An integrated prediction model for water supply-demand ability

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Keywords: supply and demand, simple polynomial regression prediction ,grey prediction,

Abstract. In this paper, a model is developed to measure the ability of water supply in a region, based on the dynamic nature of the factors that affect both supply and demand. We pick China, a water-strapped country, to begin our analysis. For water demand, we assume the water demand can be approximately thought as the water withdrawal consumption. The withdrawal is divided into three parts: agricultural, industrial and municipal. For water supply, we mainly consider surface water, underground water and desalination. Through the historical data from China, we get the fitting curves. Using simple polynomial regression prediction and grey prediction, we establish the model Ⅰ to predict the water withdrawal in the future. As for water supply, we build model Ⅱ by using linear regression prediction and polynomial prediction.

Introduction

Fresh water is an essential portion of the production and life, constraining the development in countries. While, the fact is that billions of individuals, approximately a quarter of the world, are going through water scarcity. It was mainly caused by two reasons. The one is that water use has been continuously growing. The other is that environmental and social factors limit water supply. Increasingly, countries are paying attention to alleviating water scarcity, and predict future availability of water. A project should be provided to go into the water scarcity and improve the situation.

In this paper, we want to find a way to measure the ability of providing clean water.

Our work

From WSI in major basins[1], we choose a water-strapped country, China, to do our analysis. In this section, Our analysis began by water demand and supply. We use regression prediction and grey prediction to build model Ⅰ, and then build model Ⅱ by regression prediction. So we can measure the ability of providing clean water by the ratio of supply to demand. Run model Ⅰ, Ⅱ and we can predict the water demand and supply in 15 years in Beijing. According to that situation, We discuss the impact on the lives of residents.

Model Ⅰ: demand forecasting model

Human water withdrawal is normally divided into three major categories, agricultural, industrial and municipal. Each has its own tends in growth. Thus, it is important to consider them separately.

We divide the progress into four steps.

Step1: Industrial water

Using historical data from Chinese water resources bulletin (shown in the Table 1), we get the fitting curve, shown in Figure 1. A mathematics model of simple polynomial regression is established.

$$W_{\mathrm{i}} = 113.887 - 1.124\mathrm{x} + 0.566x^2 \tag{1}$$

Table 1. China industrial water withdrawal 2000-2007
(source: Chinese water resources bulletin)

Year	2000	2001	2002	2003	2004	2005	2006	2007
W_{i} ($10^9 m^3$)	113.9	114.1	114.3	117.6	123.2	128.4	134.4	140.2

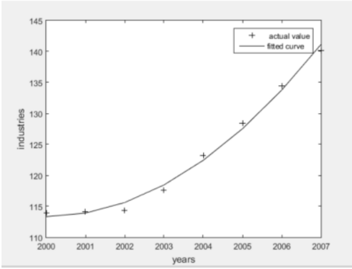


Figure 1. The fitting of industrial water withdrawal in China.

We examine the equation by MATLAB. Then we get the goodness of fit R^2 is 0.989, and the confidence level p is 0.000. Referring to literature[2], our polynomial regression is significant, which can predict the industrial water withdrawal reasonably.

Step2: Agricultural water

Similarly, we can get the fitting curve of agriculture water withdrawal in Figure 2. The fitting equation is

$$W_a = 341.360 + 6.548x - 0.346x^2 \quad (2)$$

Table 2. China agricultural water withdrawal 2003-2011
(source: Chinese water resources bulletin)

year	2003	2004	2005	2006	2007	2008	2009	2010	2011
W_a ($10^9 m^3$)	343.1	358.4	358.3	366.2	360.2	366.4	372.2	369.1	374.4

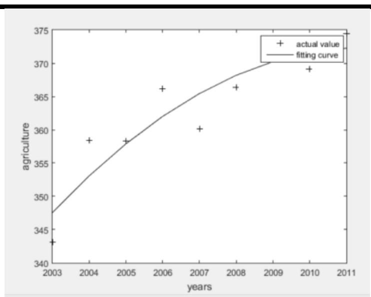


Figure 2. The fitting of agricultural water withdrawal In China.

We examine the equation. The goodness of fit R^2 is 0.794, and the confidence level p is 0.004. So our polynomial regression is significant.

Step3: Municipality water

We consider that municipal water withdrawal is closely related to the growth of population. According to the remark that population grows exponentially, put forward by Malthus, a English demographer, the municipal water withdrawal is different from the two above. In result, we collect data and establish a grey prediction model to predict that municipal water withdrawal in the future.

