

# Research on Sustainable Utilization of Water Resources Based on Grey Prediction Model

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**Abstract.** Because of people's increasing demand for water resources and excess usage of existing water, water shortage exists in many countries. Accordingly, the research on how to solve the water scarcity is of great value. Considering the dynamic influence of time on water resource supply and demand and the two factors including the degree of water resource exploitation and per capita availability of water, the water resource supply and demand model is built to measure the capacity of the region to offer clean water. Building up the grey prediction model to predict the following 15 years' population situation and the total water resource supply in north China. By combining the model in before, the result that the demand for water resource is greater than the supply is concluded, which means severe water scarcity. The water scarcity causes the decrease of agricultural planting output, the change of planting structure, the reduction of industrial agglomeration and the residents' daily usage of water not reaching the living standard.

## 1. Background and Research Status

Due to the acceleration of economic development and population growth, people's demand for water resources increases dramatically which contributes to a series of urgent problems, such as shortage, uneven distribution and serious pollution of water resources. All triggering problems of water scarcity are threatening the whole world economy, so how to solve these usefully and efficiently has become an important implementation part of our national economy.

Therefore, amounts of experts investigate water resources from different dimensions. Foreign specialist Joseph. A (2003) built Water GAP2 Model to predict demand of water for households (representing by the Sigmoid Curve), agriculture and industry (represent by the Hyperbola Curve) separately. This model includes factors of people's income, utility of water and number of rainy days. Domestic experts Li lie (2011) and Fusin Wang (2013) respectively built model to utilize water rationally. Liu offered the method to measure demand of water for households (using Logistic Population Growth Model), industry (using GM (1, 1) Model), agriculture (Developing Trend Model) and ecology in Qingdao (Quantified need of water Model) which is the representation of coastal city experiencing water shortage. Also, Wang built the Nonlinear Coupling Analysis Model to allocate water resources rationally and accurately.



## 2. Supply and Demand Model of Water Resources

Degree of developing and utilizing water resources can be defined as percentage of annually available fresh water occupying in total amount of fresh water; Index of water scarcity can be classified as low (degree of developing and utilizing water resources < 30%), median (30% < degree of developing and utilizing water resources < 50%) and high-water pressure (degree of developing and utilizing water resources > 50%).

Initially, the paper analyzes supply and demand for water resources.

(1) Factors affecting supply of water include amounts of natural water resources ( $x_1(t)$ : surface water;  $x_2(t)$ : underground water) and technological water resources ( $x_3(t)$ : artificial water-sea water desalination, recycling purification, etc.). Besides, decreasing quantity of water supply due to environmental pollution can be de represented by  $x_4(t)$ .

(2) Factors affecting demand of water include industrial usage of water  $y_1(t)$ , agriculture usage of water  $y_2(t)$  and household water  $y_3(t)$ .

Total water supply  $S(t)$

$$S(t) = x_1(t) + x_2(t) + x_3(t) - x_4(t) \quad (1)$$

Total water demand  $Q(t)$

$$Q(t) = y_1(t) + y_2(t) + y_3(t) \quad (2)$$

Degree of developing and utilizing water resources  $\eta(t)$  can be defined as ratio of total water supply and total water demand. We can estimate the number of  $\eta(t)$  to judge the moment situation of degree of water shortage.

Degree of developing and utilizing water resources:

$$\eta(t) = \frac{S(t)}{Q(t)} \quad (3)$$

**Table 1.** Degree of Developing and Utilizing Water Resources Standard

Numble	Development and utilization of water resources	division criterion
1	0.3-0.5	Slightly explode
2	0.5-0.7	Moderate explode
3	0.7-1	Heavily explode
4	>1	over-Explode

Furthermore, considering the situation of population growth by assuming total amount of population at  $t$  can be represented as  $N(t)$ . Hence, per capita available water can be expressed as

$R(t) = \frac{Q(t)}{N(t)}$  and this paper uses  $R(t)$  to measure the ability for this area offering clean water.

