Urban Water Consumption long-term Prediction Model Based on the Water Price elasticity in China

LI Cuimei[1,2] Wang Jianhua[1] Wang Hao[1] Zhang Shaoguang[3]

(1, China Institute of Water Resources and Hydropower Research, Beijing 100044;

2, depart. Of Environmental Science and Engineering, Suzhou University of Science and Technology, Suzhou 215011；3, Suzhou 3－Tsing Environmental Science and Technology Co., Ltd, Suzhou, 215011)

ABSTRACT:
With the increasing scarcity of water resources, the economic management of precious freshwater resources is also increasing. Water price is continuously rising in many urban in China. With the rapid rise of water price, there is a corresponding change in water consumption. Part of the family's water consumption declined significantly, also obviously reduced industrial water. The impact of water price on water consumption is significantly, but in the past a long time, urban water consumption projections did not consider the impact of water price. Therefore, it is need to study the influence of price-based forecasts on urban water consumption, improve the accuracy of forecasting and planning on urban water consumption.

Based on the in-depth analysis of urban water consumption long-term forecasting model, the paper pointed out that the urgent need for the study on urban water consumption forecasting based on price elasticity. First, test and verify the law of water price and water consumption by use the data about the water price and water consumption in China from 2000 to 2007; Second，simulated the water price changes, water consumption varied, the lowest water consumption adjustment based on the L.D models by use the China actual data. The results show that: China's water consumption, water prices, the price elasticity of changes in the relationship shown in line with L.D model, the model can be applied to China's urban water consumption forecast.

KEYWORDS: urban water consumption; long-term prediction; forecasting; water price elasticity; model

1. Introduction

Urban water consumption forecasts can be divided into long-term, medium-term and short-term forecasting according to the duration of water supply systems and the need，which is an important factor of the urban water resources planning and management, and also an integral part of water supply system optimal management, has very important significance.

There are greatly increased demand for urban water with China's rapid economic development, accelerated urbanization process and the improvement of living standards. Existing water resources and water supply facilities can not meet the city's water demand, supply and demand have become increasingly prominent. According to statistics, there are about 300 cities short of water in China, including which more than 40 cities in a serious water shortage and the situation is also expanding and developing. To solve water shortages, must be considered from two aspects of income and reduce expenditure for water supply, water consumption and water planning. Under the correct city's recent, long-term water supply planning and construction, reasonably and accurately predict future urban water demand will reduce the total investment in water supply facilities and play a decisive role in future water crisis, Thus predict the future of urban water consumption is an important research topic.

Long-term water consumption forecasts is to make a longer time period forecast for the future of the city (5-15 years) which are based on urban economic development, population growth, industrial production capacity, tourism, education, culture, health development, and other factors of development changes. So, it is a complex task, involving many factors, which is a multi-factor, multi-level complex system.

2. Methods and Models

Currently, several typical urban water long-term consumption and forecasting methods, including: ①Autoregressive moving average model method(ARMA); ② Regression analysis(RAM); ③Indicators analysis method (IAM); ④Grey prediction method(GPM); ⑤ Artificial Neural Network(ANN); ⑥ System Dynamics method(SDM).

The following will descript the features, advantages and disadvantages of them.

2. 1 Autoregressive moving average model method (ARMA)

ARMA model is the integrated model of auto regression model and the moving average model, and which can be more dynamic understanding of the internal data structures and complex characteristic through the analysis of the corresponding mathematical model. In general, said the formula (1) is of order (p, q) of the ARMA model.

$$y_t = \phi_1 y_{i=1} + \phi_2 y_{i=2} + \cdots + \phi_p y_{i=p} + e_i - \theta_1 e_{i=1} - \theta_2 e_{i=2} - \cdots - \theta_q e_{i=q} \quad (1)$$

ARMA model change the forecast objects' time series processed into a white noise sequence processing, therefore, it can simulate the any water process fatly with higher prediction accuracy. However, ARMA model with shortcomings of forecast cycle short, the data which used is single, only can be given the predictive value of the next cycle, and can not analyze the reasons for the formation of the predicted value and reasonable error estimates. In addition, this method has a clear lag which made large errors in predicting some outliers, even distortion. In this regard, should analyze the possible causes of abnormal values, revised ARMA model accordingly. The current improvement of the ARMA model is the form of ARIMA (p, d, q) model and the ARMA ((p, d, q) (P, D, Q) S model.

