Demand & supply analysis of China's water resources and its sustainable utilization in the first half of the 21st century

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Abstract: With the increase of water demand for population growth, rapid industrialization and urbanization, water resources have become one of main inhibitive factors to China's sustainable development. In this paper, the situation of water supply-use during 1980-2004 was reviewed briefly. According to the upward growing trend of water supply-use in the past two decades, the situations of water demand-supply in 2020 and 2050 were predicted and analyzed based on the targets of China's socio-economic development. The results showed that the total water demand would be 699.1 billion m^3 in 2020 and 740.4 billion m^3 in 2050 respectively, while the water supply would just be 601.0 billion m^3 in 2020 and 698.0 billion m^3 in 2050. It indicated that China had to overcome serious water shortage in a short-term future. For the sustainable utilization of water resources in China, some strategies, such as decreasing water use, raising water supply capacity, perfecting water resources management and controlling water pollution, were proposed.

Key-Words: Water resources, Water demand-supply, Sustainable utilization, Sustainable development, China.

1 Introduction

Water is a basic factor to human's survival and development. Our economic, social and cultural lives depend greatly on the availability and the accessibility to the fresh and clean water supplies [1]. Undoubtedly, the sustainable utilization of water resources is essential for sustainable development.

China's social-economic development process and natural conditions determined that the sustainable utilization of water resources is extremely important for its sustainable development. China has an annual amount of 2812.4 billion m^3 of fresh water resources while per capita volume is about 2200 m^3, only equal to 1/4 of the world average [10]. Among the 669 cities of China, 400 cities suffer from insufficient water supply, and 100 cities are faced with severe shortage of water. The agricultural water shortage of China was about 30 billion m^3/yr, which resulted in the reduction of food output, about 25 million ton per year [7]. Water shortage has been an inhibitive factor to the economic growth of China, especially for the northern part of China. Besides the water shortage, water pollution, low water use efficiency, and environmental deterioration are all problems in the sustainable utilization of water resources.

The period of 2000-2050 is crucial for China to reach its development objectives. Therefore, water demand will be increasing in agricultural, industrial and domestic requirements due to the process of industrialization and urbanization and the development of economy and society. The demand-supply situations of water resources in the future will be the focus issue of China. Whether or not the water supply could suffice the water demand of socio-economic development and environmental improvement in the future, it will directly impact the capability of China's sustainable development [8, 16]. In order to achieve sustainable water utilization, it is important to predict the demand-supply situations of China's water resources in 2020 and 2050. Furthermore, based on the awareness of the future situations of water demand-supply, some reasonable strategies to assure the sustainable utilization of China's water resources could be proposed pertinently.

2 Water use and supply in china during 1980-2004

2.1 Water use during 1980-2004

With the socio-economic development, the annual water use in China increased greatly in the past two decades. It was 443.7 billion m^3 in 1980

while 554.8 billion m^3 in 2003 [3]. It increased by 1.14% per year during 1980-1997, but decreased by 0.75% per year during 1997-2004 due to advancing water-saving policies in all industries and especially in agriculture. With the population growth, the annual water use per capita decreased from 450 m^3 to 427 m^3 during 1980-2004 (Table 1).

The water use structure of China changed greatly during 1980-2003. The proportion of urban domestic water use increased steadily from 1.53% in 1980 to 6.28% in 2003, while the proportion of the rural only from 4.79% to 5.58%. The proportion of industrial water use increased from 10.3% to 22.1%. Agricultural water use still was the main part of water use in China during 1980-2003, although the proportion decreased greatly from 83.4% to 64.5%.

With the improvement of the living standards, the domestic water use quota had been increased continuously. The per capita quota of urban domestic water use changed from 97 liters/d in 1980 to 175 liters/d in 2003; and the per capita quota of rural domestic water use increased from 73 liters/d in 1980 to 106 liters/d in 2003. It was predicted that domestic water use quota would keep an increasing trend in the future [5, 16]. Because of the continuous enhancement of water use efficiencies both in industry and in agriculture, their water use quotas decreased obviously. The improvement of water use efficiency plays a key role in controlling the growth of agricultural and industrial water use [7].

