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Study on the rural life water consumption forecasting model based on grey system theory

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ABSTRACT

In this article,The water consumption forecast model was established based on data from 1997 to 2004. These results showed that test value are (P = 1)>0.95,(C = 0.018)<0.35, and the forecast accuracy of the model is excellent". The model can be fully able to meet needs of water consumption forecast. At last, the water quantity for residential use from 2012 to 2018 was forecasted through this model, results show that in the next few years, the water consumption will be increasing rapidly.

KEYWORDS

Water quantity for residential use; Grey system; Prediction model.

INTRODUCTION

With the rapid development of urbanization and the growth in the farmers' living standard day by day, rural water consumption per capita are also increasing, so rural life water consumption forecast has a important role for rural water supply network planning and construction funds distribution. In the meantime, due to the data acquisition difficulty and so many kinds of uncertain factors in the prediction process, the research of rural life water consumption prediction model is very little currently. Rural life water consumption grey forecasting model is based on grey theory, and the history data of rural water consumption per capita were conduct as the original data information which form the limitary-duration sequence and differential equation. The model can reveals the laws of rural life water consumption each year and predict the rural life water consumption in future[1].

MATERIALS AND METHODS

GM (1, 1) forecasting model[2-4]

The time series $t_1, t_2, \cdots, t_n$, rural life water consumption per capita data sequence $u_1, u_2, \cdots, u_n$, That is the original data sequence.

$$\mathbf{u}^{(0)}(\mathbf{i}), (\mathbf{i} = 1,2,\cdots,\mathbf{n}) \tag{1}$$

The original data were conduct accumulation, and then a data sequence was got which has exponential growth rule and called accumulation data sequence $u^{(1)}(i)$.

$$\mathbf{u}^{(1)}(\mathbf{i}) = \sum_{\mathbf{k}=1}^{\mathbf{i}} \mathbf{u}^{(0)}(\mathbf{k}) \tag{2}$$

By first order differential equations and GM (1, 1), the single variable sequence can be expressed as follows:

$$\frac{\mathbf{du}^{(1)}}{\mathbf{dt}} + \mathbf{a} \cdot \mathbf{u}^{(1)} = \mathbf{b} \tag{3}$$

a, b are called the unknown parameters, and shown $\mathbf{A} = [a \quad b]^T$,Through the discrete and difference, least squares approximation solution $\hat{\mathbf{A}}$ of equal step time sequence can shown as follows:

$$\hat{\mathbf{A}} = [\hat{a} \quad \hat{\mathbf{b}}]^{\mathbf{T}} = [\mathbf{B}^{\mathbf{T}}\mathbf{B}]^{-1}\mathbf{B}^{\mathbf{T}} \ \mathbf{Y_n} \tag{4}$$

$$\mathbf{Y_n} = [\mathbf{u}^{(0)}(2), \mathbf{u}^{(0)}(3), \cdots, \mathbf{u}^{(0)}(\mathbf{n})]^T$$

$$\mathbf{B} = \begin{bmatrix} -[\mathbf{u}^{(1)}(1) + \mathbf{u}^{(1)}(2)]/2 & 1 \\ -[\mathbf{u}^{(1)}(2) + \mathbf{u}^{(1)}(3)]/2 & 1 \\ \cdots\cdots & \\ -[\mathbf{u}^{(1)}(\mathbf{n}-1) + \mathbf{u}^{(1)}(\mathbf{n})]/2 & 1 \end{bmatrix} \tag{5}$$

the time series $t^{(0)}(i),(i=1,2,\cdots,n)$, the initial value of $u^{(1)}(1)$ can expressed $u^{(1)}(i)$, and that $u^{(1)}(1)=u^{(0)}(1)$; Each element is one-to-one between $u^{(0)}(i)$ and $t^{(0)}(i)$, the solution of formula (3)can expressed as follows:

$$\hat{\mathbf{u}}^{(1)}(\mathbf{t})=\left(\mathbf{u}^{(0)}(1)-\frac{\hat{\mathbf{b}}}{\hat{\mathbf{a}}}\right)\mathbf{e}^{-\hat{\mathbf{a}}\mathbf{t}}+\frac{\hat{\mathbf{b}}}{\hat{\mathbf{a}}} \text{ discrete form: } \hat{u}^{(1)}(t+1)=\left(u^{(0)}(1)-\frac{\hat{b}}{\hat{a}}\right)e^{-\hat{a}k}+\frac{\hat{b}}{\hat{a}} \quad \textbf{(6)}$$

Generated value: $\hat{u}^{(1)}(i),(i=1,2,\cdots,n)$, the reducing value of original data sequence was got by generating operation.

