Analysis of China's domestic water prediction

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Abstract. With the rapid development of industrialization and urbanization rate, the domestic water consumption in China shows a rapid increasing trend. This paper summarizes the relationship between per capita domestic water consumption, urbanization rate and per capita GDP by studying the domestic water consumption laws of typical countries in the world. The domestic water structure of the United States, France, Germany and Japan were chosen as study case. And we find the similarity of domestic water structure between Japan and China, which means Japan can be used as a sample for analogy prediction. Then, the overall prediction and analogy prediction are used to forecast the domestic water demand in China. The results show that the results of these two methods are consistent. The prediction results can help decision-making departments to make reasonable policies in water resources planning.

1. Introduction

Domestic water is significant import to the survival and development of cities and countries. The total amount and proportion of domestic water consumption in China have been increasing for many years. According to the data from the China water resources bulletin in 2019 [1], the total water consumption reached 602.12 billion cubic meters, including 87.17 billion cubic meters of domestic water, accounting for 14.5% of the total water consumption.

The medium and long-term prediction of domestic water is helpful for decision-making departments to formulate reasonable policies in water resources planning and alleviate the contradiction between supply and demand of water resources [2]. The research methods related to domestic water prediction mainly include regression analysis method, system dynamics method, autoregressive moving average model, grey model, BP artificial neural network, combination model and index analysis method, and so on[3]. Now some researchers focus on improving and developing traditional forecasting models and methods[4], and others tend to combine forecasting with multiple research methods and forecasting models [5]. However, their research mainly focuses on the establishment of mathematical models, which lacks comprehensive analysis on the influencing factors such as per capita GDP and urbanization rate. At the same time, there are few researches comparing the trends of domestic water use at home and abroad.

This paper will analyze the data of domestic water consumption and the relationship between urbanization rate and GDP per capita in typical countries. The domestic water structure will be compared, and countries with similar domestic water structure will be found to predict China’s medium- and long-
term domestic water consumption by analogy. At the same time, the regression equation model in the overall prediction method will be used. These two prediction results will be compared and discussed to obtain the domestic water demand of China by 2050 eventually.

2. Domestic water consumption in typical countries

2.1. Relationship between per capita water consumption and per capita GDP
Per capita water consumption and per capita GDP have an "S"-shaped curve change law (Fig.1-a). With the take-off of industrial economy and the transfer of a large number of population from rural areas to cities, the water consumption habits will change rapidly, so the per capita domestic water consumption will enter a stage of rapid growth. After that, with the continuous development of economy and society, the growth rate of per capita domestic water consumption began to decline gradually, and finally entered the decline stage when it reached zero growth.

As shown in Fig.1-c, with the continuous growth of per capita GDP, per capita consumption showed a rapid rise first, and then reached the zero growth point, and then began to stabilize and slowly decline "S"-shaped changes.

Before reaching the zero growth point, the change relationship is expressed as:

After reaching the zero growth point, its change relationship is expressed as:

There are two important transition points in "S"-shaped curve: the take-off point and the turning point. The take-off point, appears when a country's per capita GDP reaches about $10000 dollars, which means per capita domestic water consumption began to increase rapidly. The turning point appears when a country's per capita GDP reaches about $20000 dollars and the urbanization rate of most countries has reached 80%, which means that the growth of per capita domestic water consumption has reached its limit and begins to slowly decline.

2.2. Relationship between per capita domestic water consumption and urbanization rate
There is an asymmetric inverted "V" structure between the per capita domestic water consumption and the urbanization rate (Fig.1-b), that is, as the urbanization rate increases and the urban population continues to increase, the change of water use habits and the increase of public water use make the per capita domestic water consumption continuously increase. However, after the urbanization rate reached a certain stage, with the improvement of water use efficiency and the adjustment of water use policy, the per capita domestic water consumption began to decline.