2.2 Water supply during 1980-2004

The annual water supply was 443.2 billion m^3 in 1980 and up to 562.3 billion m^3 in 1997 [3, 4], and then it decreased to 532.0 billion m^3 in 2003[11]. The water supply increased at an annual rate of 1.41% during 1980-1997 and decreased by 0.92% per year during 1997-2004 (Table 2).

Table 2 China's water supply in 1980-2004 (billion m^3)

Year	1980	1993	1997	2000	2004
Surface water	381.3	438.3	456.6	444.0	450.4
Groundwater	61.9	90.2	103.1	106.9	102.7
Other water	--	--	2.6	2.1	1.7
Total	443.2	528.5	562.3	553.1	554.8

The ratio of groundwater supply to water supply increased from 14.0% in 1980 to 19.1% in 2003. The proportion of surface water supply decreased from 86.0% in 1980 to 80.6% in 2004. Seawater utilization, as well as other approaches of water supply such as sewage reuse, was in a low proportion before 1997, but it increased rapidly at the annual rate of 17.2% from 8.5 billion m^3 in 1997 to 22.0 billion m^3 in 2004. During 1980-2004, China experienced rapid economic growth, with its gross domestic product (GDP) growing at the annual rate of 9.52%. The income-elasticity of water supply (the ratio of the annual increasing rate of water supply to the annual increasing rate of GDP) was only 0.084 during 1980-2004, which was significantly lower than those of some developed countries such as United States, Japan and Australia. In the initial development of those countries, the income-elasticity of water supply was between 0.2 and 0.3 [7].

3 Demand & supply analysis of china's water resources in 2020 and 2050

3.1 Domestic water demand

According to the statistic data of rural and urban domestic water use during 1980-2003 and the objectives of socio-economic development during 2000-2050, per capita domestic water use in the rural would be about 120 liters/d in 2020 and 150 liters/d in 2050, while in the urban it would be about 245 liters/d in 2020 and 270 liters/d in 2050 [7, 16].

China's population would be 1441 million in 2020, and reach the peak of 1470 million in 2032, then decrease to 1400 million in 2050 [12]. The ratio of urban population in China will be up to 55% in 2020 and 75% in 2050. Based on the quota of domestic water use, population, and quantities of urban population and rural population in 2020 and 2050, the amount of domestic water demand in China in 2020 and 2050 was calculated.

Table 3 China's domestic water demand in 2020 and 2050

Year	2020	2050
Total population (million people)	1440.9	1400.2
Share of urban population (%)	55	75
Urban population (million people)	792.5	1050.2
Urban domestic water use (liters per capita per day)	245	270
Urban domestic water use (billion m^3)	70.9	103.5
Rural population (million people)	648.4	350.1
Rural domestic water use (liters per capita per day)	120	150
Rural domestic water use	28.4	19.2

(billion m^3)		
Total domestic water use (billion m^3)	99.3	122.7

3.2 Industrial water demand

According to the decreasing trend of water use per industrial value-added during 1980-2003 in China and the current quota of water use per industrial value-added in the developed countries, the annual descent rates of water use per industrial value-added in the future are assumed to predict industrial water demand in 2020 and 2050.

Water use per industrial value-added decreased from 107.0 m^3 per thousand Yuan (RMB) in 1980 to 22.3 m^3 per thousand Yuan in 2003. The average annual descent rate of water use per industrial value-added was 6.6% during 1980-2003. However, the efficiency of industrial water use in China is lower than those of some other countries. Water use per industrial value-added in China in 2000 was 29.1 m^3 per thousand Yuan, but that was only 1.89 m^3 in Japan and 3.55 m^3 in Brazil in 1995. It is very important for China to enhance the efficiency of industrial water use in the next 50 years. In this paper, water use per industrial value-added was assumed to decrease at an annual rate of 5% during 2004-2020 and 3.5% during 2020-2050 [17]. It will be 9.3 m^3 per thousand Yuan in 2020 and 3.2 m^3 per thousand Yuan in 2050.

