INTRODUCTION

Water is the basic of the survival and development of all creatures on the earth. And the water resource plays an essential role in sustainable development of the society as natural and economic resource. From the agricultural perspective, irrigation water is the lifeblood of agriculture; from the industrial perspective, water is an essential element in industrial production; from the ecological perspective, water is a kind of significant environmental resource in the sustainable development of human society. Therefore, water is the key factor of economic growth and sustainable development of the society and it is necessary to find a way to rationally use the water.

In terms of economics, water is scarce and irreplaceable while the demand for water is on the increase in the economy development. More seriously, the pollution of water is getting more severe, and as a result, the water resource is becoming increasingly scarce. According to scientific estimation, more than half of the countries and regions, especially the developing countries, lack drinking water. 70% of the population namely 1.7 billion people cannot drink clean water. Nearly 80% of the population is under the threat of water scarcity. Per capita water in China is a quarter of average level in the world and about 29% of people in more than 300 cities have no access to clean drink water, so China belongs to countries that lack water resource. The annual economic loss caused by water shortage and water pollution in China is more than 100 million yuan and 400 million yuan respectively.[1]

THE RESEARCH PROCESS

Water shortage exists in most parts of China. This paper did more researches and dedicated to better solutions for the current situation.

A questionnaire on the influencing factors of the water shortage was made. It indicates that the developments of regional economy and civilization quality of the citizens are the most important factors, excluding the capacity of water resource and the population.

Generally, the criterion for the water shortage situation is based on that whether the water supply can meet the water demand. According to the data from China's National Bureau of Statistics, the water utilization rate in developed regions is higher. The water resource is mainly used in industrial, domestic life and agricultural areas. And citizens in the developed regions use more water mainly in industrial and agricultural areas.

Model of Forecasting Water Shortage Degree

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ABSTRACT: With the development of the world economy and the increasing of the population, the demand for water resources is also increasing. However, the water resource is constantly reducing and unevenly distributed. The water shortage problem aroused more attention from the public. It’s necessary to propose a simpler method to measure the shortage degree in one country or region. By using the ratio of the water supply and water demand a model to measure the water supply capacity can be established. This paper firstly established parent model 1 to measure the water supply, and model 1 includes three sub models: population prediction model, water resource per capita model and economic coefficient model. After that, another parent model 2 was established to estimate the demand for the water. Many factors like population, GNP and agricultural irrigation water can greatly impact the water demand. The data from different regions were obtained to evaluate the water shortage degree in China. By using the forecasting model, we can predict the water shortage situation of North China in 2030.

Keywords: forecast model; water shortage
A model to measure water shortage degrees in different regions was established on the basis of large amounts of data.

3 MODEL REVIEW

3.1 Model

The ratio of water supply and demand is used as the measurement of water capacity in this paper. And we established a water supply model which is divided into population prediction model, per capita water resources model and economic coefficient model. Water demand model is categorized as the multivariate regression model. Put the parameters including the population, industrial water consumption and agricultural water consumption in a certain region into the multivariate regression model, and then we can obtain:

\[ N(t) = \frac{X(t) R(t) J(t)}{Y(t)} \]

Where \( N(t) \) The water capacity; \( X(t) \) The population change; \( R(t) \) Water resources per capita; \( J(t) \) Economic coefficient; \( Y(t) \) Water demand model.

3.2 Coefficient of water shortage

Water shortage situation of different regions in the world is shown in Figure 1:

By using the data from different regions, we can obtain the coefficient range of the water shortage degrees which is shown in Table 1.

| Shortage degree  | Over exploited | Heavily exploited | Moderately exploited | Slightly exploited | No shortage |
|------------------|----------------|-------------------|---------------------|-------------------|------------|
| \( N \)          | < 0.65         | 0.65-1.32         | 1.32-2.11           | 2.11-2.87         | >2.87      |

4 MODEL ANALYSIS AND PREDICTION

The relevant data in the Northern China was brought into the model to predict the water shortage degree in 2030.