As shown in Fig.1-d, there is an asymmetrical inverted “V” structure between the urbanization rate and per capita domestic water consumption. Before the urbanization rate of 80%, there is an exponential upward trend, and after it reaches 80%, it presents a linear decline. Moreover, the zero growth point of per capita domestic water consumption in most countries lies in the urbanization rate of about 80%:

Before reaching the zero growth point, the change relationship is expressed as:

After reaching the zero growth point, its change relationship is expressed as:
3. Analysis of household water consumption in typical countries

3.1. United States
Household water in the United States can be divided into indoor and outdoor water. On average, 59% of household water consumption was used outdoors, and only 40% was used indoors [6], and the outdoor water consumption of newly built households is more [7]. Outdoor water is mainly used for garden irrigation, pool maintenance and car washing. The proportion of outdoor water use varies depending on the city and its related weather patterns. For example, from 2004 to 2011, the proportion of outdoor use in Texas ranged from 20% in Houston, to 53% in Taylor, with a statewide weighted average of 31% [8] (Figure 2-a).

3.2. France
France and Germany have similar household water structure [9,10]. Due to the relatively low frequency of cooking at home, the proportion of water used for kitchen cooking is less than 5%. Nearly 97% of its household water is used for sanitation and cleaning, and only a small part is used for food and drinking. Outdoor water, mainly used for garden and lawn irrigation, and swimming pools, also accounts for a certain proportion of domestic water. Studies have shown that water-saving awareness in France is still relatively weak, with 15-20% of household water leaking through taps and other means, which has not been effectively used.

3.3. Japan
Bathing with hot water in the bathtub in Japan has result the high proportion of water used for bathing (Fig. 2-b). The per capita annual water consumption of households has increased by 30% from 1974 to 2016. 17% of household water was used for washing clothes, 23% for cooking, 28% for flushing toilets and 24% for washing bathrooms in 2002. From 2002 to 2015, the proportion of bathing water increased

![Figure 1](image-url)
by 15%, the proportion of toilet water decreased by 6%, the proportion of kitchen water decreased by 5%, and the water used for laundry and other purposes changed little[11].

Figure 2. (a) U.S. Household Water Use Structure. (b) Japan Household Water Use Structure. (c) Chinese Household Water Use Structure in Different Regions.

3.4. China
We have selected Beijing, Yangling District of Shaanxi[12] and rural areas of Weihe District[13] as representatives of urban, township and rural household water structure respectively. The structure of household water consumption in different regions of China will be certain differences (Fig.2-c). In Beijing, toilet flushing accounted for 14% of the total household water consumption, 12% for kitchen water, 32% for bathing and gargling, 24% for laundry and 18% for cleaning. Beijing has low frequency of cooking at home. In Yangling District, the water for flushing toilet accounting for 29% of the total household water consumption, and the least water for cleaning is only 7%, with bath of 24%, laundry of 21%, kitchen of 19%. In rural areas of Weihe River, household water is mainly used for kitchen, laundry, bathing and personal hygiene, accounting for 25%, 22%, 19% and 16% respectively; and 19% of household water is used for courtyard and house cleaning.

By comparing the household water consumption structure of these countries, it is found that North America and Europe have weak awareness of water saving. Every year, more than 10% of household water in household water leaks through taps and other methods. And a large amount of outdoor water in the household water structure in the United States is mainly used for garden irrigation, swimming pool maintenance and car washing. The proportion of outdoor water in each state in household water varies from 20 to 60%. The frequency of cooking at home is relatively low in Europe, and the proportion of water used for kitchen cooking does not exceed 5% of household water. The household water structure in Japan is roughly similar to that in China.
4. Prediction of China's domestic water demand

4.1. Overall forecast

The regression equation of urbanization rate and per capita domestic water consumption can be obtained by using data fitting method:

According to the statistics and forecasts of the United Nations Economic and Social Council [14], China's urbanization rate has been increasing since 1950. It is estimated that China's urbanization rate will reach 80% by 2050. The specific trend of change is shown in Fig. 3-a. According to the above urbanization rate and regression equation, we can get the change rule of per capita domestic water in the future, as shown in the Fig. 3-b. At the same time, combined with the United Nations Economic and Social Council, the future population of China is predicted. With the increase of years, the total population of China will reach a peak around 2030, and then it will continue to decrease. By 2050, China's population will be about 1.37 billion. The specific change trend is shown in the Fig. 3-c.

