Analysis of domestic water consumption in typical countries and its enlightenment to China

Boyu Du [1, 2], Xiaoqian Guo [2, *], Qiang Yan [2], Hongmei Duan [3], Guwang Liu [2]

[1] School of Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China
[2] Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China
[3] Chinese Academy of International Trade and Economic Cooperation, Ministry of Commerce, Beijing 100010, China

Abstract. With the development of the country and the improvement of the level of science and technology, the use of water resources in China is on the rise. Among them, the domestic water consumption is increasing rapidly, and it is predicted that the domestic water consumption in China will reach two to three times that in the early 21st century in the middle of the 21st century. Based on the data of domestic water consumption in ten typical countries in the world, such as the United States, Germany and Japan, this paper studies the variation of per capita domestic water consumption in these countries with per capita GDP, urbanization rate and other factors. Taking these data as samples, the domestic water consumption in China is predicted. The prediction results can further help relevant departments to formulate reasonable policies in water resources planning.

Keywords: Domestic water; typical country; structure analysis; predication model.

1. Introduction

China is a country with a serious shortage of water resources, and its per capita water resources are only about 25% of the world's per capita water resources. Our country not only has the problem of insufficient water resources per capita, but also has the problem of unbalanced distribution of water resources. China has a vast territory, but there are still more water resources in the south than in the north and in the east than in the west. For example, overlooking North China from a high altitude, we can see that the earth's crust has sunk, which is due to the serious soil erosion in North China. At the same time, due to the increase of residents' water consumption and climate change, the shortage of water resources in China is aggravated, China's water shortage and unbalanced distribution are becoming more and more serious [1].

According to the data from the China water resources bulletin in 2019, China's total water consumption is 581.29 billion cubic meters [2]. Affected by the epidemic situation in COVID-19 and abundant precipitation, the water consumption decreased by 20.83 billion cubic meters compared with that in 2019. And domestic water is 86.31 billion cubic meters, accounting for 14.9% of the total water. Domestic water is divided into urban domestic water and rural domestic water. Urban domestic water includes urban residents' domestic water and public water, while rural domestic water refers to rural residents' domestic water and domestic livestock water [3]. China is in a period of rapid development, and the urbanization rate and people's living standard are getting higher and higher, so is the total domestic water consumption and the proportion of domestic water consumption in the total water consumption. Therefore, the medium-and long-term forecast of China's water consumption, especially domestic water consumption, is conducive to relevant departments to formulate policies that are more in line with China's national conditions, and is conducive to China's more efficient use of water resources.

With the increase of urbanization rate, Yang et al. studied farmers' domestic water [4]. Based on the planned behavior theory and structural equation, Fan constructed a water-saving behavior model of residents, and analyzed the dominant factors of rural household domestic water consumption and the change of rural per capita domestic water consumption in the future [5]. Taking the domestic water consumption of urban residents in Lanzhou of Gansu Province, Yang et al. analyzed energy consumption in the process of urban household water consumption [6]. Wang analyzed the influencing factors of urban domestic water consumption by using the method of system dynamics, and predicted the total amount of urban domestic water consumption in 31 provinces from 2016 to 2025 [7]. However, their research basically only analyzes China, and lacks a comparative study of the development trend between China and other countries. Comprehensive analysis of other countries is

* Corresponding author: guoxiaoqian@mail.cgs.gov.cn

conducive to analyzing the changing trend of domestic water consumption at different stages of development in China.

In the process of this study, by extracting economic and social development indicators such as per capita GDP and urbanization rate, and selecting typical countries such as the United States, Japan, Germany and France, we obtained long-scale data such as water resources, economy and society, and screened the forecasting methods suitable for different research objects through various methods such as law, analogy and regression equation, and selected different models to determine the parameters and extract relevant indicators. From different time points, we carried out the domestic water demand in China (Fig.1).

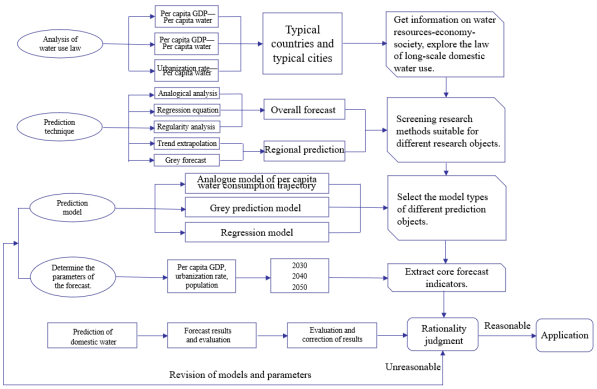


Figure 1. Technical drawing of domestic water.

