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Urban Fresh Water Resources Consumption of China

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Abstract: From the point of view of urban consumption behavior, urban fresh water consumption could be classified as three types, namely, direct, indirect and induced water consumption. A calculation approach of urban fresh water consumption was presented based on the theory of urban basic material consumption and the input-output method, which was utilized to calculate urban fresh water consumption of China, and to analyze its structural change and causes. The results show that the total urban fresh water consumption increased $561.7\times10^9 m^3$, and the proportion to the total national fresh water resources increased by 20 percentage points from 1952 to 2005. The proportion of direct and induced water consumption had been continuously rising, and it increased by 15 and 35 percentage points separately from 1952 to 2005, while the proportion of indirect water consumption decreased by 50 percentage points. Urban indirect water consumption was mainly related to urban grain, beef and mutton consumption, and urban induced water consumption had a close relationship with the amount of carbon emission per capita. Finally, some countermeasures were put forward to realize sustainable utilization of urban fresh water resources in China.
Keywords: urban fresh water consumption; direct water consumption; indirect water consumption; induced water consumption; China

1 Introduction

As one of the most important natural resources and environment controllable elements, fresh water resources are important part of national power (Wang et al., 2002). The sustainable utilization of urban fresh water resources is vital to residents living and urban socio-economic sustainable development (Zhai et al., 2003). The previous studies on urban water consumption mainly centred on urban direct water consumption, which involves urban industry, domestic and environment water consumption. The studies on urban industry water consumption focused on the total amount of industry water consumption, its changing trend, and the correlation between industry water consumption and economy development (Qian et al., 2002; Jia et al., 2004; Merrett, 1997); those on urban domestic water consumption mostly aimed at its influencing factors and prices (Qi, 2002; Yin and Yuan, 2005; Shen et al., 2006); and those on urban environment water consumption mainly involved the consumption amount and its values (Jenerette et al., 2006a; 2006b). Additionally, some researches focused on the changing trend of the amount of urban water consumption (including urban industry and domestic water consumption) in China (Qian et al., 2002; Wu, 2005). In a word, previous studies on urban water consumption were merely related to urban direct water consumption, which is only a very small part of urban water consumption.

With the development of urbanization, the composition of urban fresh water consumption has evolved from "direct and indirect water consumption" to "direct, indirect and induced water consumption". From the point of view of ecosystem theory, the urban water consumption in this paper was extended to the rural and natural ecosystems, involving all of the direct, indirect and induced water consumption (Zhang and Zhu, 2008). The paper presented a calculating method of urban fresh water consumption, which was used to calculate the amount and structure of urban fresh water consumption, and to analyze its fluctuant causes, subsequently to reveal the rule of urban fresh water consumption. Based on the above work, we could bring forward some countermea-

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sures to guarantee the sustainable utilization of urban fresh water resources in China.

2 Data and Methods

2.1 Data sources

Data for statistical analysis in this study were collected from the following sources: *China Water Resources Bulletin* (*1997–2005*) (The Ministry of Water Resources of the People's Republic of China, 1998–2006), *China Statistical Yearbook* (*1981–2006*) (National Bureau of Statistics of China, 1982–2007), *China Agriculture Yearbook* (*1980–2006*) (China Agriculture Yearbook Editorial Commission, 1981–2007), *China Land and Resources Almanac* (*1999–2005*) (Ministry of Land and Resources, 2000–2006), *China Compendium of Statistics 1949–2004* (National Bureau of Statistics of China, 2005), and other related statistical data (Wang, 2006; Liu et al., 2000; Feng, 2007; Liu, 1995; Liu and He, 1996; Liu and Chen, 2001; Water Resources and Hydropower Planning Academy of the Water Resources Hydropower and Electric Power Ministry, 1989; Zhang, 2009).

2.2 Calculation methods

2.2.1 Direct water consumption

Urban direct water consumption is the sum of urban industry and domestic water consumption (before 2003, the domestic water consumption included environment water consumption in statistical yearbooks). And the related data can be obtained and checked from national and regional data.

2.2.2 Indirect water consumption

Based on the theory of urban basic material consumption and the input-output method, the calculation method of urban indirect water consumption was presented. In order to calculate indirect water consumption, we need to calculate the amount of water that is consumed by all kinds of agriculture and by-products, which are consumed by urban household domestic life. Based on the principle of counting convenience and data acquirability, the paper chose the following eight kinds of products to calculate water consumption: grain, vegetables, eatable plant oil, pork, mutton and beef, poultry, poultry egg, and fruit.

In the calculating process, indirect water consumption was divided into indirect agriculture and grassland water consumption, and they were calculated separately. Agriculture water consumption is the amount of indirect water resources consumed by farmland, forestry and animal husbandry. And grassland water consumption is the amount of indirect water resources consumed by grassland.