With the rapid industrialization, the industrial value-added increased rapidly during the past two decades. The ratio of industrial value-added to the secondary industrial value-added, which includes the industrial value-added and the value-added of the construction industry, varied less than 0.01 in 1980-1990, and it increased steadily from 0.84 in 1990 to 0.87 in 2003. According to this trend, this ratio is expected to be 0.89 in 2020 and 0.90 in 2050.

In our previous study, it was shown that the value-added of secondary industry would be 15615 billion Yuan in 2020 and 50619 billion Yuan in 2050. Based on the value-added of the secondary industry and water use per industrial value-added in 2020 and 2050, the industrial value-added and the industrial water use were calculated (Table 4).

Table 4 China's industrial water demand in 2020 and 2050

Year	2020	2050
Value-added of the secondary industry (billion Yuan)	15615	50619
Industrial value-added(billion Yuan)	13897	45557
Water demand per industrial value-added (m^3/thousand Yuan)	9.3	3.2
Total industrial water demand (billion m^3)	129.2	145.8

3.3 Agricultural water deman

The agricultural water demand includes the water demands of irrigation, forestry, animal husbandry and fishery.

The irrigated area increased from 44.9 million ha in 1980 to 54.0 million ha in 2003 in China. Because of the grain demand growth caused by population growth, irrigated area will increase greatly in the future. It is reported that the irrigated area would be up to 60.0 million ha in 2020 on the program of irrigation and drainage development in China. Some studies showed that the irrigated area of China would be at least 64.5 million ha in 2050 [9, 16].

There is more potential to improve the integrated water use efficiency of irrigation in China. The study by Liu and Chen showed that if the water-saving irrigation technologies were applied widely in the whole country, it is impossible for the integrated water use efficiency of irrigation in China to be over 0.60 in the future [7]. However, influenced by terrain conditions and the low standards of water resources projects, it is difficult to improve the water use efficiency of irrigation greatly in a short term. Therefore, based on the increasing trend in the past two decades, the integrated water use efficiency of irrigation in China was expected to be about 0.50 in 2020 and 0.60 in 2050.

The irrigation water demand could be calculated by the following equations:

$$IWD_t = IA_t * IWDP_t \quad (1)$$

$$IWDP_t = IWDP_{t1} * IWUE_{t1} / IWUE_t \quad (2)$$

where IWD represents irrigation water demand, IA represents irrigated area, IWDP represents the irrigation water demand per ha, IWUE represents the integrated water use efficiency of irrigation, t represents the year of 2020 or 2050, t1 represents the year of 2000.

The results of the irrigation water demands in 2020 and 2050 were in Table 5.

Forestry, animal husbandry and fishery developed steadily in China in recent years. The ratio of the output value of forestry, animal husbandry and fishery to that of agriculture increased gradually from 0.24 in 1980 to 0.47 in 2003. Correspondingly, the ratio of the water use of forestry, animal husbandry and fishery to that of agriculture increased from 0.03 in 1980 to 0.10 in 2003.

With the implementation of reforesting formerly cultivated land and restoring grazing areas to grasslands, the forestry, animal husbandry and fishery of China will get a great development, and

the water demand of forestry, animal husbandry and fishery will increase greatly in the future. According to this increasing trend, the ratio of the water demand of forestry, animal husbandry and fishery to that of agriculture was expected to be about 0.15 in 2020 to 0.20 in 2050. Therefore, the water demand of forestry, animal husbandry and fishery could be calculated with the following equation:

$$WDF=(WDF+WDI)*R \quad (3)$$

And this equation could be transformed into:

$$WDF=WDI*R/(1-R) \quad (4)$$

where WDF represents the water demand of forestry, animal husbandry and fishery, WDI represents the water demand of irrigation, R represents the ratio of the water demand of forestry, animal husbandry and fishery to the water demand of agriculture. And R will be 0.15 in 2020 and 0.20 in 2050 respectively.