2. Domestic water in typical country

According to the data of the United Nations Statistics Division on water consumption in major countries around the world, the total water consumption in the world is about 4 trillion cubic meters, of which domestic water accounts for about 10% [8]. In the past century, the growth rate of human water consumption was more than twice that of population, and about 77% of the growth occurred in developing countries [9-10]. However, previous studies have shown that there are huge differences in water use structure in different regions. For example, most of the water resources extracted by Asian countries are used for agriculture (82%), while few are used for industry and domestic sectors (9%). In Europe, by contrast, most of the water resources are used for industrial activities (55%), followed by agriculture (29%) and the household sector (16%) [11]. The annual total water consumption in Asia is estimated to be 642 cubic metre per capita, but it is only 82 cubic metre per capita in Europe [12]. At the same time, due to water-saving appliances (dishwasher, water-saving toilet, drum washing machine, etc.), water price, climate, geographical location, living standard of residents, etc., there is still a big gap between the per capita domestic water consumption and domestic water structure in each country. Therefore, 10 typical countries, such as the United States, Germany, France and Japan, were selected to collect their data of per capita domestic water consumption, and then according to the data of urbanization rate and per capita GDP of the World Bank (Fig.2-a, Fig.2-b), the relationship between per capita domestic water consumption and national development level was analyzed [13].

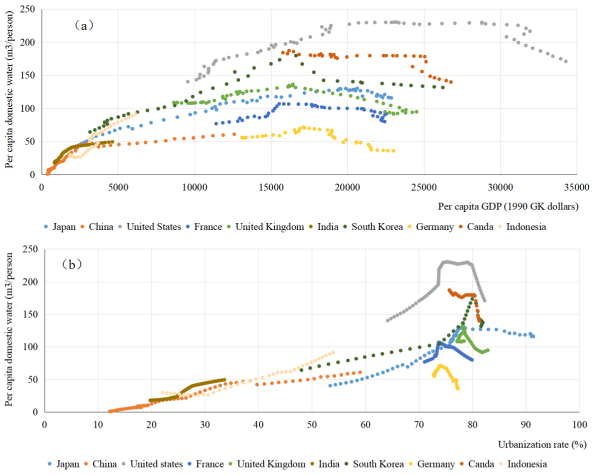


Figure 2. (a) Per capita GDP vs. per capita domestic water consumption. (b) Urbanization rate vs. per capita domestic water consumption.

As shown in Fig.2-a, the law of per capita domestic water consumption changing with per capita GDP (1990 GK dollars) can be summarized into three stages. Before GDP per capita reached 15000-20000 dollars (1990 GK dollars), the per capita domestic water consumption gradually increased, but the increasing rate gradually slowed down. After that, the per capita domestic water consumption of each country is relatively flat. When it reached about 20000 dollars (1990 GK dollars), the per capita water consumption in most countries began to decline one after another. The law of per capita water consumption in each country changing with urbanization rate can be summarized as inverted "U".

As shown in Fig.2-b, the law of per capita domestic water consumption changing with urbanization rate can be summarized into two stages. With the increase of urbanization rate, the per capita water consumption also rises. When the urbanization rate reaches 70% to 80%, the per capita water consumption of each country has reached its peak one after another. After that, the per capita water consumption decreased with the increase of urbanization rate. The law that the per capita water consumption of each country changes with the urbanization rate can be summarized as inverted "V".

Among them, due to the differences in lifestyle and development level of nationals in different countries, there are certain differences in per capita domestic water consumption. For example, in the United States, there is a large amount of outdoor water for reasons such as washing cars and maintaining swimming pools, so the domestic water consumption is higher than that in other countries. The urbanization rate and GDP per capita (1990 GK dollars) at the peak of per capita domestic water consumption in each country are shown in Table 1. (since China, Indonesia and India have not yet reached the peak of water consumption, the data in 2018 are adopted).

