Solving Water Scarcity of North China Based on Method of Mathematical Modeling

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Abstract. In this paper, the Logistic model of population forecast, gray theory, neural network model, regression analysis and curve fitting are used to analyze and discuss the region of North China where is in heavily lack of water resources. Firstly, the water demand model and water supply model based on Logistic population prediction and GM (1, 1) are established. Then total water demand in 15 years in the provinces of North China can be judged and calculated using per capita of water requirement. We can draw the conclusion that the total gap in North China is about 35.8 billion cubic meters by MATLAB. Moreover, the result obtained by gray prediction before are tested with the application of Neutral Network Model and shows the result is relatively accurate. Secondly, an intervention plan is designed with the intention of handling water scarcity, which mainly includes building reservoirs and protection of water resources. A mathematical model can be built to determine the pollution degree of four provinces in North China. Regression analysis and curve fitting are used to deal with the forecasting of sewage disposal in the provinces. Finally, the overall strengths and weaknesses of the plan as well as the effect on the surrounding areas and the entire water ecosystem are synthetically discussed.

Keywords: Water scarcity; GM (1, 1); BP neutral network; Intervention; Regression analysis; Evaluation.

1. Introduction

Water is believed as the key element for life on earth. With the development of society, the conflict between water resources and human life has become a constant topic. The total amount of water resources on the earth is about 13.8 billion cubic kilometer, and 97.5% is sea water (about 13.45 billion cubic kilometer), freshwater only accounts for 2.5%, the vast majority of it is polar ice, snow glaciers and groundwater. The available water for the enjoyment of human beings is only 0.01%. In the 20th century, the population of the world has increased by two times, and water for human consumption five times, many countries in the world are facing water crisis.

Water on the earth is the most widely distributed and most important material. Humans require water resources for industrial, agricultural and residential purposes. However, according to the United Nations, 1.6 billion people (one quarter of the world’s population) experience water scarcity. The present situation of water scarcity in the world is to be solved urgently. There are two primary causes for water scarcity: physical scarcity and economic scarcity. Meanwhile, human population increase or increasing rates of industrial consumption also places increased burden on the supply of fresh water.

In this paper, the Logistic model of population forecast, gray theory, neural network model, regression analysis and curve fitting are used to analyze and discuss the region of North China where is in heavily lack of water resources.

2. The Models

2.1 The forecast of water demand using population prediction model

For the four provinces of North China, the number of population of four provinces in 2005 to 2014 can be derived from data attached list one, doing Logistic regression analysis [1] with MATLAB model and getting the results, as shown in Fig.1.