(1) Agriculture water consumption. The expression of urban indirect agriculture water consumption is as follows:

$$IAW = (M + \frac{TAW}{TAE})\sum_{i=1}^{8}\frac{T_a \times P \times C_i}{TC_i} + \alpha TFW \qquad (1)$$

where IAW is indirect agriculture water consumption; M is water producing per unit area obtained from *China Water Resources Bulletin* (*1997–2005*) (The Ministry of Water Resources of the People's Republic of China, 1998–2006); P is urban population; T_a is the total sown area of different kinds of agriculture and by-products consumed; C_i is the consumption of the ith agriculture and by-product per capita (the consumption of pork, poultry and poultry egg is first transformed into the consumption of grain); TC_i is the total output of the ith agriculture and by-product; TAW is the total amount of the irrigation water; TAE is the total sown area; TFW is the total water consumption of forestry, animal husbandry and fishery, and its value is from *China Water Resources Bulletin* (*1997–2005*) (The Ministry of Water Resources of the People's Republic of China, 1998–2006); α is the coefficient of indirect water consumption, and its value is from Zhang's research (2009).

(2) Grassland water consumption. The expression of urban indirect grassland water consumption is as follows:

$$IGW = M \times \frac{T_g \times P \times C_g}{TC_g} \qquad (2)$$

where IGW is indirect grassland water consumption; T_g is the total area of grassland; C_g is mutton and beef consumption per capita; TC_g is the total output of mutton and beef.

(3) Total indirect water consumption. The expression of urban total indirect water consumption (IW) is as follows:

$$IW = IAW + IGW \qquad (3)$$

2.2.3 Induced water consumption

Calculation of the induced water consumption is mainly based on the total amount of urban carbon emission. In terms of the counting convenience and data acquirability, the forest land was selected as the only factor that absorbed carbon emission. Firstly, the area of forest land that absorbs carbon emission was counted. Secondly, the total water consumption that was consumed by the forest land was counted, which was urban induced water consumption.

The expression of urban induced water consumption is as follows:

$$IDW = M \times \frac{T_c}{C_d} \tag{4}$$

where *IDW* is induced water consumption; T_c is the total amount of urban carbon emission and its value is from Zhang's research (2009); and C_d is carbon absorbing coefficient and its value is from the research of Liu et al. (2000).

2.2.4 Total water consumption

Total urban water consumption is the summation of direct, indirect and induced water consumption. The expression is as follows:

$$TWC = \sum(DW, IW, IDW) \tag{5}$$

where *TWC* is total urban water consumption; and *DW* is direct water consumption.

3 Results and Analyses

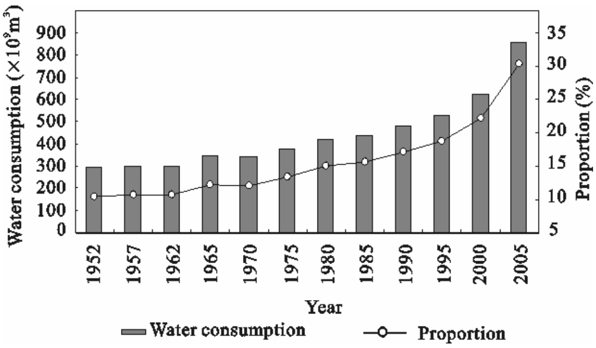
3.1 Change in water consumption

3.1.1 Total water consumption

Urban fresh water consumption had being continuously increasing, with slightly fluctuation in particular period, from 1952 to 2005. What's more, from 1995 to 2005, it had a trend of speedup (Fig. 1). Water consumption increased from 293.46×10^9m^3 in 1952 to 855.18×10^9m^3 in 2005, increasing 561.7×10^9m^3. And the proportion of the consumption to the total national fresh water resources increased from 10.43% in 1952 to 30.41% in 2005, increasing about 20 percentage points. The pressure of cities on the fresh water resources was constantly increasing in China.

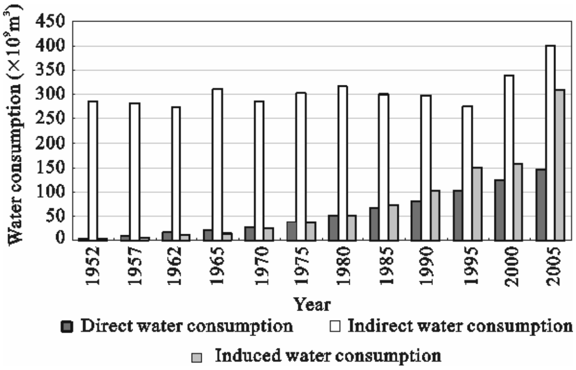
3.1.2 Water consumption for each component

Urban direct water consumption had increased about 30 times from 1952 (4.90×10^9m^3) to 2005 (145.25×10^9m^3) (Fig. 2). Based on the speed changes, the whole process was divided into two phases: 1) Slow increasing phase in 1952–1980. Urban direct water consumption increased 47.60×10^9m^3, and increasing speed was only 1.7×10^9m^3 per year. 2) Fast increasing phase in 1980–2005. In this period, water consumption increased 92.70×10^9m^3, and increasing speed was 3.7×10^9m^3 per year.