Therefore, the urbanization rate in typical countries is 70% to 80% when the per capita domestic water consumption reaches the peak.

Table 1. Peak value and corresponding index of per capita domestic water consumption in typical countries.

Country	Per capita domestic water consumption（m³）	Urbanization rate（%）	Per capita GDP（1990 GK dollars）
United States	230.29	75.30	24323
United Kingdom	136.09	78.14	17257
France	106.58	73.65	15813
Canada	186.96	75.66	16176
Germany	71.39	73.92	17118
Japan	130.02	78.27	24349
South Korea	179.42	80.31	17208
India	49.28	33.62	4640
Indonesia	91.15	53.96	6217
China	60.77	58.98	15427

2.1 United States

Since 1950, the United States Geological Survey began to make statistics on the utilization of water resources in the country, which was published every five years. The water use structure of this institution is similar to that of China, which can be divided into agricultural water, industrial water supply and domestic water. Domestic water mainly includes urban water (including public water and urban household water) and rural domestic water. Industrial water and agricultural water account for a large proportion and fluctuate greatly, while domestic water accounts for about 10% [14].

Due to garden irrigation, pool maintenance and car washing, the proportion of outdoor domestic water in the United States is high, which is also an important reason why the per capita domestic water consumption in the United States is higher than that in other countries [15]. Outdoor water consumption in the United States is influenced by many factors, such as household income, residence abbreviation time, landscape area, garden type, whether to use automatic irrigation system, precipitation, climate and local aesthetic landscape preference. However, with the development of economy, the outdoor water consumption may not be reduced, on the contrary, it is more than that of newly built households.

The change of per capita domestic water consumption in America can be divided into three stages (Fig.3-b). (1) before 1985, that is, before GDP per capita reached 21388 dollars (1990 GK dollars) and urbanization rate reached 74.49%, the per capita domestic water consumption increased. (2) From 1985 to 2000, the per capita GDP reached 31213 dollars (1990 GK dollars), the urbanization rate reached 79.06%, and the per capita domestic water consumption was basically stable at 230 cubic meters per person. (3) After 2000, the per capita domestic water consumption gradually decreased.

In 1999, the per capita indoor domestic water consumption in America was 95.65 cubic meters. In 2016, the per capita indoor domestic water consumption was 80.97 cubic meters [16]. Due to the improvement of living standards and the development of science and technology (such as the popularity of water-saving appliances such as dishwashers, water-saving toilets and drum washing machines), the structure of domestic water has undergone significant changes (Fig.3-c). The water consumption in bathing part increased, while that in cooking, flushing and laundry part decreased (Table 2).

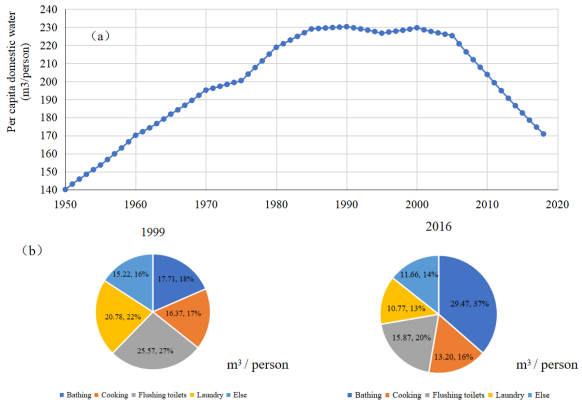


Figure 3. (a) Structure of per capita domestic water in the United States over the years. (b) Per capita living water structure in the United States over the years.

Table 2. Changes of domestic water structure in the United States.

	1999	2016
Per capita GDP (1990 GK dollars)	30158.63	38250.39
Urbanization rate (%)	78.74	81.86
Per capita domestic water consumption (m³)	95.75	80.97
The structure of domestic water	Bathing 18% + Cooking 17% + Flushing toilets 27% + Laundry 22% + Else 16%	Bathing 37% + Cooking 16% + Flushing toilets 20% + Laundry 13% + Else 14%
Trend of per capita water consumption (m³)		Bathing increased 66.39%, Cooking decreased 19.39%, Flushing toilets decreased 37.92%, Laundry decreased 48.17%.