If

$$X^{(0)} = \{X^{(0)}(1), X^{(0)}(2), \ldots, X^{(0)}(n)\} \quad (3)$$

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i) (\text{ k=1,2,...,n }) \quad (4)$$

so

$$d(k) = x^{(0)}(k) = x^{(1)}(k) - x^{(1)}(k-1) \quad (5)$$

We assume $z^{(1)}$ is the mean sequence of $x^{(1)}$:

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1), \text{ k=2,3,...,n} \quad (6)$$

So

$$z^{(1)} = (z^{(1)}(2), z^{(1)}(3), \ldots, z^{(1)}(n)) \quad (7)$$

For the grey differential equation of GM (1,1):

$$x^{(0)}(k)+az^{(1)}(k)=b \tag{8}$$

if we regard the time k=2,3,···,n of $x^{(0)}(k)$ as continuous variable, then the sequence $x^{(1)}$ can be regarded as the function of time t, denoted by $x^{(1)}=x^{(1)}(t)$. And grey differential equation $x^{(0)}(k)$ corresponds to $\frac{dx^{(1)}}{dt}$. the background value $z^{(1)}(k)$ corresponds to $x^{(1)}(t)$. Then we can get the corresponding white differential equation:

$$\frac{dx^{(1)}}{dt}+ax^{(1)}=b \tag{9}$$

Assuming that raw data sequence $x^{(0)}$ has n observed values (shown in the following equation), accumulate it to generate a new sequence

$$X^{(1)}=\{X^{(1)}(1),X^{(1)}(2),\ldots,X^{(1)}(n)\} \tag{10}$$

And fit the curve of function. Using the fitting function, we can get the predicted value sequence $\boldsymbol{X}_{(1)}$ of $\boldsymbol{X}^{(1)}$. Through regressive revivification of

$$X_{(0)}(k)=X_{(1)}(k)-X_{(1)}(k-1) \tag{11}$$

Then we can get grey predicted value sequence

$$X_0=\{X_0(1),X_0(2),\ldots,X_0(n+m)\}\text{(m predicted values)} \tag{12}$$

We divide $\boldsymbol{X}^{(0)}$ into $\boldsymbol{Y_0}$ and $\boldsymbol{Z_0}$. They separately reflect the deterministic growth trend and stable periodic trends.

Using MATLAB, we get the the error analysis Table 3. According to Figure 3, our model can predict the municipal water withdrawal reasonably.

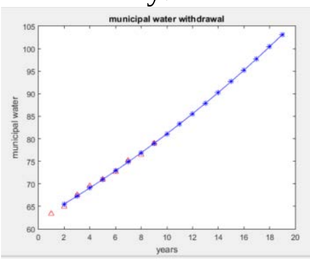


Figure 3. Grey forecasting of municipal water withdrawal

Table 3. China municipal water withdrawal 2003-2011
(source:Chinese water resources bulletin)

year	2003	2004	2005	2006	2007	2008	2009	2010	2011
$W_m\ (10^9 m^3)$	63.3	64.9	67.6	69.5	71.0	72.7	75.2	76.5	79.0

Step4: The total water withdrawal

Sum up all the water use, we can get a equation:

$$W_t=W_i+W_a+W_m \tag{13}$$

Model Ⅱ: supply forecasting model

There are varies of water supply, surface water, underground water, desalination, precipitation, and so on. As for China, we consider the mainly water supply, surface water, underground water, desalination, ignoring other supplies.

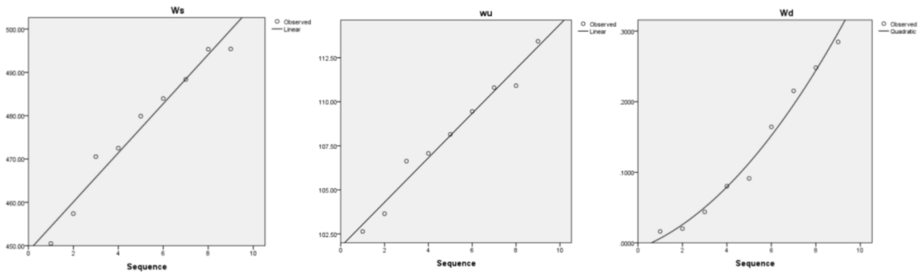
Analyzing the historical data of China, we build linear regression models to predict the surface water and underground water , separately shown in the following equations.

$$W_s = 448.726 + 5.675x \tag{14}$$

$$W_u = 101.776 + 1.261x \tag{15}$$

For the desalination’s growth trend, we use quadratic curve-fitting model to fit the data.

$$W_d = -0.008 + 0.012x + 0.002x^2 \tag{16}$$



(a) (b) (c)

Figure 4. Fitting curves of the supply

(a) The fitting curve of surface water

(b) The fitting curve of underground water

(c) The fitting curve of desalination

So we can establish a equation (17) to predict the supply in the future.

$$W_p = W_s + W_u + W_d \tag{17}$$

Measure the ability of providing clean water

We determine to use the ratio of supply to demand of a region to measure its supply ability. Thus we establish the following equation:

$$M = \alpha \frac{W_t}{W_p} \tag{18}$$

α is the coefficient of water supply affected by natural factors.

The size of M shows the ability of water supply.

References

[1] J. van der Geer, J.A.J. Hanraads, R.A. Lupton, The art of writing a scientific article, J. Sci. Commun. 163 (2000) 51-59.

[2] W. Strunk Jr., E.B. White, The Elements of Style, third ed., Macmillan, New York, 1979.

Reference to a chapter in an edited book:

[3] Information on http://www.weld.labs.gov.cn