Research on Forecast of Water Demand in Jinzhou Based on Grey Model

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Abstract. According to the related requirements of water demand prediction in Jinzhou, and based on the current situation of water resource carrying capacity in Jinzhou from 2011 to 2017 and the grey model, the water demand from 2021 to 2025 was predicted, and the grey GM(1,1) model of ecological water demand, virtual aquatic yield, residential water consumption and urban public water consumption was established. The results showed that the regional water demand showed a trend of slow increase, among which the urban public water demand had a larger growth space, while the ecological water demand and virtual aquatic production had a smaller growth range. The accuracy of the grey forecast model is more than 90%. It can provide a new way to forecast the main water use and total water demand.

1. Introduction

As an important industrial city in Liaoning Province, the per capita water resource of Jinzhou is about 56% of that of Liaoning Province and 19% of that of the whole country. With the rapid development of the city, the original scarce water resources become more scarce, water resources has become one of the main factors restricting the economic and social development. Therefore, it is necessary to forecast the urban water demand systematically and comprehensively, which can provide certain guidance for the construction of national economy, water supply system construction and reasonable planning and allocation of water resources[1,2].Existing water demand prediction methods can be divided into artificial neural network, random forest model, grey prediction method and system dynamics method according to their different data processing methods. Grey prediction model is suitable for processing poor information system such as water demand prediction, simple and practical, the principle is easy to understand and the prediction result is more accurate [3], so it has been widely used.

Based on the water resources carrying capacity level of Jinzhou from 2011 to 2017, this paper carries out the water demand prediction and water resources carrying capacity analysis of Jinzhou City from 2021 to 2025, proposes the optimal allocation of water resources, promotes the coordinated development of regional water resources, economic society and ecology, improves the water resources carrying capacity, ensures the ecological environment water use, and alleviates the water shortage.

2. Grey system model

2.1. Gray GM (1,1) model

Professor Deng Julong proposed the GM (n, h) model at the early stage of the birth of gray theory, which is the basis of gray system prediction. At present, the most common model used by the majority of researchers in forecasting is GM(1,1) [4].
The first data of the initial sequence of the GM(1,1) model has nothing to do with the development coefficient of the model [5].

The general steps of GM(1,1) modeling:

1) Set the original data sequence: \( X^{(0)} = \{X^{(0)}(1), X^{(0)}(2), ..., X^{(0)}(n)\} \), Among them \( X^{(0)}(k) \geq 0 \) for \( k = 1, 2, 3, ..., n \). Generate data sequence by a one-time accumulation (1-AGO)
\[
X^{(1)} = \{X^{(1)}(1), X^{(1)}(2), ..., X^{(1)}(n)\}
\]

2) Construct the data series \( B \) and the data vector \( Y_n \):
\[
\begin{bmatrix}
-0.5[X^{(1)}(1) + X^{(1)}(2)] & 1 \\
-0.5[X^{(1)}(2) + X^{(1)}(3)] & 1 \\
-0.5[X^{(1)}(n-1) + X^{(1)}(n)] & 1
\end{bmatrix};
Y_n = \begin{bmatrix} X^{(0)}(2) \\ X^{(0)}(2) \\ X^{(0)}(2) \end{bmatrix}
\]

3) Determine \( a, b \)

The whitening differential equation of grey GM (1,1) model is established, namely
\[
\frac{dx^{(1)}}{dt} + ax^{(1)} = b
\]

In the formula, parameter \( A \) is the development coefficient, and \( B \) is the gray action. The least square method is used to obtain the parameters: \( \hat{a} = [a, b]^T = (B^TB)^{-1}B^TY_n \)

4) The grey GM (1,1) prediction formula was established
\[
\hat{x}^{(1)}(k + 1) = x^{(0)}(1) - \frac{b}{a} e^{-ak} + \frac{b}{a}
\]

After the progressive reduction (1-AGO), the prediction formula is as follows:
\[
\hat{x}^{(0)}(k + 1) = x^{(1)}(k + 1) - x^{(1)}(k) = (1 - e^a) \left( x^{(0)}(1) - \frac{b}{a} \right) e^{-ak}
\]

2.2. Model test

This paper uses residual test to judge the accuracy of GM (1,1) model.

Model residual order is listed as:
\[
\Delta^{(0)} = \{\Delta^{(0)}(1), \Delta^{(0)}(2), ..., \Delta^{(0)}(n)\}
\]

In the formula:
\[
\Delta^{(0)}(k) = x^{(0)}(k) - \hat{x}^{(0)}(k), (k = 1, 2, ..., n)
\]

Then the relative error is:
\[
\varepsilon(k) = \frac{\Delta^{(0)}(k)}{x^{(0)}(k)} \quad (k = 1, 2, ..., n)
\]

The average relative error is:
\[
\bar{\varepsilon} = \frac{1}{n - 1} \sum_{i=1}^{n-1} \varepsilon(k), \quad (k = 1, 2, ..., n)
\]

The accuracy of GM (1,1) model: \( P = 1 - \bar{\varepsilon} \), the smaller the better, the greater the \( P \), the better. Refer to Table.1. to judge the accuracy level of the model.

| Table.1. Model accuracy level | Mean relative error |
|------------------------------|---------------------|
| Level 1                      | 1%                  |
| Level 2                      | 5%                  |
| Level 3                      | 10%                 |
| Level 4                      | 20%                 |
3. Forecast of water demand in Jinzhou

Based on the data of Jinzhou from 2011 to 2017, the data of ecological water demand, virtual aquatic production, domestic water consumption and urban public water consumption were fitted, and the grey GM (1,1) prediction model of each index was established.