The forestry, animal husbandry and fishery water demand would be 58.6 billion m^3 in 2020 and 74.4 billion m^3 in 2050 (Table5).

Table 5 China agricultural water demand in 2020 and 2050

Year	2020	2050
Irrigated area (million ha)	60.0	64.5
Irrigational water demand (m^3/ha)	5534	4612
Irrigated water demand (billion m^3)	332.0	297.5
Forestry, animal husbandry and fishery water demand (billion m^3)	58.6	74.4
Agricultural water demand (billion m^3)	390.6	371.9

The environmental water demand generally refers to the water resources amount that is needed to ensure environment not to be deteriorated and to improve environmental quality progressively [6, 7, 14]. The environmental water demand of China mainly involves the water resources to wash river sand, to maintain the base flow of major river ecosystems such as Yellow river, Huaihe river, Haihe river, to restore the excessive adopting groundwater in North Plain of China, to protect and improve the fragile ecosystems of inland river basin in the Northwest China, and to maintain and improve the environment of cities. Based on *the National Ecological Environment Protection Program* [13], China will make great efforts to restrain the trend of environmental degradation by 2010, improve the national environment obviously by 2030 and set up the healthy ecosystems that adapt to the sustainable socio-economic development by 2050. The environmental water demand of China will make up to 60-80 billion m^3 in 2010, 80-90 billion m^3 in 2030 and more than 100 billion m^3 in 2050 in order to achieve the objectives of China's national environment protection [2, 16].

3.4 Total water demand

In general, total water demand includes national economic water demand and environmental water demand, and the national economic water demand comprises domestic water demand, agricultural water demand and industrial water demand. The national economic water demand would be 619.1 billion m^3 in 2020 and 640.4 billion m^3 in 2050, and the environmental water demand would be 80 billion m^3 in 2020 and 100 billion m^3 in 2050. Therefore, the total water demand would be 699.1 billion m^3 in 2020 and 740.4 billion m^3 in 2050 (Table 6).

Table 6 China's water demand in 2020 and 2050 (billion m^3)

Year	2020	2050
National economic water demand	619.1	640.4
Domestic	99.3	122.7
Agricultural	390.6	371.9
Industrial	129.2	145.8
Environmental water demand	80.0	100.0
Total	699.1	740.4

3.5 Water supply in 2020 and 2050

Some studies showed that the limit of water resources exploitation ratio could be up to 30%-40% under the condition of no environmental deterioration, namely the exploitable water resources amount of China could be up to 850-1100 billion m^3, but the proportion of water resources exploitation was only 18.9% in 2003 [8, 15, 16]. There is more potential in exploiting water resources in China.

According to the trend of economic development in future, if the income-elasticity of water supply in 2004-2050 were 0.10, slightly greater than that in 1980-2003, the projects of water resources would supply freshwater 601.0 billion m^3 in 2020 and 698.0 billion m^3 in 2050, and the proportion of water resources exploitation would be 21.4% in 2020 and 24.8% in 2050. Therefore, water demand could be contented through strengthening the investment to the projects of water resources to enhance the capability of water supply.

4 Conclusion

Water shortage is the serious factor that impacts the sustainable utilization of water resources in China. There will exist acute contradictions

between water supply and water demand for the social-economic development and the environmental protection in 2020 and 2050. The gap between the water supply capacity and the total water demand will be 98.1 billion m^3 in 2020 and 42.4 billion m^3 in 2050. The water supply capacity of water resources projects might ensure the water demand of national economy in 2020 and 2050, but it would not ensure the total water demand in the next fifty years.

Improving the utilization efficiency of water resources would be a key approach to solve the problem of water shortage. At present, China is striving to make itself a kind of water-saving society, enhance the safety of water supply and alleviate water pollution. At same time, some other approaches have been put into practice, such as constructing inter-basin water transfer projects, increasing financial input for water resources projects to improve the capacity of water supply, reforming water price mechanism as well as improving water management system, for the sustainable utilization of water resources in China.

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