2.2 Japan

The change of per capita domestic water consumption in Japan is divided into three stages (Fig.4-a). (1) before 1990, that is, before the per capita GDP reached 21045 dollars (1990 GK dollars) and before the urbanization rate reached 77.34%, the per capita domestic water consumption increased. (2) From 1990 to 2004, the per capita GDP reached 26951 dollars (1990 GK dollars), the urbanization rate reached 84.64%, and the per capita domestic water consumption was basically stable from 126 to 130 cubic meters. (3) After 2004, the per capita domestic water consumption gradually decreased.

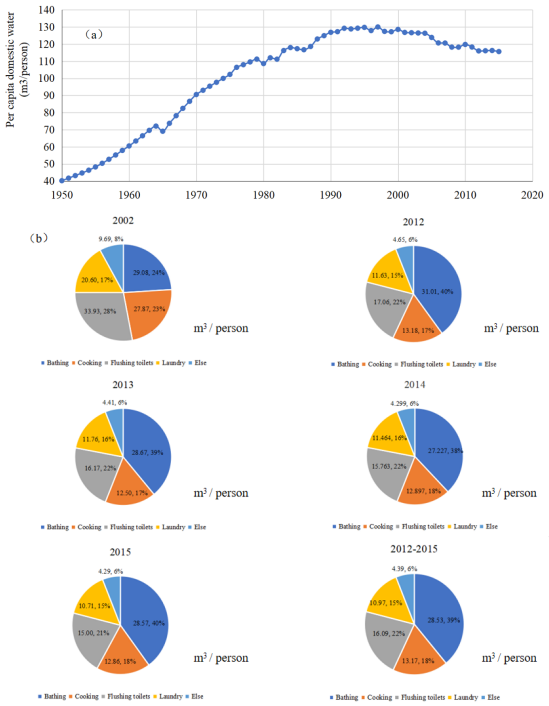


Figure 4. (a) Per capita domestic water consumption in Japan over the years. (b) Structure of per capita domestic water consumption in Japan over the years.

In 2002, the per capita domestic water consumption in Japan was 121.17 cubic meters. In 2012, the per capita domestic water consumption in Japan was 116.02 cubic meters. From 2012 to 2015, the per capita domestic water consumption was stable at about 116 cubic meters, and the water consumption structure remained basically unchanged [17-18].

Similar to the United States, the water consumption in bathing part increases, while the water consumption in cooking, toilet and laundry part decreases (Fig.4-b, Table 3). The reason for the increase of water consumption in bathing part is that Japanese people have the habit of taking a bath with hot water in the bathtub. Part of the water consumption in toilets has decreased, which may be due to the fact that more and more families choose to flush toilets with seawater and the popularity of water-saving toilets. However, the water consumption for cooking and washing has decreased. Apart from the popularity of water-saving appliances such as dishwashers and drum washing machines, it is also possible that living alone is increasing and the lifestyle has changed.

Table 3. Changes of domestic water structure in Japan.

	2002	2012	2015
Per capita GDP (1990 GK dollars)	25732.22	29135.56	30545.80
Urbanization rate (%)	81.65	91.15	91.38
Per capita domestic water consumption (m^3)	121.17	77.53	71.43
The structure of domestic water	Bathing 24% + Cooking 23% + Flushing toilets 28% + Laundry 17% + Else 8%	Bathing 40% + Cooking 17% + Flushing toilets 22% + Laundry 15% + Else 6%	Bathing 40% + Cooking 18% + Flushing toilets 21% + Laundry 15% + Else 6%
Trend of per capita water consumption (m^3)		Bathing increased 6.64%, Cooking decreased 52.71%, Flushing toilets decreased 49.73%, Laundry decreased 43.55%.	Bathing decreased 7.87%, Cooking decreased 2.45%, Flushing toilets decreased 12.06%, Laundry decreased 7.87%.

2.3 France and Germany

The change of per capita domestic water consumption in France is divided into three stages (Fig.5-a). (1) Before 1985, that is, before the per capita GDP of France reached 15813 dollars (1990 GK dollars) and before the urbanization rate reached 73.65%, the per capita domestic water consumption increased. (2) From 1985 to 1990, the per capita GDP reached 18131 dollars (1990 GK dollars), the urbanization rate reached 74.06%, and the per capita domestic water consumption was basically stable at about 106 cubic meters. (3) After 1990, the per capita domestic water consumption gradually decreased.