### 3. Choice of water scarcity area

China have been listed as one of the country among 13 countries where undergoing severe water shortage. Even though amounts of fresh water in our country holds 6% of whole world, per capita fresh water for China only 1200m<sup>3</sup> which accounts for quarter of average per capita in the world. According to the below pictures (supply and demand of water in China 2015):

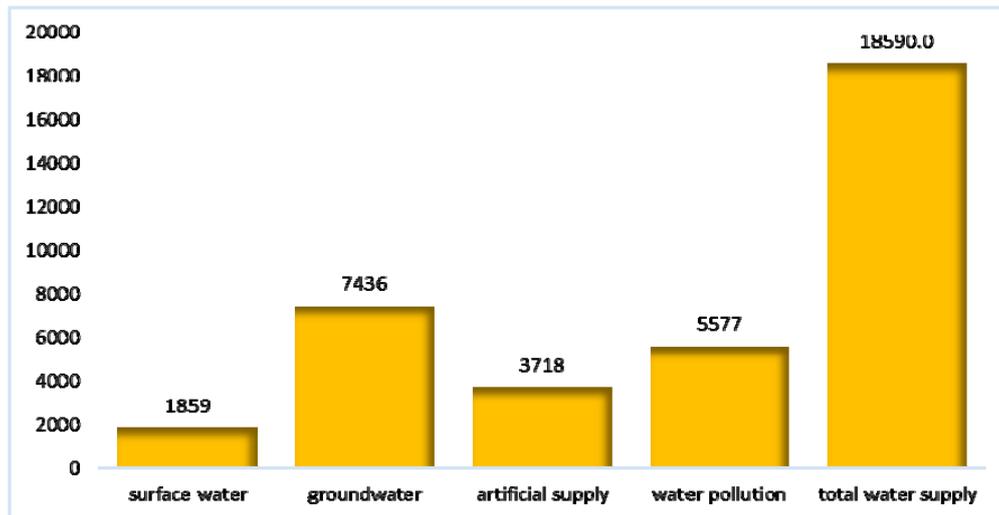


Figure 1. Water supply in China

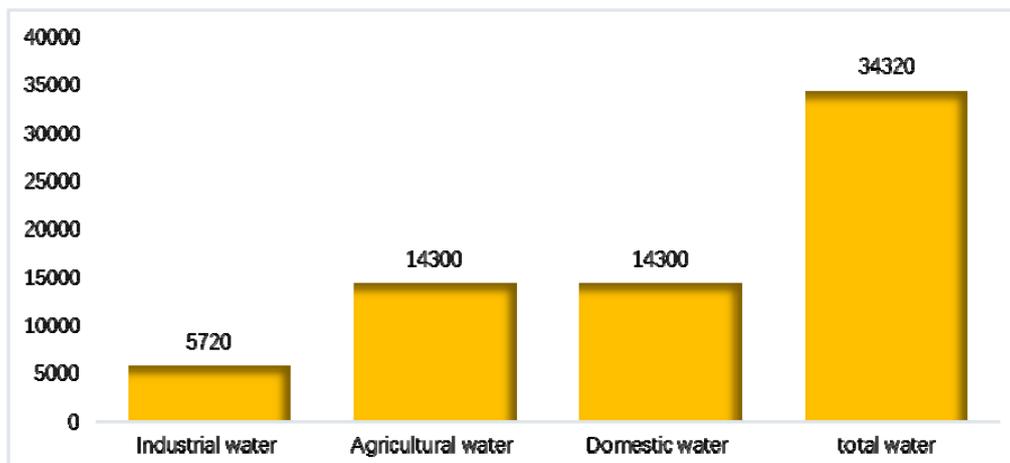


Figure 2. Water demand in China

$$\text{When } y = 2015: \quad \eta = \frac{S}{Q} = \frac{18590}{28600} = 0.65 \quad \eta = \frac{Q}{N} = \frac{28600}{13} = 1200m^3$$

Comparing to the international standard for division for degree of available water resources (shown in the table 2), degree of water shortage in China is between moderate and severe water shortage.

Thus, this paper choose China as the researching object of facing water country. According to the table 2, the distribution of water resources in China is uneven and there is a large difference of available water resources between different parts in China. It suggests that per capita in northern part of China is 449m<sup>3</sup>. Although northern part holds 7.7% ranking number two among different parts of China, per capita water resource is the least one (Table 3).