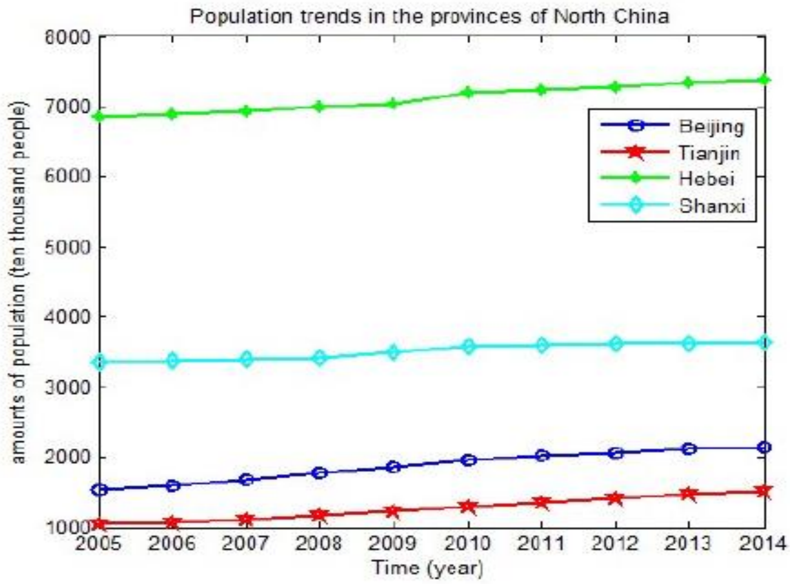

Fig 1: The trend chart of population in the provinces of North China

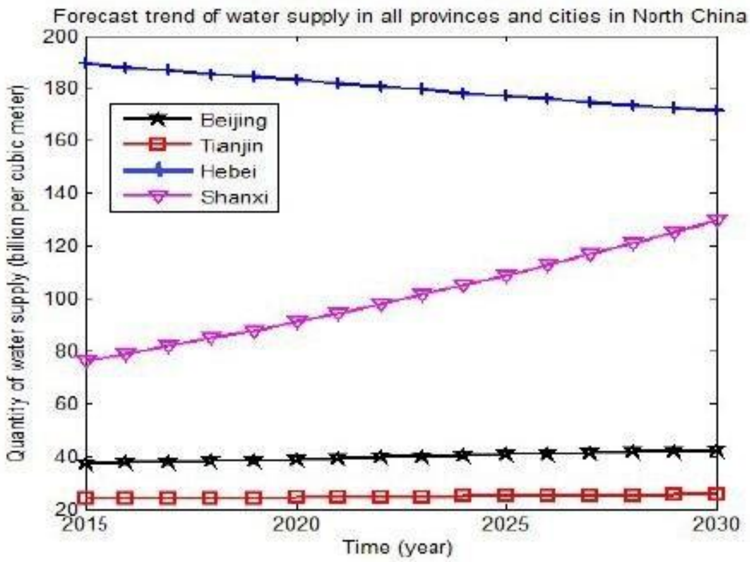

Fig 2: The forecast trend of water supply in the provinces of North China

From Fig.1, we can see, the population growth speed in Hebei and Shanxi have no decreasing trend in the short term, closely related to the reality of its development stage in the two provinces. The saturation in Beijing and Tianjin will bring greater pressure of population to Hebei and Shanxi, will also bring new challenges on water resources. The population in Beijing and Tianjin will grow slowing 2020, gradually stabilized, there is no increase in population. But in 2030, the population is still increasing, making water resources tenser.

The formulas obtained in each province are as follows:

$$Beijing: P = \frac{3601}{1 + 1.64e^{-0.062t}} \tag{2.1}$$

$$Tianjin: P = \frac{2532}{1 + 1.73e^{-0.061t}} \tag{2.2}$$

$$Hebei: P = \frac{14068}{1 + 1.1e^{-0.0128t}} \tag{2.3}$$

$$Shanxi: P = \frac{7148}{1 + 1.2e^{-0.016t}} \tag{2.4}$$

2.2 Forecast of water demand and water supply in North China in 2030

(1)Prediction of water demand

Seeking out the number of provinces in 2030, and getting the water required of every province in 2030 as shown in Tab.1 by the per capita consumption of provinces and cities [2].

(2)Forecasting and gap of water supply

In order to get the gap of water resources in 2030, supply quantities of various provinces and cities in North China are predicted in this paper by the establishment of grey prediction model GM(1,1) [3] and the data in Schedule 2. The results as shown in Fig.4.

Tab.1: Water requirement of all provinces in North China in 2030

Variable Symbols	Definition			
Province	Beijing	Tianjin	Hebei	Shanxi
The number of population(million people)	2433	1839	7821	3961
Per capita water consumption(m3)	172	161	260	203
Water requirement(billion cubic kilometer)	41.8	29.6	203.3	80.4

The final predicted value of water supply in various provinces in 2030 is shown in Tab.2. At the same time, it can be seen from Fig.2 that the water supply in Hebei province has a clear downward trend, which is caused by the development of industrial water pollution and the imperfect water resources management system. Shanxi has a slight rise, which is prone to drought, the rose of this year’s water supply is contributed by the implementation of the Huang Jijin project. There is no change in Tianjin and Beijing. Basically, the stability of the water supply in north China, will be sustainable supplied in the near future. But it is known by the situation of population and demand, the water resources will be unable to meet the needs of production and daily life with the increase of population and rising demand for water. If water supply keeps the same as the original level and the law of development, without any measures, the situation will be more and more severe. The resulting gap is shown in Fig.5.

Tab.2: The quantity of water supply in the provinces of North of China in 2030

Provinces	Beijing	Tianjin	Hebei	Shanxi
Water supply in 2030(billion cubic kilometer)	37.6	27.1	176.1	78.5

