function of the internal relationship, including time variables among water consumption per 10,000 yuan of GDP, actual water consumption per mu of cultivated land for irrigation and water consumption per 10,000 yuan of industrial added value. Finally, the sensitivity analysis of the internal relationship model of the above indexes is carried out. The two indexes of industrial added value water consumption of 10,000 yuan and effective utilization coefficient of farmland irrigation water are compared to explore the indexes that greatly influence total water consumption.

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