4.1 Predict the population growth

The population and water resource per capita can be used as the criteria for the measurement of water supply capacity, and thus the population is an essential factor need to be taken into consideration.

4.1.1 Parameters

- \( x(t) \) Population growth
- \( r(x) \) Growth rate of the population
- \( x \) The population

4.1.2 Assumptions

1. There is no big accident leading to significant fluctuations.
2. The birth rate and death rate are the same every year.

4.1.3 Model description

When this paper sets up the population growth model, we refer to the Logistic model. The application condition of the model is that the population growth is slowing down and gradually to zero. To be specific, due to the limited resources and the influence of the environment, the growth rate will decline when the population reaches to a certain number. In other words, the growth rate \( r(x) \) is a decreasing function of \( x \) and the relationship between \( r(x) \) and \( x \) is described as \( r(x) = r(1-x/x_m) \). This is based on the assumption of population growth rate.

\[ r(x)=r(1-x/x_m) \]

Then the population growth rate is \( dx/dt=r(1-x/x_m) \), and we can obtain population at time \( t \) and \( t_0 \).

\[ x(t)=x_m/[1+(x_m/x_0-1)e^{rt_0}t] \]

Where, \( x_m \) is the largest population capacity (the maximum population the environment and resources can bear.)

However, it is hard to inquire the data of the largest population capacity, so we adopt Excel fitting method. According to regional demographic data in recent years, we use Excel to fit the curve, and then obtain the actual formula of fitting model \( x(t) \), thus establishing the population growth model.

Compared to the Logistic model, the fitting model cannot predict the population change with declining population. What’s more, the Logistic model only considers the influence of the birth rate and death rate, so the fitting model is more practical.
The population data of North China from 2000 to 2014 obtained from China Statistics Bureau is shown in Table 2.

Table 2. Population change in North China.

| (year) | 2000   | 2001   | 2002   | 2003   | 2004   | 2005   | 2006   |
|--------|--------|--------|--------|--------|--------|--------|--------|
| Population (Million) | 146.58 | 147.41 | 148.43 | 149.36 | 150.54 | 151.9  | 153.64 |

According to the population prediction model and the population in North China from 2000 to 2014, we use the curve fitting to obtain the curve with the highest accuracy: \( Y = 0.00079X^2 - 3.1392X + 3132 \). Under this circumstance, the determination coefficient \( R^2 \) is 0.98706 and it is very close to 1. The high fitting precision shows that the independent variable and the dependent variable are very closely correlated. We bring \( t = 2030 \) into \( Y = 0.00079X^2 - 3.1392X + 3132 \), the population in North China in 2030 is 240.51 million people.

4.2 Water resource per capita model evaluation

4.2.1 Parameters

- \( P \): Water resource per capita
- \( s \): Surface water
- \( g \): Underground water
- \( f \): Repeated computation

4.2.2 Assumptions

1. The water derives from surface water and underground water. And here we need to deduct the amount of the repeated computation of these two kinds of water.
2. There are no droughts, floods and any other natural disasters that lead to significant changes to the proportion of surface water and underground water.
3. Administrative division line remains the same.

4.2.3 Model description

Per capita water resource can be represented by a function composed of the surface water, underground water and the repeated computation.

\[ P = F(s, g, f) \]

Take the derivation of formula (1) with respect to time, we can get:

\[ \dot{P} = \frac{\partial P}{\partial s} \dot{s} + \frac{\partial P}{\partial g} \dot{g} + \frac{\partial P}{\partial f} \dot{f} \]

To obtain the derivative of \( P \), we multiply numerator and denominator by \( s, g \) or \( f \), and then,

\[ \dot{P} = \frac{\partial P}{\partial s} \frac{s}{p} \dot{s} + \frac{\partial P}{\partial g} \frac{g}{p} \dot{g} + \frac{\partial P}{\partial f} \frac{f}{p} \dot{f} \]  (2)

Where, \( \dot{P} \) is growth rate of water resource per capita, and it is represented by \( p\omega \); \( \frac{\partial P}{\partial x} \) is the output elasticity of water resource, and it is represented by \( \alpha_x \), \( s\dot{s} \) and \( g\dot{g} \) are the growth rate of surface water and underground water respectively, and they are expressed by \( sw, gw \) and \( fw \).