The change of per capita domestic water consumption in Germany is divided into three stages (Fig.5-b) (1) Before

1994, that is, before Germany's per capita GDP reached 16874 dollars (1990 GK dollars) and before the urbanization rate reached 73.71%, the per capita domestic water consumption increased. (2) From 1994 to 2001, the per capita GDP reached 18985 dollars (1990 GK dollars), the urbanization rate reached 75.14%, and the per capita domestic water consumption decreased slowly year by year. (3) After 2001, the per capita domestic water consumption dropped rapidly.

The domestic water structure in France and Germany is similar (Fig.5-c). In recent years, due to the popularity of water-saving appliances, the water consumption of household appliances decreased, and the transformation of factories and transmission networks reduced the loss, etc., the household water consumption decreased year by year. As for the structure of domestic water consumption, France, Germany and other countries cook at home at a relatively low frequency, so the water consumption for cooking is low. Similar to America, France also has many residents with gardens, lawns and outdoor swimming pools, but the outdoor water consumption only accounts for about 6% of the total domestic water consumption. In addition, France's awareness of water saving is weak, and about 15% of domestic water is still wasted every year because of faucet leakage and other reasons.

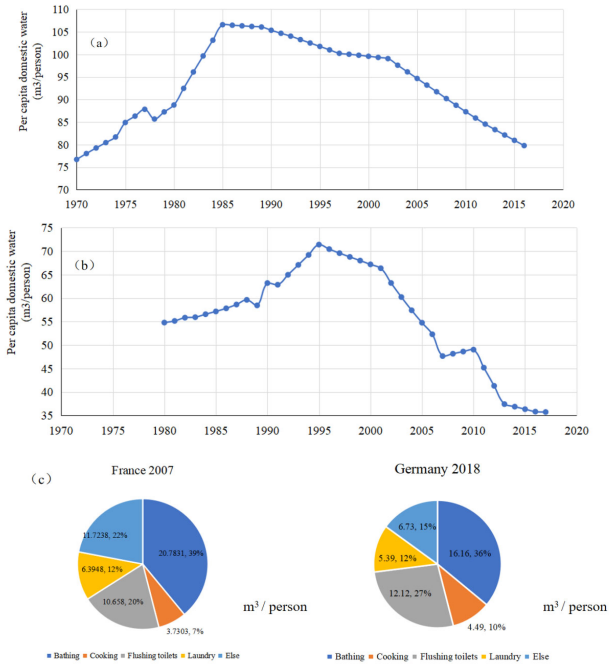


Figure 5. (a) Per capita domestic water consumption in France over the years. (b) Per capita domestic water consumption in Germany over the years. (c) Comparison of domestic water consumption between France and Germany.

2.4 Discussion

Because of the differences in living habits, development, climate and other factors in each region, there are certain differences in domestic water consumption and domestic water structure. Therefore, the United States was selected in North America, Germany and France were selected in Europe, and Japan was selected as a comparative sample in Asia. Through research, it is found that:

There is a large amount of outdoor water in American domestic water, even exceeding indoor water consumption. Outdoor water is mainly used for car washing, garden irrigation and swimming pool maintenance. However, the per capita indoor water consumption is similar to that of other typical countries, and the domestic water consumption in China is mainly indoor water. Therefore, when making a comparative study, we can compare and analyze the indoor water consumption per capita in the United States with that in China.

Because more and more residents live alone in Japan and flushing toilets with seawater is becoming more and more popular, the water consumption of cooking, laundry and toilets is decreasing year by year. And the lifestyle of Japanese residents is most similar to that of Chinese residents.

The lifestyles in Germany and France are similar to those in the United States, but the proportion of outdoor water consumption is small, and there is a lot of waste of domestic water. In addition, because of the low frequency of cooking at home, the proportion of water used for cooking is low.

In addition, due to the development of science and technology and the further popularization of water-saving appliances, the water consumption of cooking, laundry and toilet will be further reduced.