$$\hat{\mathbf{u}}^{(0)}(\mathbf{k}+1)=\hat{\mathbf{u}}^{(1)}(\mathbf{k}+1)-\hat{\mathbf{u}}^{(1)}(\mathbf{k})=\left[\mathbf{u}^{(0)}(1)-\frac{\hat{\mathbf{b}}}{\hat{\mathbf{a}}}\right]\mathbf{e}^{-\hat{\mathbf{a}}\mathbf{t}}-\left[\mathbf{u}^{(0)}(1)-\frac{\hat{\mathbf{b}}}{\hat{\mathbf{a}}}\right]\mathbf{e}^{-\hat{\mathbf{a}}\mathbf{k}+\hat{\mathbf{a}}}$$

$$=(\mathbf{1}-\mathbf{e}^{\hat{\mathbf{a}}})\left(\mathbf{u}^{(0)}(1)-\frac{\hat{\mathbf{b}}}{\hat{\mathbf{a}}}\right)\mathbf{e}^{-\hat{\mathbf{a}}\mathbf{k}} \quad (\mathbf{k}=1,2,\cdots,\mathbf{n}-1) \quad \textbf{(7)}$$

The inspection of prediction accuracy[5]

In order to validate the prediction model that can meet the practical needs or not, the model is tested by Variance tests.

$$\varepsilon^{(0)}(\mathbf{i})=\mathbf{u}^{(0)}(\mathbf{i})-\hat{\mathbf{u}}^{(0)}(\mathbf{i}) \quad \textbf{(8)}$$

Mean value: $\bar{\varepsilon}^{(0)}=\frac{1}{\mathbf{n}}\sum_{\mathbf{i}=1}^{\mathbf{n}}\varepsilon^{(0)}(\mathbf{i})$ **(9)**

Residual variance: $S_1^{\,2}=\frac{1}{n}\sum_{i=1}^{n}(\varepsilon^{(0)}(i)-\bar{\varepsilon}^{(0)})^2$ **(10)**

original data mean: $\bar{\mathbf{u}}^{(0)}=\frac{1}{\mathbf{n}}\sum_{\mathbf{i}=1}^{\mathbf{n}}\mathbf{u}^{(0)}(\mathbf{i})$ **(11)**

Original sequence variance: $S_2^{\,2}=\frac{1}{n}\sum_{i=1}^{n}(u^{(0)}(i)-\bar{u}^{(0)})^2$ **(12)**

posterior error ratio: $\mathbf{C}=\mathbf{S}^{1}/\mathbf{S}^{2}$ **(13)**

Small error probability: $\mathbf{P}=\left(\left|\varepsilon^{(0)}(\mathbf{i})-\bar{\varepsilon}^{(0)}\right|<0.6745\mathbf{S}^{2}\right)$ **(14)**

A good prediction model require the smaller C value, and Generally $C < 0.35$. Another indicator of good prediction model is a small error frequency, And Generally $P > 0.95$. According to the values of P, C, prediction accuracy can be divided into 4 grades. As defined in TABLE 1

TABLE 1: Prediction accuracy grade

Grade	P	C	Good	P	C
Good	> 0.95	< 0.35	Qualification	> 0.85	< 0.45
Ordinary	> 0.7	< 0.5	Disqualification	≤ 0.75	≥ 0.65

RESULTS AND DISCUSSION

The consumption of all social total water, agricultural water and rural life water per capita see TABLE 2 in 1997 ~ 2004. The annual water consumption were predicted by the established GM (1, 1), and the accuracy of model was test by correlation test.

TABLE 2 : The country's water consumption situation in 1997 ~ 2004 Units: billion cubic meters.

Year	1997	1998	1999	2000	2001	2002	2003	2004
The total water consumption	5566	5435	5591	5498	5567	5497	5320	5548
agricultural water consumption	3920	3766	3869	3784	3826	3736	3712	3703
Rural life water consumption	278	288	296	291	293	298	303	309
Rural water consumption per capita (l/day)	84	87	89	89	92	94	96	99

Model data

Agriculture and rural water consumption shown in TABLE 2 in 1997 ~ 2004

The curve of all social water consumption, agricultural water consumption, rural life water consumption and rural life water consumption per capita were shown in Figure 1 and Figure 2.

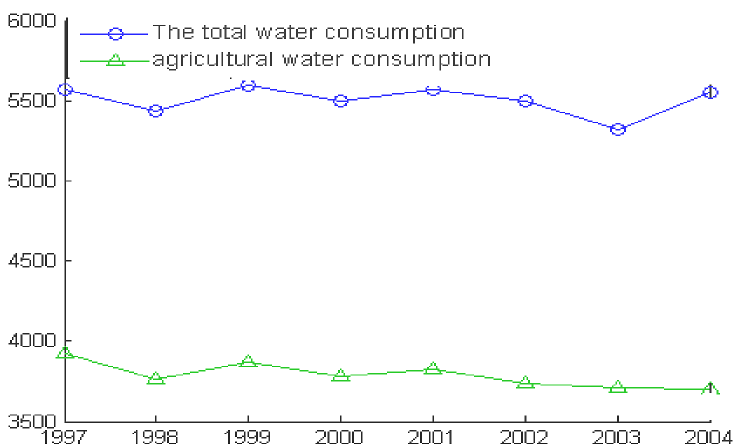

Figure 1 : Full social water consumption and agricultural water consumption curve