**Table 2.** Standard for Division for Degree of Available Water Resources

Internationally accepted standards	Per capita water consumption
slight water shortage	< 3000
moderate water shortage	< 2000
severe water shortage	< 1000
Extreme water shortage	< 500

**Table 3.** The regional distribution of water resource China

partition	Water resource	population	2010	Average per hectare of cultivated land
northeast	7.0	9.6	1501	9900
north China	7.7	34.7	449	5595
northwest	4.8	2.1	4140	23835
South of the Yangtze River	80.4	53.6	2952	64755
whole country	100	100	2050	28320

Thus, this paper uses the typical area northern part of China to illustrate reasons for water shortage in China.

#### 4. Prediction of water resources in China during the following 15 years' period

China Statistical Yearbook shows amounts of population and total water supply of North China from 2010 to 2014 (table 4).

**Table 4.** Total Population and Water Supply of North China in 2010-2015

year	Population	Total Water Supply
2010	497.05	497.05
2011	513.92	513.9
2012	512.06	512.08
2013	508.42	508.42
2014	507.78	507.78

Logistic Model was proposed by Verhulst-Pearl 1938 and often used by population prediction later. Hence, this paper built Logistic Model to predict tendency of the number of population in north China during the following 15 years. Because of resources limiting, Logistic model predicting population growth could be expressed as (6) equation:

$$\frac{dx}{dt} = rx\left(1 - \frac{x}{x_m}\right) \quad (4)$$

Where  $r$  stands for growth rate of population,  $x(t)$  stands for amounts of population,  $x_m$  stands for the maximum amounts of population.

Transforming the above equation to (5) equation:

$$x(t) = \frac{x_m}{1 + \left(\frac{x_m}{x_0} - 1\right) e^{-rt}} \quad (5)$$

Applying Logistic Model to predict population change in northern area of China:

**Table 5.** Prediction of Total Population in the following 15 years

Year	population (ten thousand)	Year	Population (ten thousand)
2015	18015.2	2023	26908.8
2016	18439.6	2024	31822.5
2017	18936.3	2025	43833.6
2018	19528.6	2026	53833.6
2019	20258.1	2027	65833.6
2020	21185.1	2028	80833.6
2021	22424.4	2029	98833.6
2022	24184.5	2030	119833.6

Use the total population forecast to further predict the total water demand in north China in the next 15 years, as shown in Table 6.

**Table 6.** Total water demand for the next 15 years in North China

Year	population (ten thousand)	Year	Population (ten thousand)
2015	17316.5	2023	26908.8
2016	17645.4	2024	31822.5
2017	18015.2	2025	43833.6
2018	18439.6	2026	53833.6
2019	18936.3	2027	65833.6
2020	19528.6	2028	80833.6
2021	20258.1	2029	98833.6
2022	21185.1	2030	119833.6

Grey Prediction Model was proposed by Chinese specialist Jalon Deng in 80th 19 century and developed prosperously which have been applied in lots of field, such as demography, economy geography and meteorology. This paper applies this model to predict total water supply in northern part during the following 15 years.  $x^{(0)}$  Represents initial series,  $x^{(1)}$  represents accumulated series based on the initial series; “ $a$ ” represents developing parameter; “ $b$ ” represents model coordinating coefficient.

Given a series of observation data:  $\hat{x}^{(0)} = \{\hat{x}^{(0)}(1), \hat{x}^{(0)}(2), \dots, \hat{x}^{(0)}(N)\}$

After accumulating:  $\hat{x}^{(1)} = \{\hat{x}^{(1)}(1), \hat{x}^{(1)}(2), \dots, \hat{x}^{(1)}(N)\}$

And then:

$$x^{(1)}(k) = \sum_i^k x^{(1)}(i), (k = 1, 2, \dots, n) \quad (6)$$

Satisfying first order linear differential model:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \quad (7)$$

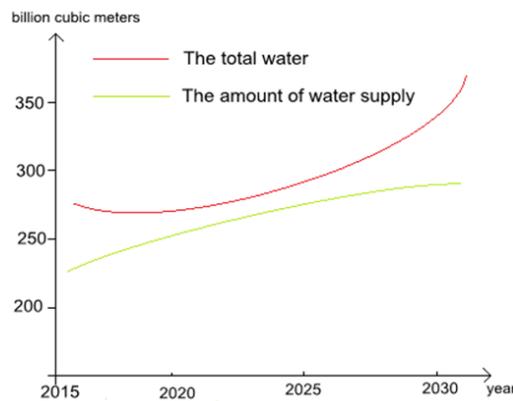
Getting:

$$x^{(0)}(k+1) = x^{(1)}(k+1) - x^{(1)}(k), (k = 0, 1, 2, \dots)$$

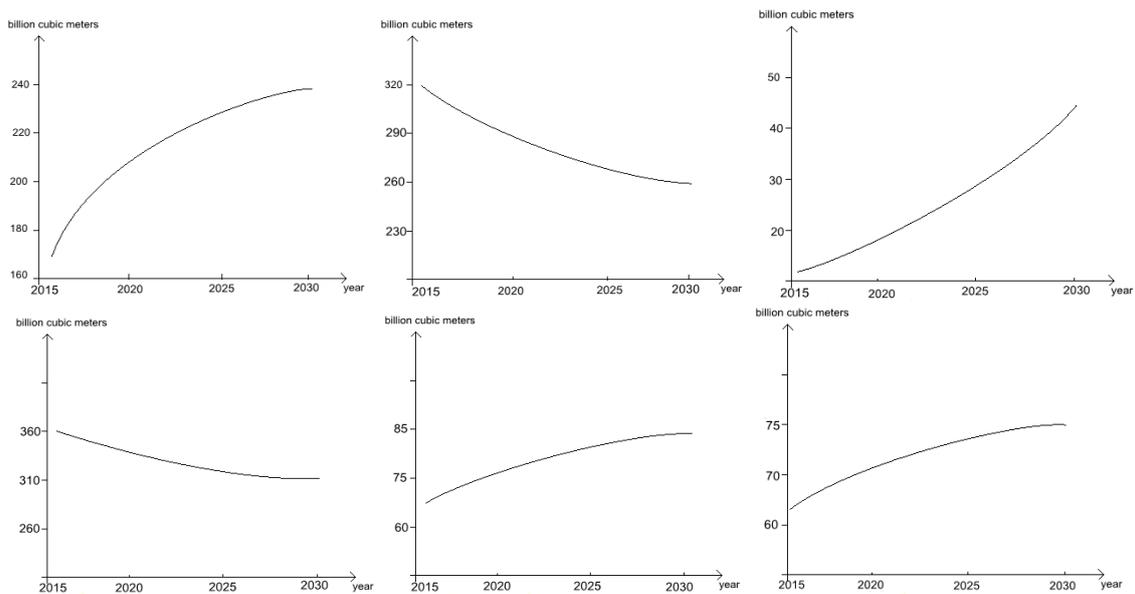
As shown in the following table 7, results of prediction of water supply for north area in China through Grey Prediction Model are increasing lightly.

**Table 7.** Total Water Supply in the following 15 years

Year	Total supply(m3)	Year	Total supply(m3)
2015	606.2121	2023	728.4853
2016	619.8375	2024	746.0022
2017	633.9765	2025	764.4202
2018	648.5298	2026	765.4356
2019	663.4183	2027	766.2479
2020	678.9396	2028	767.1911
2021	694.9539	2029	768.1472
2022	711.469	2030	769.0114



**Figure 3.** Change of Supply Water of North Area in China in the following 15 years



**Figure 4.** Change in the Supply (above) and Demand (below) of water resources (agriculture, industry and household)

**Table 8.** Standard of Households' Water usage

Numble	Daily water usage(L/per·d)	Region
1	80~135	Heilongjiang,Jilin,Liaoning,Inner Mongolia
2	85~140	Beijing,Tianjin,Hebei,Shanxi,Shan'xi,Ningxia,Gansu
3	120~180	Shanghai,Jiangsu,Zhejiang,Fujian,Jiangxi,Hunan,Anhui
4	150~220	Guangxi,Guangdong,Hainan
5	100~140	Chongqing,Sichuan,Guizhou,Yunnan
6	75~125	Xinjiang,Tibet,Qinghai

### 5. Influence of Situation of Water Resources for Residents' Daily Life

Shows the gap between supply and demand of water becomes larger in the future. According to the Grey Prediction Model, results shown in the table 7 predict that water resource in north part of China cannot meet the demand of household water usage (Table 8).

### 6. Conclusion

Thus, water scarcity has become the serious problem for resident's daily life. Then, treating daily water usage for household as the research object.

Calculating based on the providing data, the average daily water usage for north residents in China would be 75< (80~135L/per·d), which suggests that water supply cannot meet the demand for those people.

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