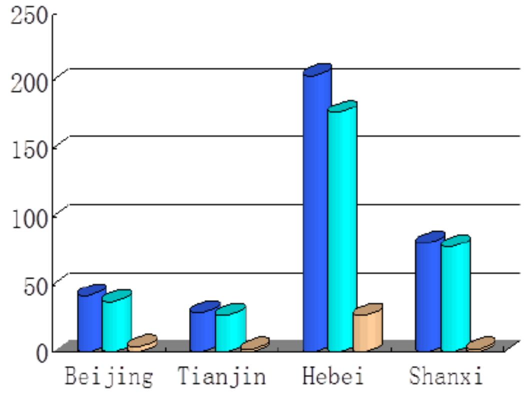

Fig 3: The supply and demand of water resources in North China

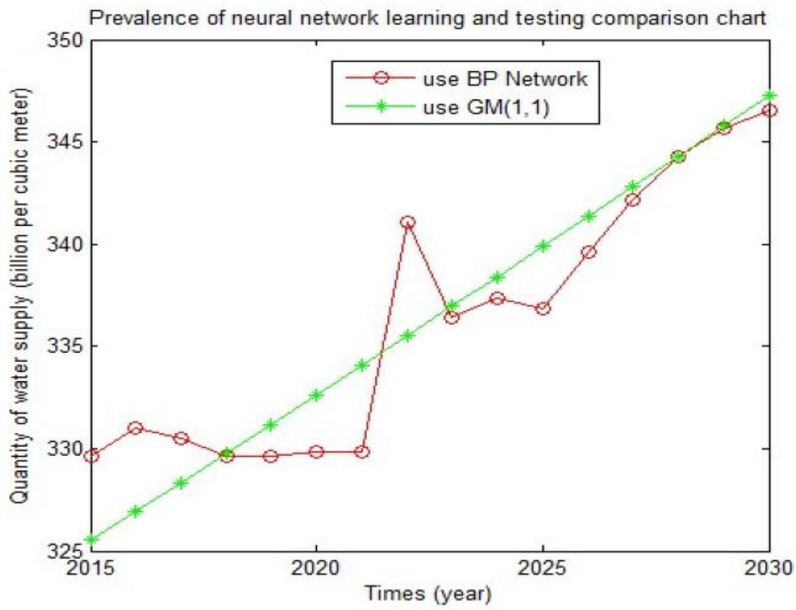

Fig 4: The result comparison diagram

As is shown in Fig.3, the total amount of water gap in North China is 35.8 billion cubic meters, if there is no effective strategy of water resources program taken in, Hebei will face great shortage of water resources by 2030. Beijing, Tianjin and Shanxi will also face varying degrees of water shortage soon. The shortage of water resources will restrict the development of industrial and agricultural production in North China, and affect the normal production and life of people.

2.3 Testing on the model

To outburst the difference and efficient furthermore, we transform the official data to the actual number of people who have been infected every week. And test the prediction error and precision of GM (1, 1) using BP Neural Network [4] and the Gray prediction. The results are as follows.

It is obvious that the results of the GM (1, 1) and the Neural Network are close to each other, which prove the correctness of Model 1 furthermore.

Tab.3: Results comparison in 16 years

Raw data		Data to predict		
Year	Data	Year	BP	GM(1,1)
2005	308.5	2015	325.525	329.593
2006	320.6	2016	326.932	330.997
2007	319.4	2017	328.345	330.495
2008	309.3	2018	329.765	329.609
2009	308.9	2019	331.19	329.601
2010	315.2	2020	332.622	329.812
2011	315.2	2021	334.06	329.812
2012	327.7	2022	335.504	341.066
2013	325.3	2023	336.954	336.441
2014	325.8	2024	338.411	337.386
-	-	2025	339.874	336.861
-	-	2026	341.343	339.606
-	-	2027	342.819	342.201
-	-	2028	344.301	344.258
-	-	2029	345.789	345.671
-	-	2030	347.284	346.548

3. The problem analysis with an intervention plan

3.1 Intervention plan 1: Building reservoirs

Water storage includes two aspects: groundwater and surface water. Changing environment constantly and increasing vegetation coverage are needed for the storage of groundwater, it is difficult to achieve in the short term. Therefore, we build reservoirs to increase the storage of surface water primarily, in order to make up for the gap of water supply and demand gap in 2030. First of all, we determine the number of reservoirs should be built through the supply and demand of various provinces' water supply and demand. Then evaluate of the effectiveness of the construction of the reservoirs through the impact of their flood control, power generation, aquaculture and other aspects. Tab.4 can be gathered by looking for the reservoirs' capacity and quantity in provinces and cities.