3. Analysis and Forecast of Domestic Water Consumption in China

3.1 Analysis of Domestic Water Consumption in China

3.1.1 Analysis of total domestic water consumption

Since 1950, the change of domestic water consumption in China has been divided into three stages (Fig.6-a). (1) the slow rising period from 1950 to 1980. At this stage, the proportion of domestic water consumption in total water increased from 0.3% in 1950 to 2.2% in 1980, with an average annual growth rate of 7.2%. Domestic water consumption increased from 330 million cubic meters to 10.1 billion cubic meters, an increase of about 29 times, with an average annual increase of 322 million cubic meters. (2) The period of rapid growth from 1980 to 2000. During this period, domestic water consumption increased from 10.1 billion cubic meters to 57.5 billion cubic meters, with an average annual increase of 2.4 billion cubic meters, and the proportion of domestic water increased from 2.2% to 10.5%, with an average annual growth rate of 8.1%. (3) The growth rate has declined since 2000. In 2020, the domestic water consumption and its proportion will be 86.3 billion cubic meters and 14.9% respectively, the total water consumption will increase by 28.9 billion cubic meters, and the average annual water consumption will increase by 1.4 billion cubic meters. It can be seen from Fig.6-a that the variation law of domestic water consumption and its proportion in total water

consumption in China from 1950 to 2020 is highly consistent.

3.1.2 Analysis on the structure of domestic water

There is no systematic survey on family life structure in China, so Beijing, Yangling District of Shaanxi Province and rural areas of Weihe District are selected as the representatives of domestic water structure in cities, towns and villages (Fig.6-b).

By analyzing the domestic water consumption in rural areas of Weihe District, Yangling District of Shaanxi Province and Beijing, we can roughly analyze the change of the proportion of each part of water consumption to domestic water consumption in the process of increasing urbanization rate in China [5,19]. It can be seen from Fig.6-b that with the increase of urbanization rate, the proportion of water used for bathing in China has increased (from 24% to 32%), while the proportion of water used for cooking and washing has decreased (from 30% to 12% for cooking and from 27% to 24% for washing), while the proportion of water used for toilet has increased first and then decreased. It also shows that with the increase of urbanization rate, residents' awareness of water saving has generally increased, and the popularity of water-saving appliances has reduced the proportion of water consumption in cooking, laundry and toilets. However, due to the further increase of urban residents living alone, the proportion of water used for cooking decreased significantly.

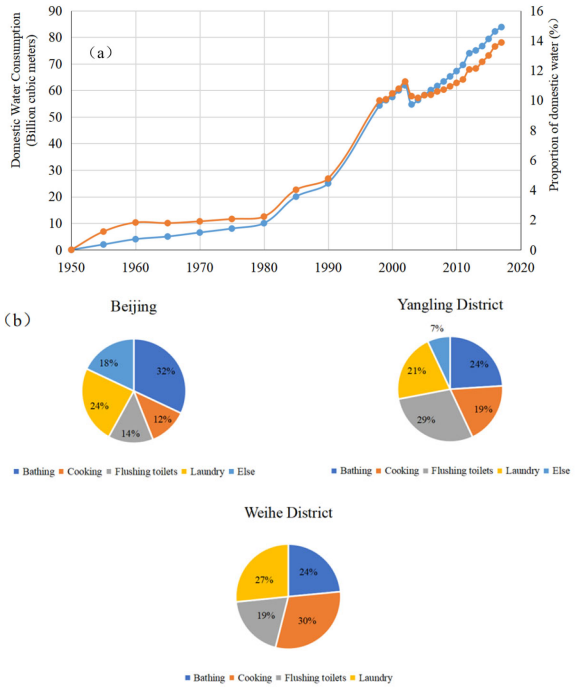


Figure 6. (a) Trend of domestic water consumption in China.

(b) Comparison of Domestic Water Consumption among Urban, Township and Rural in China.

3.2 Forecast of domestic water consumption in China

3.2.1 Forecast of total domestic water consumption

For the calculation of China's future domestic water consumption, we can fit the curve according to the data of urbanization rate and per capita domestic water consumption of the World Bank from 1950 to 2019, and then predict the per capita domestic water consumption of China in the future according to the curve. Five models are adopted to forecast (Fig.7-a, Table 4).

(1) Model 1.

$$y = 41.1961\ln x - 107.74 \quad (1)$$
$$R^2 = 0.9727$$

This curve is a logarithmic function curve. According to this curve, with the increase of urbanization rate, the per capita domestic water consumption will increase. However, compared with typical countries such as the United States and Japan, when the development level is the same, the per capita domestic water consumption is too low, and the predicted results are inconsistent with the development trend of China.