The contributions of various kinds of water resources to the water resource per capita can be expressed by a linear regression model as below:

\[ pw = \alpha_s sw + \alpha_g gw + \alpha_f fw + \varepsilon \]  (3)

Where, \( \varepsilon \) is random disturbance.

In order to discuss the dynamic state of water resource per capita with the time, convert equation (3) to:

\[ \ln(p) = \alpha + \alpha_s \ln(s) + \beta \ln(g) + \gamma \ln(f) + u \]  (4)

With consideration of the times, the model is further transformed into:

\[ \ln(p) = \alpha + \alpha_s \ln(s) + \beta \ln(g) + \gamma \ln(f) + bt + u \]  (5)

Where, \( t \) is the time.

And formula (5) is the water resource per capita model.

It can be know from the National Statistics Bureau, the water resource per capita in North China in 2014 is 526 m³. The corresponding data of water resource per capita, surface water and underground water from 2005-2014 is shown in Table 3.

Table 3. Water resource per capita in North China.

| (year) | \( g \) (m³) | \( s \) (m³) | \( f \) (m³) | \( p \) (m³) |
|--------|-------------|-------------|-------------|-------------|
| 2005   | 276.36      | 304         | 113.81      | 466.55      |
| 2006   | 263.25      | 262.52      | 109.65      | 416.12      |
| 2007   | 272.54      | 194.38      | 110.67      | 356.25      |
| 2008   | 306.61      | 264.42      | 116.69      | 454.34      |
| 2009   | 272.73      | 234.85      | 106.42      | 401.16      |
| 2010   | 267.44      | 227.62      | 100.36      | 394.7       |
| 2011   | 276.17      | 278.44      | 109.62      | 444.99      |
| 2012   | 323.44      | 342.24      | 117.7       | 547.97      |
| 2013   | 298.43      | 581.67      | 116.57      | 763.53      |
| 2014   | 263.52      | 302.17      | 107.39      | 458.31      |

It can be seen from Table 3 that water resource per capita was declining with time and the decline rate is about 1%.

\[ R (t) = 526 * 0.99 t \]
Bring \( t = 2030 \) into the above formula, we can know that the per capita water resource in 2030 is 452.4 m\(^3\).

### 4.3 Economic coefficient model

In addition to the influence of natural factors, social factors can also significantly impact the water supply. The developed countries have more perfect infrastructures and can reduce the wastage caused by the facilities, thus providing better protection for the water resource. Therefore, this paper combines the economic coefficient in the model to analyze its influence on the water supply. The infrastructure influence by the economic development and the management decided by the science and technology development are two most important factors.

#### 4.3.1 Parameters
- \( a \) Economic development level
- \( b \) Management level
- \( \delta \% \) Economic growth rate
- \( t \) The year to be predicted

#### 4.3.2 Assumptions
1. Economy develops stably in the given area.
2. Importance of the water resources in a region will not change.
3. The extent of emphasis on the water resources is constant.
4. Economic growth rate remains the same at \( \delta \% \).