Sources: The Ministry of Water Resources of the People's Republic of China, 1998–2006; National Bureau of Statistics of China, 1982–2007; China Agriculture Yearbook Editorial Commission, 1981–2007; The Ministry of Land and Resources of P. R. C., 2000–2006; National Bureau of Statistics of China, 2005; Wang, 2006; Liu et al., 2000; Feng, 2007; Liu, 1995; Liu and He, 1996; Liu and Chen, 2001; Water Resources and Hydropower Planning Academy of the Water Resources Hydropower and Electric Power Ministry of China, 1989; Zhang, 2009

Fig. 1 Total urban water consumption and its proportion to total fresh water resources in China from 1952 to 2005



Data sources are the same as Fig. 1

Fig. 2 Changes of each part of urban water consumption in China from 1952 to 2005

Different from urban direct water consumption variation, indirect water consumption had a characteristic of fluctuation, and water consumption had only a little increase (Fig. 2). Based on the different changing characteristic, the whole process was divided into two phases: 1) Fluctuating and stasis phase in 1952–1995. In this period, water consumption fluctuated regularly, but the extent was small. And it maintained about 280×10^9m^3. 2) Fast increasing phase in 1995–2005. Urban indirect water consumption increased about 120×10^9m^3 in ten years.

Urban induced water consumption had been continuously increasing since 1952 (Fig. 2). And the induced water consumption increased about 100 times from

1952 ($3.12\times10^9m^3$) to 2005 ($310.00\times10^9m^3$). The annual increasing rate reached 90.6% due to the rapid increase of urban energy consumption.

3.2 Change in water consumption structure

The proportion of urban indirect water consumption was the biggest among the three components in the study period (Fig. 3). However, as far as changing characteristic was concerned, the proportion of urban indirect water consumption had a trend of decrease, and its proportion was even under 50% in 2005 (it ever reached as much as 97% in 1952). From 1952 to 2005, the proportion of urban indirect water consumption decreased by about 50 percentage points. While the proportions of direct and induced water consumption had a trend of increase (with an exception of particular period), and they increased 15 and 35 percentage points separately from 1952 to 2005. The increase speed of induced water consumption was more rapid.

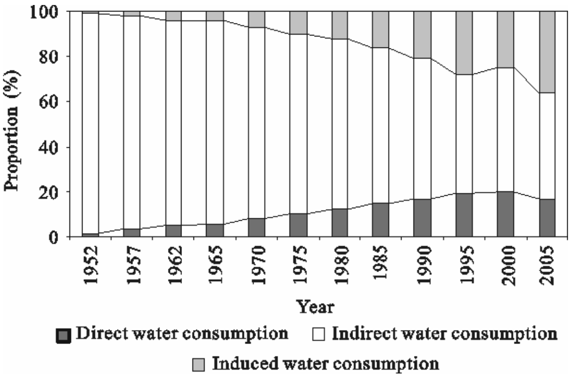


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Fig. 3 Evolvement of urban water consumption structure in China from 1952 to 2005

3.3 Causes of change in water consumption

As mentioned above, the amount of indirect and induced water holds the majority of urban total water consumption. So we can expound the causes of urban water consumption change by analyzing the causes that influences urban indirect and induced water consumption.

3.3.1 Indirect water consumption

Urban indirect water consumption is divided into urban indirect agriculture and grassland water consumption. On account of the majority of indirect agriculture water consumption being consumed by indirect grain land, the paper made correlation analysis between the amounts of urban grain consumption and indirect agriculture water consumption. From Fig. 4 we can see that indirect agriculture water consumption has a strong relationship with urban grain consumption. With the rapid increase of urban grain consumption, the corresponding agriculture water consumption also increased very quickly.