(2) Model 2.

$$y=-0.0222x2+2.8704x-33.905 \quad (2)$$
$$R2=0.9796$$

This curve is a polynomial function curve. According to this curve, China's per capita domestic water consumption has reached its peak in 2023. In 2023, China's urbanization rate will be 64.57%. In fact, according to the law of per capita domestic water consumption changing with urbanization rate in other typical countries, when the water consumption reaches its peak, the urbanization rate of each country is 70% to 80%. The predicted results are inconsistent with the development laws of typical countries.

(3) Model 3.

$$y=0.015x2.1679\ y = 0.015x^{2.1679} \quad (3)$$
$$R^2 = 0.8777$$

This curve is a power function curve. According to this curve, with the increase of urbanization rate, the per capita domestic water consumption will increase. However, compared with the known data, there is a cliff-like growth in the predicted data. It is inconsistent with the facts, so the prediction results are unreliable.

(4) Model 4.

$$y=289.1382(1-e-0.01013x$$
$$y=289.1382(1-e-0.01013x\ y = 289.1382(1 - e^{-0.01013x}) \quad (4)$$

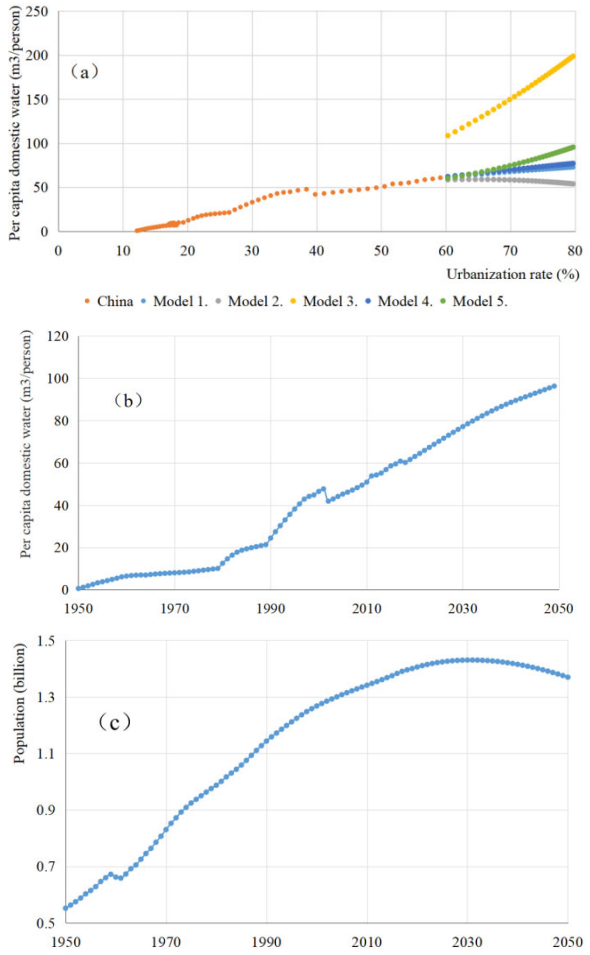
This curve is an exponential function curve. With the increase of urbanization rate, the per capita domestic water consumption increases, and the rate of increase gradually slows down. According to the analysis of domestic water consumption in other typical countries, the predicted results conform to the changing law. However, compared with typical countries such as the United States and Japan, when the development level is the same, the per capita domestic water consumption is still too low, which is inconsistent with the development law of China.

(5) Model 5.

$$y = 39.7019 + (8.1385E-6)x^{3.5949} \quad (5)$$
$$R^2 = 0.9885$$

This curve is a polynomial function curve. Compared with (2), some parameters are adjusted, which makes the forecast result more close to the development trend of per capita domestic water consumption in typical countries. After analyzing typical countries such as the United States and Japan, it is considered that the forecast results are within the normal range, which is in line with the development trend of China's per capita domestic water consumption.

According to (5) the predicted per capita domestic water consumption (Fig.7-b) and the World Bank's forecast data of China's population from 2020 to 2050 (Fig.7-c), the total domestic water consumption in China in the next 30 years can be predicted (Fig.7-d). The results show that the predicted results are increasing year by year, and the growth rate is decreasing year by year, and the predicted results are relatively smooth. In 2030, China's domestic water consumption will reach 108.37 billion cubic meters. In 2040, China's domestic water consumption will reach 124.02 billion cubic meters. In 2050, China's domestic water consumption will reach 131.81 billion cubic meters.