Tab.4: Number and capacity of reservoirs in four regions

Regions	Beijing	Tianjin	Hebei	Shanxi
Large reservoir capacity(billion cubic meters)	36.68	7.76	56.48	6.13
The quantity of large reservoir	4	3	18	6
Average library capacity(billion cubic meters)	9.17	2.59	3.14	1.02

To solve the problem of water shortage by building a reservoir to increase water storage capacity, it can also bring huge benefits. Building a reservoir to increase water storage capacity can not only solve the problem of water shortage, but also can bring huge benefits. For example, the construction of Zhangfeng Reservoir in 2005, of which generating capacity is up to 770, meanwhile, flood control standard from once every 5-10 years is increased to once in 20 years, enhancing the flood control capacity greatly. Therefore, the pressure on the entire North China can be decreased by building reservoirs in the four regions. Meanwhile, it can also save energy and protect the environment by turning thermal power generation into hydropower. In addition, the ability of flood control can be enhanced by increasing the quantity of reservoirs. Precipitation in North China is seasonal changing, the measures to better storage of precipitation and avoiding precipitation of wasted and seasonal shortage of water. Last but not least, we can also improve economic efficiency through aquaculture, etc. There will be some risk when building reservoirs inevitably. The general service life of reservoir is about 50 years. As a result, the water can only be fully guaranteed within 50 years by building reservoirs. With time goes on, repairing measures should be taken to solve the reemergence of water supply and security issues.

3.2 Intervention plan 2: Water resources protection and sewage treatment

It can be found that through the study of above of water flow that the cost of building reservoir is high while sustainability is poor. There are many using the existing water diversion project water resources flow cost is low, poor sustainability and environmental benefit is low, high cost of sea water desalination, sustainability, environmental benefits are higher. In recent years, the sewage treatment has become the object of consideration for its low cost and the characteristics of the environment protection. The sewage treatment will be discussed here. Environmental pollution which lead to the production of sewage, water shortages, and other serious impact on the quality of water resources. For example, soil salinization, heavy metal pollution. It makes the sewage discharge and treatment very important, so we need to ease the problem by the means of building a sewage treatment plant. Meanwhile, enormous environmental benefits and social benefits can be gained through the use of reuse water, which can be fully used of. Illustrating the environmental benefits of pollution control firstly, considering the size of the degree of environmental pollution. In order to simplify the model, the content of ammonia nitrogen is used to measure the amount of pollutants, and establish the following formula:

$$M = p \times c \tag{3.1}$$

$$Z = \frac{1000e^{0.1M}}{y} \tag{3.2}$$

Where M means the total content of ammonia nitrogen in wastewater, c means the tons of sewage treatment, p means the ammonia nitrogen content of sewage in every ton, and Z means the population in the area.

The value of the objective function is greater, the more serious pollution in the area, the need to establish a sewage treatment plant is greater. The following is the prediction of sewage discharge on the provinces. The ammonia nitrogen in per ton of sewage is related to the type of sewage, but there is of little change in one province or city, so it can be considered to a constant in this paper. At the same time, we can calculate the values of each of the provinces and observe the pollution degree by using the prediction of population above, forecast of the sewage emissions and sewage ammonia nitrogen, in order to provide the basis on the necessity to build a sewage treatment plant.

The constant value of ammonia nitrogen content in the units of various provinces and cities as shown in Tab.5.

Tab.5: Amounts of ammonia nitrogen in sewage

Provinces	Beijing	Tianjin	Hebei	Shanxi
Ammonia nitrogen content of sewage in every ton	1.3	3.3	4.1	4.2

The regression analysis [5] is made to predict the total waste water in 2030 in the total discharge of sewage of the provinces in North China. Take Hebei Province as an example, draw the scatterplot and curve fitting. The results are as shown in Fig.5.

From Fig.5 it can be seen that the total discharge of sewage is year by year index rising trend in Hebei Province from 2004 to 2013. That means with the development of social economy and population, the industrialization deepening and living waste water increases. As a result, the sewage emissions continue to increase, great influence is caused on the environment, and the waste water treatment needs are increasing.

For the other three provinces, the four curves above obtained from the regression equation, in the same way. Following is the regression equations of Beijing, Tianjin, Hebei and Shanxi:

$$g_1(t) = 9.2\times 10^4 e^{0.051(t-2003)} \tag{3.3}$$

$$g_2(t) = 4.8\times 10^4 e^{0.050(t-2003)} \tag{3.4}$$

$$g_3(t) = 1.9\times 10^5 e^{0.049(t-2003)} \tag{3.5}$$

$$g_4(t) = 8.5\times 10^4 e^{0.046(t-2003)} \tag{3.6}$$

It can be predicted the total discharge of sewage that in 2030, as shown in Tab.6.