2. 2 Regression analysis method

One of the purposes to establish the regression equation is used to predict. Once the Y and the regression relation between x, when x is a certain value, we can estimate the value of Y. Let $x_1, x_2, \cdots, x_p$ is a deterministic variable, Y is a random variable, the relationship between them:

$$Y = \beta_0 + \beta_1 x_1 + \cdots + \beta_p x_p + \varepsilon \tag{2}$$

Among them, $\beta_1, \beta_2, \cdots \beta_p$ - regression coefficient;

ε - Influence of random factors on the sum of Y.

This is the P linear regression model. This method is through regression analysis, predict the object and find the causal relationship between factors to build the regression model for prediction. And when significant changes occur in the system, we can also change according to the corresponding correction factors predictive value, while the predictive value of the error also has a broad grasp of, therefore, the model is very affable for long-term forecasts.

For short-term forecasting, as water consumption data volatile, complex factors, and the factors difficult to predict future values, it should not be used. The method is independent variables (factors) to predict the response variable (predicted objects), therefore, the selection of independent variables and independent variables predictive value of accuracy is essential. In view of the shortage of basic data, imperfect forecasting and decision-making system status, based on seize the main factors in the system; the independent variables should be properly introduced. Too many variables will not only increase the amount of computation, model stability degradation, also easy to unreliable predictor variables into the model, the cumulative error on the response variable, resulting in significant errors.

2. 3 Indicators analysis method (IAM)

Target analysis of water systems through a comprehensive analysis of historical data, to develop a variety of water quota, and then calculate the long-term water consumption by the water quota and long-term water service population (or industrial production, etc.). As the water quota emphasis on versatility, water consumption forecasting will cause great prediction errors in particular cities or areas. Water indicators affect the accuracy of the prediction of urban water directly. So, the key is reasonable choose indicators in the planning of urban water consumption forecast.

2. 4 Grey prediction method(GM)

Grey system theory is the core of the establishment of the gray model (GM), it generated differential equations by observed or statistical time-series data directly, modeling and standardization the structure of the gray system, and as the basis dynamic analysis and control for forecasting system. GM (1, 1) is one of commonly used predictive models.

Urban water systems, both with known information, but also with unknown, unascertained information; therefore, it can be seen as a gray system. When the water consumption has grown exponentially, the model has high prediction accuracy, required less sample data, the calculation is simple and can be tested and so on. To further improve the accuracy of the model, the original data can be established GM (1, 1) parameter estimates and residual prediction model updating; can also be introduced in the gray-element model. For water consumption with a series of changes in volatility, there is greater error in use of GM (1, 1) model, the current improvement focus on two aspects: establish dimensional information of the gray prediction model and treat the original data sequence for processing.

2.5 Artificial Neural Network(ANN)

Artificial neural network is made of a lot of simpler and wide range artificial neural connections, to mimic the human brain's complex network system. ANN commonly used artificial neural network back-propagation learning algorithm (BP Algorithm), which is not only has the input and output layer, but also has one or more layers hidden neurons, the input information passed to the hidden layer neurons. After each type of neuron properties operation to the role of sigmoid function, neurons in the hidden layer output information to the out neuron then draw conclusion final.

There are a lot of uncertainty changes in urban water consumption, which is more difficult to find a clear relationship between various factors and changes within the system to identify the mechanism of interaction. This makes the regression analysis restrictions in the water prediction, the traditional time series analysis method rely on historical observations, and obtained the single results corresponding. For the uncertainties and nonlinear systems that are difficult to establish accurate mathematical model, application of artificial neural network can solve the problem which the traditional methods often be difficult to deal with.

BP algorithm is a very efficient algorithm, but it also has some shortcomings, such as: it is not easy to determine the number of hidden layer neurons, may fall into local minima, spend a lot of computing time, and forget the trend has been studied samples etc. Domestic scholars put out that increases steepness of the role function node, transform the form of nodes' function in the hidden layer, adaptive learning parameters to improve the learning speed of BP network.

2.6 System Dynamics method(SDM)

System dynamics model is the mathematical model that is established in accordance with system dynamics theory, using a dedicated language, simulation with the computer system, to deal with system problems which behavior change over time. System Dynamics is the essence of the feedback, build model after the analysis of feedback mechanism of the system, to predict the overall level of system development with a certain degree of accuracy in the lack of basic data and the quantitative expression is difficult to establish the circumstances.