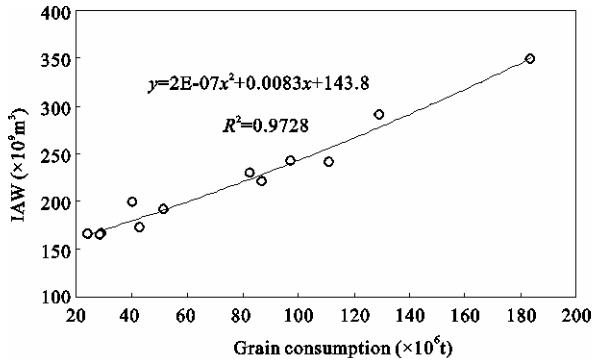

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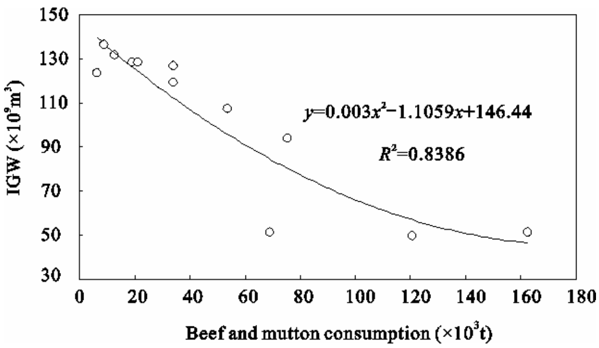
Fig. 4 Correlation between urban grain consumption and indirect agricultural water consumption (IAW)

Indirect grassland water consumption also has a strong relationship with urban beef and mutton consumption (Fig. 5). Different from the changing trend of indirect agriculture water consumption, the indirect grassland water consumption has a trend of fast decrease with the increase of urban beef and mutton consumption. And this shows that the bearing ability of grassland improved remarkably.

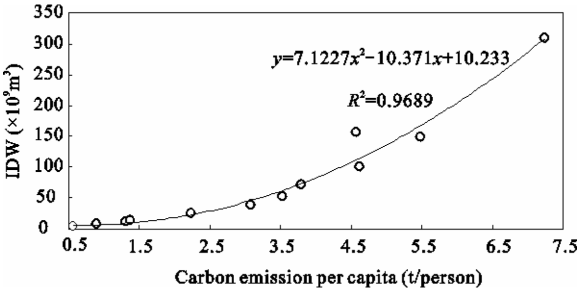


Data sources are the same as Fig. 1

Fig. 5 Correlation between urban beef and mutton consumption and indirect grassland water consumption (IGW)

3.3.2 Induced water consumption

Induced water consumption has a strong relationship with urban carbon emission per capita (Fig. 6). With the rapid increase of urban carbon emission per capita, induced water consumption increased very quickly. The fast increase of urban energy consumption, especially coal consumption resulted in the consequence.



Sources: The Ministry of Water Resources of the People's Republic of China, 1998–2006; National Bureau of Statistics of China, 1982–2007; National Bureau of Statistics of China, 2005; Liu et al., 2000; Liu and Chen, 2001; Zhang et al., 2009

Fig. 6 Correlation between urban carbon emission quantity per capita and induced water consumption (IDW)

4 Conclusions and Discussion

Fresh water resources are the foundation of urban existence and development. With the development of urbanization, the composition of urban water consumption has evolved from "direct and indirect water consumption" to "direct, indirect and induced water consumption". From the viewpoint of urban basic material consumption, the paper presented the numeration expressions of urban indirect and induced water consumption separately. And based on this, the paper developed the total urban water consumption calculation model.

The calculation results show that: 1) With the modern urbanization development, urban fresh water consumption had been increasing rapidly after 1952. The total urban fresh water consumption increased $561.7\times10^9\text{m}^3$, and the proportion to the total national fresh water resources increased 20 percentage points from 1952 to 2005. As far as urban water consumption structure is concerned, the proportions of direct and induced water consumption had been continuously rising, and they increased by 15 and 35 percentage points separately from 1952 to 2005, while the proportion of indirect water consumption decreased by 50 percentage points. 2) Indirect and induced water consumption holds a majority proportion to the total urban water consumption, and they decide the changing trend of the total urban water consumption. Indirect water consumption includes indirect agriculture and grassland water consumption, and they have a very close relationship with urban grain and beef and mutton consumption separately. While induced water consumption has a close relationship with urban carbon emission per capita.

In order to deal with the severe state of rapid increase in urban water consumption and realize the sustainable utilization of urban fresh water resources, we have to take the following measures. Firstly, we have to strictly control water pollution and protect water environment. Secondly, we should increase agriculture investment and improve agriculture productivity and water consumption utilization efficiency (Enrique and Luciano, 2006). At the same time, we should improve grassland productivity by increasing the artificial grassland proportion (Liu and Xiu, 2007). Thirdly, we should import agriculture and by-products properly by international trade (Hoekstra and Hung, 2005; Yang et al., 2002), and protect and improve water environment indirectly (Dabrowski et al., 2008). Last, we should regulate urban industry structure (Yao et al., 2008), and improve urban energy utilization structure and efficiency (Zhang, 2003).

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