Tab.6: The discharge capacity of sewage in 2030

Province	Beijing	Tianjin	Hebei	Shanxi
The discharge capacity of sewage(ten thousand tons)	280750.52	147059.77	559845.96	365480.55

4. Analysis and summary

Water is the key element for life on earth. With the development of society, the conflict between water resource and human life has become a constant topic. The total water resource on earth is about 13.8 billion cubic kilometer, and 97.5% is sea water (about 13.45 billion cubic kilometer), freshwater only accounts for 2.5%, the vast majority of it is polar ice, snow glaciers and groundwater, suitable for the enjoyment of human beings is only 0.01%. In the 20th century, the population of the world has increased two times, and human water increased 5 times, many countries in the world are facing water crisis.

As a country with large population, the water resources situation is particularly grim. China's total water resources are 2.8 billion m^3, ranking sixth in the world, while the per capita share of it is 2240m^3, about 1/4 of the world's per capita, ranking 109th in the world. China has been listed as one of the 13 water poor countries in the world. Currently, there are sixteen provinces' per capita water resources (not including transit water) under the serious lack of water-line, six provinces and autonomous regions (Ningxia, Hebei, Shandong, Henan, Shanxi, Jiangsu) per capita water resources amount less than 500m^3. The shortage of water resources has become a deep concern of the government and the people in our country [6].

$$\lambda = \frac{GDP}{Q} \quad (4.1)$$

Where λ is the level of water saving, Q is the total amount of water used in a region, GDP is the gross product of the region. According to data from the third schedule, the trend of the λ change in the four provinces of North China and in whole country is as Fig.6.

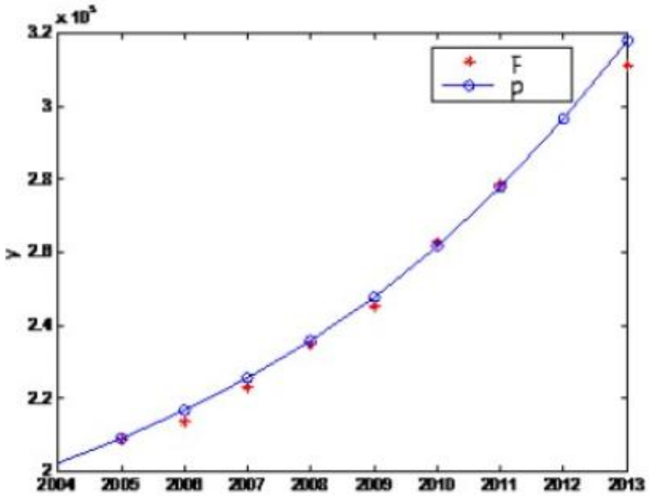

Fig 5: Fitting curve of total sewage in Hebei and whole country

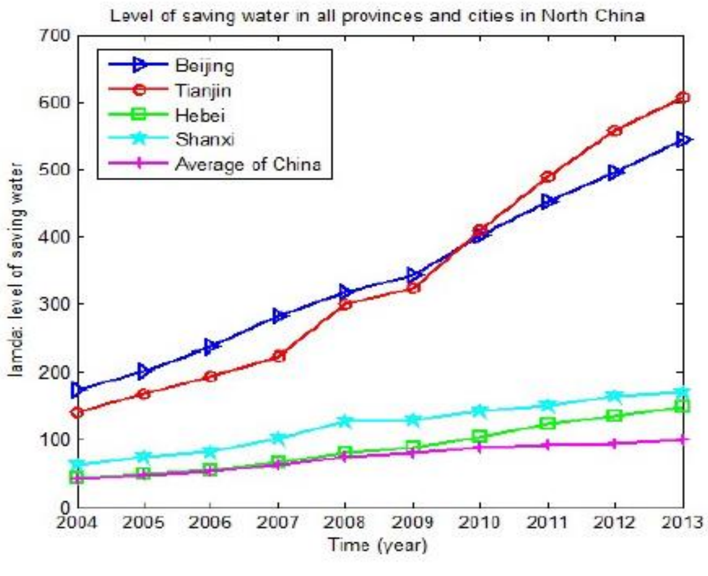

Fig 6: The water-saving level in North China

From Fig.6, in the provinces of North China, Beijing and Tianjin have the highest water-saving level, while the water-saving level in Hebei and Shanxi are generally higher than the national level, lower than the average level in North China. In addition, the development speed of the two provinces is slow, obviously investment in water-saving project of Hebei and Shanxi are relatively small. Overall, it is necessary to increase the investment in water conservation in Hebei and Shanxi to mitigate water scarcity of North China.

Acknowledgments

In this paper, the research was sponsored by the Chongqing 151 major projects of science and technology (cstc2013jcsf - jfzhX0002) "Agriculture and Rural Comprehensive Information Service Collaborative innovation and key technologies".

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