The model has a good intuitive, can be more comprehensive consideration of various factors affect the water demand, combined the expert's experience and mathematical prediction organically, overcome two shortcomings: one is unclear of the physical concept when the historical data fit prediction methods; The second is when forecasting results are not satisfactory can not adjust the predict model. However, one important problem of the method is the objective can not be completely flexible to adapt to changes in the environment. Thus, it is very difficult to realize when there are much more changes factors for the future more predictable phenomena. This is the system dynamics method requires further development.

Each one of water consumption forecasting methods has its own advantages and disadvantages. Water consumption forecasting is a reasonable choice of one or several forecasting methods combined with predict purpose, features, and changes in water law, and collect the required data to predict. Therefore, there must be the problem of preferred method; following are some points in this study:

(1)For water resources planning and pre-urban water balance, as water usage object are complex, require long-cycle predict, more importantly the formulation of policies to affect the system dynamic after the predicting work is completed, therefore, should be choose the regression analysis or system dynamics to adopt the above demand.

(2) Hourly or daily forecast for water optimal operation system, ARMA model or artificial neural network model should be adapted to the situation and water systems take full account of the impact of other factors (such as weather etc.), transfer the actual data in a timely manner to the computer, build dynamic modeling by computer, achieve the process: modeling-forecasting-remodeling-reforecast.

(3) Use the gray prediction model to forecast water consumption can be more satisfactory results when lack of basic data of the urban water system.

(4) Indicators analysis method (IAM) can meet the requirements of water consumption forecast for the design of the new water plant, pipelines, pumping stations and other water facilities.

(5)When the data of water consumption forecast used for alteration of the old facility, we could establish trends appropriate model based on historical data to predict the water consumption if there are little change in the structure of water and the water has a significant historical trend data. This method is more targeted than the indicator method, more accurate predictive value, and is also very simple calculation. However, if the previous conditions are not met, the index method should be used.

However, the above discussed models and methods (ARMA, RAM, IAM, GM, ANNM, SDM) which did not take the price elasticity of water as an important factor to consider in the model, and also did not think out the water price elasticity how to affect the urban water consumption well. The reports on the influence of the price elasticity of urban water consumption forecast are very seldom. However, with the impact of water price on the water consumption increasing, the study of water price elasticity is an urgent topic.

3. Urban water consumption long-term forecasting model based on price elasticity

3. 1 model

Water demand is a function of all possible prices when income and other factors constant, water consumption is becoming less while water price is high, water consumption is high when water price is low. Therefore, the water demand curve slope to the right oblique, as the price increase will not lead to reduced water demand in the same proportion, so the demand curve should be non-linear curve. According to price elasticity theory we can write domestic water demand equation:

$$P = P_1 + \left[\frac{(P_2 - P_1)}{(q_2 - q_1)} \times q \right] \cdot \frac{(q_1 - q)}{q} \qquad (3)$$

Where: q—the absolute value of water demand;

q_2-q_1—the change in water demand;

P_2、P_1—water price respectively before and after the corresponding increase.

This equation can be used to predict the domestic water demand changes caused by price in urban and the desire of consumers to pay. When average domestic water price increased to 0.9 yuan/m^3 in 1998 from 0.55 yuan/m^3 in 1997 in China, increased by 10% per year eight years later, water loss rate is l5%, household income growth is 4%, inflation rate is 3%, water usage population growth rate is 2%, the simulation curve of water price and domestic water demand could be shown in Figure 1.

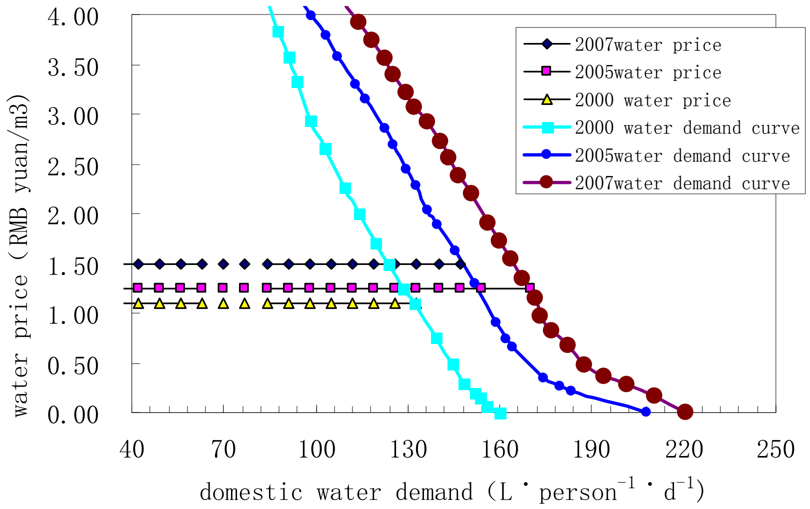

Fig.1 the curve of domestic water demand under water prices

Figure 1 show that in China the relationship between water consumption and water price is in line with the general laws that in the ideal state. L.D. James and R.R. Lee put forward the model on water price and water demand in that water is a commodity through extensive research.

$$Q_2 = Q_1 (P_1 \cdot P_2^{-1})^{E_d} \qquad (4)$$

Where: Q_2 - water demand after adjust; Q_1 -water demand before adjust;

P_1 -water price before adjust; P_2 -water price after adjust;

E_d - Water price elasticity.