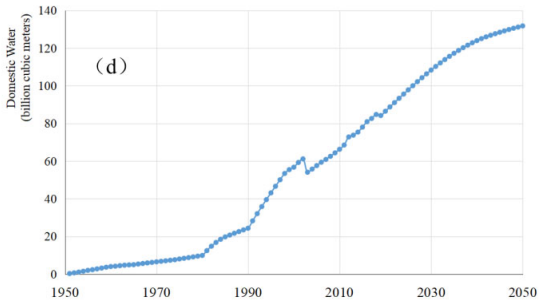


Figure 7. (a) Per capita domestic water consumption forecast. (b) Forecast of China's per capita domestic water consumption. (c) China's population forecast. (d) Forecast of total domestic water consumption in China.

Table 4. Forecast results of per capita domestic water consumption.

	2030	2040	2050
Model 1.	67.65	70.90	72.80
Model 2.	58.09	55.79	53.63
Model 3.	152.92	181.51	200.51
Model 4.	70.26	74.64	77.26
Model 5.	75.79	87.65	96.26

3.2.2 Forecast on the structure of domestic water

By analyzing the changing trend of domestic water structure in the United States, Japan, France, Germany and other countries, and forecasting the urbanization rate in China, we can find that:

(1) With the increase of urbanization rate, the proportion of water used for bathing increased, but the proportion of water used for cooking, toilet and laundry decreased. With the development of cities and the improvement of people's living standards, more and more young people prefer to order takeout instead of cooking at home. Therefore, the proportion of water used in the cooking part gradually decreases, and then the proportion of water used in this part tends to be stable. While the proportion of the other two parts decreased slowly.

(2) Although the proportion of water used for bathing will increase with the increase of urbanization rate, the peak value of water used for bathing in various countries is about 40%, and the urbanization rate is about 80% to 90% .

(3) In 2020, China's urbanization rate will be 61.4% [20]. According to the World Bank's forecast of China's urbanization rate, China's urbanization rate will be 80.0% in 2050. At this time, the proportion of water used in bathing part will reach near the peak. The structure of domestic water in 2030, 2040 and 2050 is shown in the Fig 8.

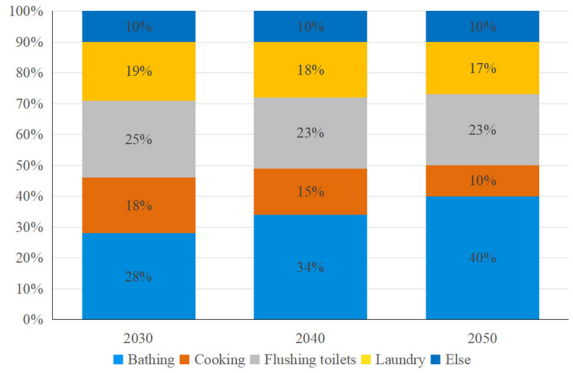


Figure 8. Prediction of domestic water structure in China.

4. Conclusion

(1) There are differences in national conditions and development stages in different countries, so there are differences in the peak value of domestic water in different countries. However, the change of per capita domestic water is regular. The law of per capita water consumption changing with urbanization rate can be summarized as inverted "U", and the law of per capita water consumption changing with urbanization rate can be summarized as inverted "V".
(2) By extracting economic and social development indicators such as GDP per capita and urbanization rate, and selecting typical countries such as the United States, Japan, Germany and France, we obtained long-scale data such as water resources, economy and society, and analyzed them. It is found that there is a large amount of outdoor domestic water in the United States, but indoor domestic water can still be divided into five parts: bathing, cooking, flushing, laundry and other parts, and the analysis of indoor domestic water in the United States is still of reference. The old capitalist countries in Europe have different domestic water consumption, but the structure of water consumption is similar, which may be due to similar development level and similar living habits. The structure of Japan's domestic water is similar to China's, which may be due to its similar living habits.
(3) By studying the domestic water consumption in typical countries, the domestic water consumption in China is predicted. In 2050, China's domestic water consumption will reach 131.8 billion cubic meters.

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