Finally, the prediction results of domestic water use in China can be obtained by Eq. 1. As shown in the Fig. 3-d, China's domestic water demand will maintain a rapid growth in the future, but the growth rate will gradually slow down and reach the peak around 2050. Specifically, China's domestic water consumption will reach 88.2 billion cubic meters in 2020, 97.6 billion cubic meters in 2030 and 99.476 billion cubic meters in 2050.

4.2. Analogy prediction

In the third section, we made it clear that China’s future domestic water consumption trends are similar to Japan. Based on the data of water consumption and population in Japan over the years as sample input, the parameters are fitted by grey prediction method. Combined with the historical water use data of China, and using the least square method to calibrate the parameters, we can get the predicted change of per capita domestic water (Fig 3-e). Combining the United Nations Economic and Social Council's forecast data on China's population, we finally get the trend of China's domestic water consumption (Fig 3-f).

According to the forecast data, in 2030, the per capita water consumption is 65.69 cubic meters, and the domestic water consumption is 95.422 billion cubic meters; in 2040, the per capita water consumption is 69.12 cubic meters, and the domestic water consumption is 97.971 billion cubic meters; in 2050, the per capita water consumption is 72.64 cubic meters, and the domestic water consumption is 99.113 billion cubic meters.
Figure 3. (a) China's urbanization rate. (b) Medium and long-term prediction of China's per capita water consumption by overall prediction method. (c) Population change in China. (d) Medium and long-term forecast of water consumption change in China. (e) Medium and long-term prediction of China's per capita water consumption by analogy prediction method. (f) Medium and long-term forecast of water consumption in China.

4.3. Discussion
As shown in the table 1, the maximum error between the two prediction results obtained by overall prediction and analogy prediction is 3.85%, which is less than 5% of the allowable value. The prediction results are consistent and the prediction is reasonable.

Table 1. Comparison of the results of the two prediction methods

| Year | Overall forecast results | Analogy prediction results | Relative error |
|------|--------------------------|----------------------------|----------------|
| 2020 | 883.00                   | 913.15                     | 3.41%          |
| 2025 | 938.81                   | 969.33                     | 3.25%          |
| 2030 | 976.33                   | 945.22                     | 3.19%          |
| 2035 | 998.10                   | 959.70                     | 3.85%          |
| 2040 | 1006.54                  | 979.71                     | 2.66%          |
| 2045 | 1004.13                  | 1001.04                    | 0.31%          |
| 2050 | 994.76                   | 991.13                     | 0.36%          |

5. Conclusion
(1) Although there are differences in the per capita domestic water consumption and the peak value that can be reached, the relationship between per capita water consumption and per capita GDP in the traditional developed capitalist countries has a "S"-shaped curve change and there is an asymmetric inverted "V" structure between the urbanization rate and the per capita domestic water consumption. With the help of relationship, we can forecast the domestic water demand in China in the medium and long term.
Through the analysis of domestic water structure of typical countries in different regions, we find that North America and Europe have weak water-saving awareness. In addition, there is a large amount of outdoor water in the domestic water structure of the United States. The frequency of cooking at home in Europe is relatively low, and the proportion of water used for kitchen cooking is also low. The structure of domestic water consumption in Japan is similar to that in China, which can be used as a sample for comparative prediction of domestic water demand in China.

By using the overall prediction method of regression analysis, China's domestic water consumption in 2050 is 99.476 billion cubic meters, while through the comparative prediction and analysis of Japan, China's domestic water consumption in 2050 is 99.113 billion cubic meters. The two prediction results are consistent within the allowable error range.

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