This model has a very distinct advantage: it is simple, data is easy to access; secondly, it was adapted to a market economy environment, and so it is easy to accept. When the water price is the full cost price while which is included the sewage treatment fee.

That would be able to overcome the shortcomings of ignoring the ecological impacts. Therefore, this model is widely used all over the world as the relational between domestic water price and water demand. This study uses this model as a predictive model of domestic water, before using this model must be the actual simulation and verification.

3.2 Model Validation

3.2.1 Simulation and verification relationship between water price and water demand

We could simulate the curve of water demand meet degree with the different water price elasticity by using the model in equation (4) and the data of actual average domestic water price and domestic daily water demand in China, shown in Figure 2.

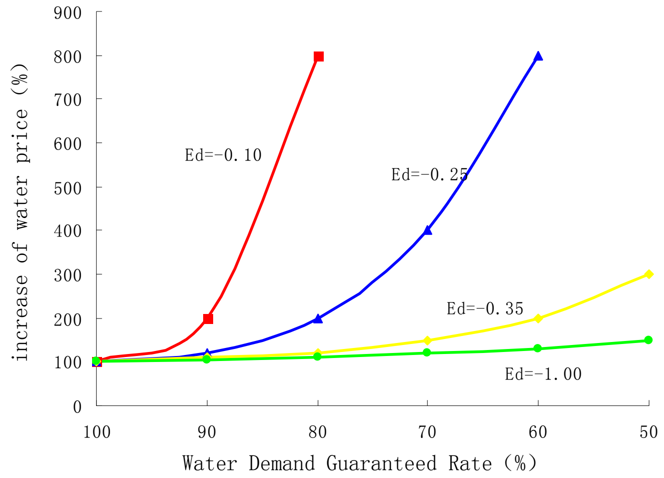

Fig.2 Water Demand Guaranteed Rate under different E_d and water price increase

Figure 2 simulated four cases when E_d were -0.10, -0.25, -0.35 and -1.00, represent a weak elasticity, low elasticity, medium elasticity and flexibility of four degree reflect water demand to water prices, simulation results show that: the trend of water consumption of its demand percentage is downward residents the of water trend with water price increases if water price elasticity is constant, that means: domestic water consumption could be reduced by rising water price and saving water; Second, with the increase of the absolute value of water price elasticity, with the water consumption flexibility of water price increased, the same price increase led to a greater reduction in water consumption. Curve can be seen from Figure 2, when the water price elasticity is high, price increases double will be reduced approximately 50% the amount of water consumption; the same price changes can only be reduced by about 7% of the water consumption when water price elasticity is low.

3.2.2 Simulation of lowest water consumption and water price and it's elasticity under inadequate water supply

We could simulate the relationship between the lowest domestic water consumption and water price under different water price elasticity when water supply inadequate, shown in Figure 3.

With the accelerated process of urbanization or climate reasons (such as: drought), urban water supply is likely to occur in a certain period of short supply, this time requires the construction of new water supply projects to meet the city's development. However, if the city's own water resources development has been extremely limited, and water supply can not meet the water demand, we only can be resolved the contradiction between water supply and demand by water-saving measures. This time to study how to reduce the residents' lowest water consumption by water pricing may be a good solution. Figure 3 shows that: when the absolute value of water price elasticity is larger, with the increase in the lowest water consumption, water price rose slightly to solve the shortage of water supply. That means: the compressible space of water consumption is larger in the higher lowest domestic water then which in the lower. When the lowest domestic water consumption is constant, different water price elasticity reflect the inconsistent to price rise. The greater the price elasticity is, the extent of price increases is lower; the lower the price elasticity is the greater increase of water rate is need. Therefore, we could scientific estimate the water price elasticity and make rational water pricing policies to solve contradictions of water demand and supply by Fig.3 when the urban water supply is insufficient and could not increase the total urban water supply.