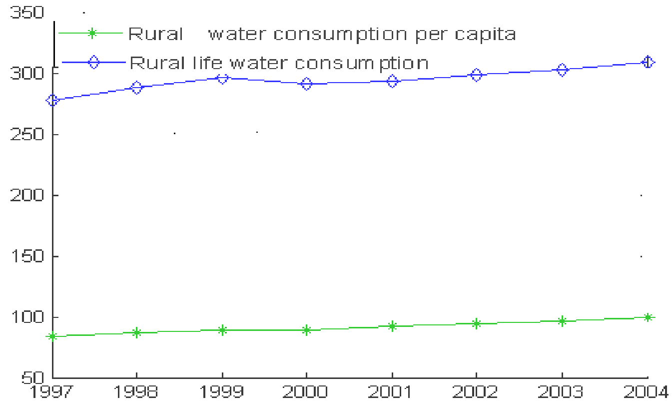

Figure 2 : Rural life water consumption and life water consumption per capita curve

Figure 1 shows that the whole social annual water consumption is 550 billion cubic meters or so, and the agriculture water consumption is declining. This is mainly because that agricultural irrigation water to total water consumption is large; a large amount of water resources was saved by improving irrigation efficiency. In recent years, agricultural irrigation area has been increased year by year, but because of water saving irrigation (such as sprinkler irrigation, drip irrigation, etc.), the volume of irrigation water was greatly reduced.

Figure 2 shows that total rural life water consumption and consumption per capita is increasing which is mainly due to the improvement of the peasants' living standard and water conservancy facilities. In recent years, with the development of urbanization, the rural population is reducing gradually, but the rural water consumption is increasing instead.

Model prediction and test

In this model, n =8;The raw data of rural per capita consumption $u^{(0)}$ ={84, 87, 89, 89, 92, 94, 96, 99}

An accumulation formation was carried out through the original sequence, new data sequence was gotten, $u^{(1)}$ ={84,171, 260, 349, 441,535, 631, 730}

From the formula (4) and formula (5):

$$B = \begin{bmatrix} -127.5 & 1 \\ -215.5 & 1 \\ -304.5 & 1 \\ -395 & 1 \\ -488 & 1 \\ -583 & 1 \\ -680.5 & 1 \end{bmatrix} \quad Y_n = \begin{bmatrix} 87 \\ 89 \\ 89 \\ 92 \\ 94 \\ 96 \\ 99 \end{bmatrix} \qquad \textbf{(15)}$$

$$\hat{\mathbf{A}} = [\hat{a} \;\; \hat{b}]^T = [\mathbf{B}^T\mathbf{B}]^{-1}\mathbf{B}^T\mathbf{Y}_n = \begin{bmatrix} -0.0214 \\ 83.75 \end{bmatrix} \qquad \textbf{(16)}$$

Grey forecasting model of the national rural water consumption per capita was received by substituting $\hat{a}$, $\hat{b}$ into formula (7).

$$\hat{u}^{(0)}(k+1) = (1-e^{\hat{a}})\left(u^{(0)}(1) - \frac{\hat{b}}{\hat{a}}\right)e^{-\hat{a}k} = 84.65\,e^{0.0214k} \quad (k = 1,2,\cdots,n-1) \tag{17}$$

In order to validate the precision of the model, the model was test by posterior deviation test, shown as TABLE 3 TABLE 4.

TABLE 3 : Actual values and the predicted value of rural water consumption per capita.

Year	*actual values (Liters/day)*	*predicted values (Liters/day)*	*relative error /%*
1999	89	88.35	-0.73
2000	89	90.26	1.42
2001	92	92.22	0.24
2002	94	94.21	0.22
2003	96	96.25	0.26
2004	99	98.33	-0.68

TABLE 4 : Calculation results.

$\bar{u}^{(0)}$	S_1^2	$\bar{\varepsilon}^{(0)}$	S_2^2	C	P
91.25	0.38	-0.094	21.44	0.018	1

From the above table it can be seen that $(P=1)>0.95$, $(C=0.018)<0.35$, So the prediction accuracy of the model is excellent.

Rural water consumption per capita in 2012 ~ 2018 was forecasted by the model, and prediction results are as follows.

TABLE 5 : Predicted value of rural water consumption per capita in 2012-2017; Units: Liters/day.

Year	2012	2013	2014	2015	2016	2017	2018
rural water consumption per capita	116.69	119.21	121.79	124.43	127.12	129.87	132.68

CONCLUSION AND RECOMMENDATION

In this article, rural water consumption prediction model was established based on the data in 1997 ~ 2004, and the model has high precision and good prediction effect. The prediction results showed that test value are $(P=1)>0.95$, $(C=0.018)<0.35$, and the model can be fully able to meet needs of water consumption forecast. At last, the water quantity for residential use from 2012 to 2018 was forecasted through this model, results show that in the next few years, the water consumption will be increasing rapidly; it will reach 124.43 liters/day by 2015.

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