#### 4.3.3 Model Description

Countries or regions can be divided into four categories according to the different levels of per capita GNP: high income (per capita GNP>9700$), above average income (per capita GNP 3000-9700$), below average income (per capita GNP 790-3000$) and low income (per capita GNP<790). Their corresponding value is 0.4, 0.6, 0.8, and 0.9. Management level is decided by the science and technology development and the emphasis of the government. An approximate range has been obtained: \( 0.3 \leq b \leq 0.9 \), and we can determine the management levels of the countries in this range. With considering the two factors comprehensively, we can obtain the economic coefficient model as below:

\[
J(t)=ab(1+\delta\%)(t-2015)
\]

By calculation, the GDP growth rate in North China is:

\[
\delta \%=\frac{(219285.531-201681.21)}{201681.2}*100\%=4.4\%
\]

Bring \( t=2030 \) into the economic coefficient model,

\[
J(t)=0.6*0.75*(1+0.044)(t-2015)=0.45*1.044(t-2015)
\]

We can get that:

\[
J(2030) = 0.858.
\]

### 4.4 Water demand model

Many influencing factors including the population, climate change, industry, agriculture, GDP, economic structures and management of the water resource can largely affect the water demand. And these influencing factors can be generally devised into three categories: industrial water, agricultural water and GDP\[1\]. A large amount of data shows that the water demand is closely correlated with the population, GDP and the agricultural irrigation water. With the application of multiple regression analyses, we tried to figure out the relationship between the water demand and the above three factors.

#### 4.4.1 Parameters
- \( C \) Regression coefficient corresponding to the population;
- \( d \) Regression coefficient corresponding to GDP;
- \( e \) Regression coefficient corresponding to agricultural irrigation water;
- \( Y(t) \) Water demand;
- \( C(t) \) Population;
- \( D(t) \) GDP;
- \( E(t) \) Agricultural irrigation water.

#### 4.4.2 Assumptions
1. Factors leading to water shortage would not be particularly impacted unless there is serious abnormal climate.
2. Industrial structure has no major changes in a short period and the water demand of industrial water does not need major adjustment.
3. The equipment for domestic water is not updated. water consumption has no significant adjustment.
4. Without human intervention, the external factors have no influence on geographical disaster.
5. There is no large population discrepancy in a short period of time.
6. The water conservancy facilities have no significant impact on the water resources in short term.

### Table 4. GDP of North China from 2012 to 2014(Unit: Billion yuan).

| GDP   | 2012       | 2013       | 2014       |
|-------|------------|------------|------------|
| Beijing | 4258.927   | 4648.08    | 5028.716   |
| Tianjin | 3052.117   | 3408.81    | 2620.9361  |
| Hebei  | 6329.604   | 6771.545   | 7019.752   |
| Shanxi | 2910.564   | 3025.785   | 3059.891   |
| Inner Mongolia | 3616.909 | 4482.317   | 3997.858   |
| Total  | 20168.121  | 22336.537  | 21928.5531 |

By calculation, the GDP growth rate in North China is:

\[
\delta \%=\frac{(219285.531-201681.21)}{201681.2}*100\%=4.4\%
\]

Bring \( t=2030 \) into the economic coefficient model,

\[
J(t)=0.6*0.75*(1+0.044)(t-2015)=0.45*1.044(t-2015)
\]

We can get that:

\[
J(2030) = 0.858.
\]
4.4.3 Description
The general form of multiple linear regression model is as follows:

\[ Y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_i x_i + \ldots + b_n x_n (i=1, 2, \ldots, n) \]

In the study of practical problems, the change of the dependent variables is often influenced by several important factors. So we need to consider two or more factors as the independent variables to explain the change of the dependent variable. This is the multivariate regression, which is known as multiple regression[16]. When there is a linear relationship between several independent variables and dependent variables, the regression analysis is a pluralistic regression. After several independent variables and dependent variables, the regression analysis is a pluralistic regression. After several years can be collected. Fit their regression coefficients \( c, d, e \) and then the water demand model is obtained:

\[ Y(t) = cC(t) + dD(t) + eE(t) + f \]

With considering the dynamic characteristics of factors that influences the water supply and demand, with the help of Matlab, we can get the simulated fitting curve of \( C(t), D(t), E(t) \) by using MATLAB.