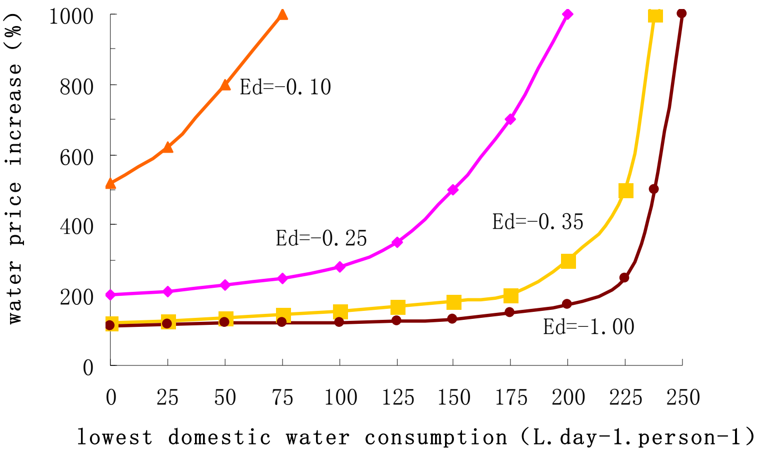

Fig.3 the relationship between water price and lowest domestic water consumption under different elasticity

3.2.3 **Simulation the relationship between the water price change and it's elasticity with comprehensive water consumption**

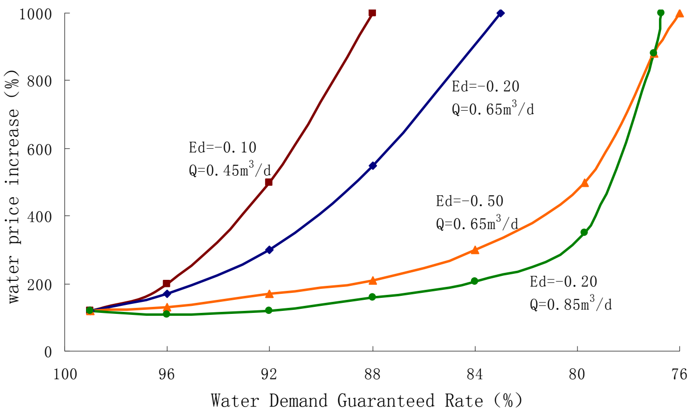

Fig.4 the relationship between water price increase and capita total water consumption, water demand guaranteed

Figure 4 simulated the proportional relationship under different water price elasticity and comprehensive water consumption, combined with the actual water use data of various cities in China, daily comprehensive water consumption were considered 0.45m^3 / Capt., 0.65 m^3/ Capt. and 0.85 m^3/ Capt. Water price elasticity were collected -0.10, -0.20 and -0.50.

Simulation results show that: when the comprehensive water consumption is fixed, a small rise in water price can be achieved to overcome a certain lack of water supply if water price elasticity is larger. For reaching the same water supply target (water supply rate is 92%), water price is need to increase 270% when Ed=-0.20, while water price is need to increase 150% if Ed =- 0.50. When the water price elasticity is fixed, the larger the water consumption is, the larger space could be compressed, so slightly increase the water price can reach the established goal of water supply. For reaching the water supply target (water supply rate is 92%), water price is need to increase 270% if E_d =- 0.20 and Q = 0.65m^3/d, while water price only is need to increase 120% if E_d =- 0.20 and Q=0.85m^3/d.

Figure 4 reveals the relationship between water price elasticity, comprehensive water consumption; how to adjust the water price when the water supply target is determine or how to adjust the water supply when the water price is fixed.

4. Conclusion

Reasonably formulating urban water prices is an important issue related to sustainable development of urban water resources. Water scarcity is one of the serious problems needed to be addressed urgently. Formulating water prices can be considered a promising way for coordinating water allocation and thus must be justified in a rational way. This paper studied the relationship between water prices elasticity and water consumption by simulating and verification relationship between water price and water demand; simulation of lowest water consumption and water price and it's elasticity under inadequate water supply; simulation the relationship between the water price change and it's elasticity with comprehensive water consumption. Based on the study, we can draw the following conclusion:

(1) For the discussed models and methods, such as ARMA, RAM, IAM, GM, ANNM, SDM and etc. which did not take account the water price elasticity as an important factor that would affect the accuracy of urban water long-term forecast.

(2) L.D model can be used in China an urban water long-term forecast through model validation by using the data of water prices and water consumption in different cities.

(3)According to the study, we could make proper water planning and policy for water sustainable management.

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