| Year | Water requirement (million cu.m) | Ecological water demand | Virtual water production | Domestic water | Urban public water | A combined |
|------|---------------------------------|-------------------------|--------------------------|----------------|-------------------|------------|
| 2011 | 6.02                            | 41.31                   | 0.77                     | 0.32           | 48.42             |
| 2012 | 6.02                            | 44.45                   | 0.79                     | 0.33           | 51.59             |
| 2013 | 6.03                            | 50.32                   | 0.81                     | 0.34           | 57.5              |
| 2014 | 6.03                            | 49.93                   | 0.83                     | 0.35           | 57.14             |
| 2015 | 604                             | 5417                    | 84                       | 38             | 6142              |
| 2016 | 605                             | 4780                    | 106                      | 41             | 5532              |
| 2017 | 605                             | 4457                    | 98                       | 41             | 5201              |

3.1. Model building

1) Based on the grey system theory, GM(1,1) prediction models of ecological, virtual water production, daily life, public and total water consumption are established. The prediction models of water consumption in each industry are expressed as follows:

1) The prediction model of ecological water demand based on grey system theory is as follows:

\[
x^{(k+1)} = 6017.63e^{0.001k} - 6011.6
\]

2) The virtual aquatic yield prediction model based on grey system theory is as follows:

\[
x^{(k+1)} = 32590.5767e^{0.0015k} - 32549.2667
\]

3) The forecast model of residential water demand based on the grey system theory is as follows:

\[
x^{(k+1)} = 13.3489e^{0.0055k} - 12.5789
\]

4) The urban public water demand measurement model based on the grey system theory is:

\[
x^{(k+1)} = 6.4189e^{0.0499k} - 6.0989
\]

3.2. Verification of the model

3.2.1. Test and analysis of ecological water demand prediction model. According to the prediction
model of Formula (9) and (10). As shown in Figure 1., the ecological water demand showed an increasing trend from 2011 to 2017, with an average of 602 million cu.m increasing steadily to 605 million cu.m. The simulation accuracy is 99.95%, as shown in Table 1., the relative error is 0.05%, less than 5%, and the model accuracy is level 1, which is suitable for the prediction of ecological water demand. The fitting value of grey prediction model is consistent with the change trend of actual value, and the error is small.

3.2.2. Inspection and analysis of virtual water production forecast model. According to Formula (11) and Formula (12), it can be seen that the fitting value of virtual aquatic yield from 2011 to 2017 ranges from 1.31% to 18.12%, and the average relative error is 7.72%, so the simulation accuracy is 92.28%. As can be seen from Table 1, the accuracy of the model is level-three, which can be used to predict virtual aquatic yield within the allowable range. It can be seen from Figure 2. that from 2011 to 2015, the virtual water production increased from 4131 million cu.m to 5417 million cu.m. It began to decline in 2016 and fell to 4457 million cu.m in 2017. Because with the progress of society and the development of science and technology, the virtual aquatic yield may decline.

3.2.3. Test and analysis of the prediction model of residents' water demand. According to Formula (13) and (14), it can be known that the fitting value of residential water demand from 2011 to 2017 ranges from 0.15% to 9.54%, and the average relative error is 4.73%. Thus, the simulation accuracy is 95.33%, and the model accuracy is level 2, which is suitable for the prediction of residential water demand. As can be seen from Figure 3., the household water demand increased continuously from 77 million cu.m in 2011 to 106 million cu.m in 2016, and declined slightly in 2017. Generally, although the increase was small, the overall trend was on the rise.

3.2.4. Test and analysis of prediction model for urban public water demand. According to Formula (13) and (14) and Figure 4., urban public water demand maintained a steady and sustained growth from 2011 to 2017, with a relative error of 0.42% to 3.02% and an average relative error of 1.88%. Thus, the simulation accuracy was 98.12%. When comparing with the simulation accuracy level in Table 1., it can be seen that the model accuracy was level 2.
3.3. Water demand forecast

The water demand of Jinzhou is between 5.589 billion cu.m and 5.608 billion cu.m from 2021 to 2025, the minimum water demand is 5.589 billion cu.m in 2020, and the maximum water demand is 5.608 billion cu.m in 2025. The virtual aquatic yield may decrease due to the application of water-saving technology. With the increase of people's income and the improvement of living standard, the demand for the quality of life and the living environment is getting higher and higher, and the demand for water resources may also increase.

Table 3. Forecast of water demand in Jinzhou City from 2020 to 2025

| Year/Water requirement (million cu.m) | Ecological water demand | Virtual water production | Domestic water | Urban public water | A combined |
|--------------------------------------|-------------------------|--------------------------|----------------|------------------|------------|
| 2021                                 | 607.76                  | 4805.89                  | 126.75         | 50.93            | 5591.33    |
| 2022                                 | 608.4                   | 4798.61                  | 134.02         | 53.51            | 5594.54    |
| 2023                                 | 609.03                  | 4791.34                  | 141.71         | 56.22            | 5598.3     |
| 2024                                 | 609.67                  | 4784.07                  | 149.84         | 59.08            | 5602.66    |
| 2025                                 | 610.3                   | 4776.82                  | 158.44         | 62.07            | 5607.63    |

4. Conclusions

Considering the complexity, uncertainty and regionality of water resources prediction, the Grey GM(1,1) prediction model for Jinzhou water demand from 2021 to 2025 has been established in this study, and its accuracy reaches more than 90%, which can provide a new method for predicting the main water use and the total water demand. The results show that the regional water demand shows a slow increasing trend, among which the larger increasing space is the domestic water demand, while the virtual water production water demand shows a downward trend. The simulation accuracy of all kinds of water demand prediction values is less than or equal to level 3, which can reflect the future change characteristics of water consumption in Jinzhou area, and can provide scientific guidance for regional water resource management planning and sustainable utilization of water resources.

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