4.4.4 Multivariate linear programming
The population, GDP, agricultural irrigation water and the water demand in North China from 2005 to 2013 obtained from China Statistics Bureau are shown in Table 5:

| Year | C(t) (Million people) | D(t) (Billion yuan) | E(t) (Billion m³) | Y(t) (Billion m³) |
|------|----------------------|--------------------|------------------|------------------|
| 2005 | 151.90               | 2902.83            | 353.04           | 489.85           |
| 2006 | 153.64               | 3512.36            | 356.58           | 494.55           |
| 2007 | 155.56               | 4436.52            | 363.15           | 501.63           |
| 2008 | 156.91               | 4612.53            | 365.22           | 503.2            |
| 2009 | 160.07               | 4710.32            | 367.1            | 503.7            |
| 2010 | 165.01               | 6897.354           | 377.23           | 521.32           |
| 2011 | 166.90               | 7532.561           | 382.41           | 527.63           |
| 2012 | 168.71               | 8534.17            | 385.65           | 533.52           |
| 2013 | 170.48               | 9226.752           | 389.52           | 537.61           |

We put the water demand, population, GDP and the agricultural irrigation water into the water demand model, and then,

\[ Y = 378.2121 + 0.0005 X_1 + 0.0006 X_2 + 0.0005 X_3 \]

\( R^2 = 0.9982 \) shows that the fitting accuracy is higher and the effectiveness of the multivariate regression model can be obtained.

4.4.5 The curve fitting of independent variables
The relationship between GDP, agricultural irrigation water and time was fitted by curve fitting, so that the correlation between the water demand and time is obtained.

Three curve fittings are conducted by EXCEL. With the consideration of the precision of curve fitting and equation of complexity, three forecast formulas of industry GDP are obtained respectively.

1. Curve fitting of the population
\[ Y = 7.8697 x^2 - 31392 x + 30000000; \text{at this time the decision coefficient} \ R^2 = 0.9876 \]

2. Curve fitting of GDP
\[ D(t) = 417.94 t^2 - 20000000 t + 2000000000; \]

Put \( R^2 = 0.97095 \) into the \( t = 2030, D(2030) = 366800; \)

3. Curve fitting of the agricultural irrigation water
\[ E(t) = 4.7277 t - 9126.8; \text{at this time the decision coefficient} \ R^2 = 0.98083. \]

Put \( t = 2030 \) into the model, so \( E(2030) = 471.231. \)

4.5 Predicted results
By putting the population, GDP, and agricultural irrigation water in 2030 into the multivariate linear equation, we can obtain the water demand correspondingly.

And by bringing the population, per capita water resource, the economic coefficient and the water demand into the model, we can obtain \( N(2030) = 1.56. \) It can be seen that the situation of water shortage in North China will be slightly alleviated after 15 years.

Combining the aforementioned four models, the population in 15 years will continue to grow under the formula: \( Y = 7.8697 x^2 - 31392 x + 31392 \) (IMF). Per capita water resource is predicted to be reduced. The economy growth in North China will be stable at 4.76%. The economic coefficient \( J(2030) = 0.858 \) can provide a complete infrastructure of water supply and water resources management.

By comparison with Table 1, the water situation in North China has been improved slightly, but it will still remain in the state of water shortage in 2030.

5 CONCLUSION
Whether the water resource in one region or country is in shortage is related to many factors, we should increase the water supply capacity and reduce the water demand to relieve the water shortage situation. To ensure the water supply capacity, it needs to fasten the economy development. Also, to improve the civilization quality can raise the awareness of rational utilization of water resources.

In addition, it needs to strengthen the scientific and technology innovation to provide more water supplies, such as the desalination of sea water and the improvements of water resource management. The south
area needs to improve the utilization of water resources. With all these efforts, the current situation of water shortage can be greatly relieved.

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