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Water demand forecasting of Beijing using the Time Series Forecasting Method

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Abstract: It is essential to establish the water resources exploitation and utilization planning, which is mainly based on recognizing and forecasting the water consumed structure rationally and scientifically. During the past 30 years (1980–2009), mean annual precipitation and total water resource of Beijing have decreased by 6.89% and 31.37% compared with those perennial values, respectively, while total water consumption during the same period reached pinnacle historically. Accordingly, it is of great significance for the harmony between socio-economic development and environmental development. Based on analyzing total water consumption, agricultural, industrial, domestic and environmental water consumption, and evolution of water consumed structure, further driving forces of evolution of total water consumption and water consumed structure are revealed systematically. Prediction and discussion are achieved for evolution of total water consumption, water consumed structure, and supply-demand situation of water resource in the near future of Beijing using Time Series Forecasting Method. The purpose of the endeavor of this paper is to provide scientific basis for the harmonious development between socio-economy and water resources, for the establishment of rational strategic planning of water resources, and for the social sustainable development of Beijing with scientific bases.

Keywords: Beijing; water consumed structure; industrial structure; water demand forecasting

1 Introduction

The main aim of forecasters is to bridge the gap between theories and practice (Mohamed and Aysha, 2010). Their purpose is to make forecasting useful and relevant to decision and policy makers and to translate the findings into principles that are easy to understand and apply (Armstrong and Fildes, 2006). Forecasting can answer any questions, but the answers are not always right. Nobody can predict the future in an accurate way every time. There are many areas in which forecasting is widely used, such as sales forecasting, forecasting pro-

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duction yields, weather forecasting, forecasting demands and so on.

Recently, water demand forecasting has become an essential component in effective water resources planning and management. It provides valuable trigger in determining the time and the capacity for new water resources development (Mohamed and Aysha, 2010). Therefore, there is an increased need for water demand forecasting, because it can provide a simulated view of future, and contribute in identifying the suitable management alternative in balancing water supply and demand (Mohamed and Aysha, 2010). In Beijing, the need for accurate estimates of water supply and demand has become particularly important. The reasons for this include, and are not limited to, continuous decreasing of precipitation during the past decades, frequent extreme weather, significant reducing of surface water resource, continuing decline of groundwater level, high population growth rates, high development growth, urban expansion and so on. For Beijing, the water supply-demand forecasting would help in water resources planning, which includes assessment of economic, social, political and environmental impacts on water demand and can help in assessing financial planning.

New developments are expected to take place in Beijing in the coming decade confidently, which are predicted to increase the water demand. This paper reveals the driving mechanism of changes of water consumption and water consumed structure, and further forecasts the evolution trends of water consumption and water consumed structure in the near future by analyzing changes of water resource conditions, economic and social developments, water consumption and water consumed structure of socio-economic sectors, and influences with each other, all of which provide foundation for harmonizing the relationship between economic and social developments and water resource utilization, and establishing social and economic development planning in the near future ultimately.

2 Methodology and data

2.1 Study area description

Beijing, the capital of China, is located at the interlaced terrace of North China Plain and Mongolian Plateau, with typical warm temperate and semi-humid and semi-arid climate controlled by Continental Monsoon. The Beijing Plain, which is located at the southeast of Beijing, is surrounded by mountains at north, northwest, and west with North Mountain and West Mountain. Ridges of these mountains form an arc with mean elevation of 1000 m as a shelter for the plain area. Beijing has a clear four-season climate with drying and wind-blown sand in spring, high temperature and rainfall in summer, sunny and cool days in fall, and cold and dry days in winter, and belongs to the area of rain and heat in the same period typically.

Water resources of Beijing are mainly derived from precipitation, so the quantity and space-time distribution of precipitation determine the temporal and spatial variation of water resources radically. It is widely understood that the ecosystem and environment are under the influence of both climate change and human activities (Zhang *et al*., 2003; Zhang *et al*., 2006; Chen and Xu, 2005; Lioubimtseva *et al*., 2005; Liu *et al*., 2010). Climate change has resulted in the rise of atmospheric temperature globally, and a modified precipitation pattern (Hao *et al*., 2008; Qin and Zhou, 2010). One of the most significant potential consequences of changes in climate may be the alteration in regional hydrological cycles and subsequent changes in river quantity and quality regimes (Xu, 2000; Labat *et al.*, 2004). Due to the climate changes and human activities in the past decades, the interval of interannual variations of precipitation is large, and the seasonal distribution of precipitation is significantly uneven. The annual precipitation in Beijing is about 571.9 mm, more than 70% of which occurs in 20 days from late July to early August (Song *et al.*, 2007). Consequently, most of the rainfall does not translate into water resources available in this area. In addition, Beijing is located in the central north of the Haihe River Basin, and most of large rivers in Beijing are passing-by rivers (Ding *et al.*, 2010). Therefore, the total amount of water resource is largely influenced by the upstream.

Changes of annual precipitation and amount of water resource in Beijing from 1980 to 2009 are shown in Figure 1. The annual precipitation and the annual amount of water resource are 532.5 mm and 28×10^8 m^3/year, which decrease by 6.89% and 31.37% compared with the perennial values, respectively.

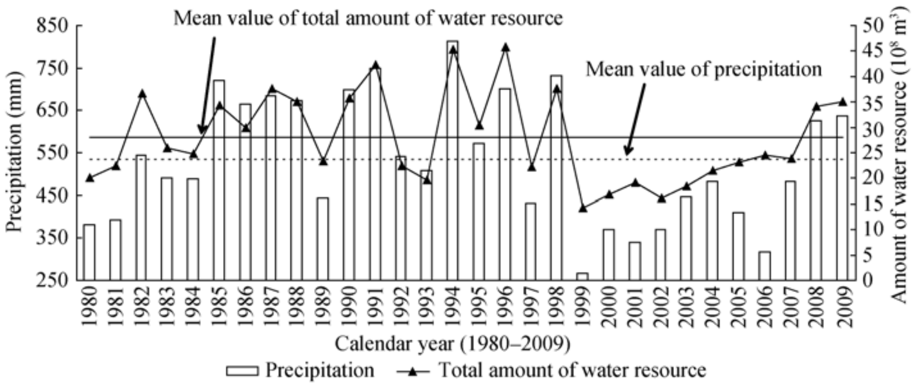


Figure 1 Changes of precipitation and quantity of water resources in Beijing during 1980–2009

The city of Beijing has more than 3000 years of history, and has more than 800 years of history as the capital from the Jin Dynasty. The ample water resource in Beijing provides a material foundation and basic conditions for the development. In thousands of years of history, despite people's unremitting efforts on the development and utilization of water resource along with the development of Beijing during each period, the city was neither short of water nor in water crisis due to excessive water consumption before 1949. However, in the past 60 years, especially since the reform and opening up started 30 years ago, with city expansion, growing population, and rapid economic and social development, Beijing becomes a dry city gradually, and the situation of water supply-demand increases grimly.

In current Beijing, the per capita water resource is less than 300 m^3, which is less than one eighth of that of China and one thirtieth of that of the world. With the rapid socio-economic development of Beijing as an international metropolis, the water shortage has become the vital constraint.

2.2 Data source

The crude data obtained (Table 1) is from Beijing Statistical Yearbook in different years and all of the signs in the table are described as follows in detail.

Table 1 Crude statistical data obtained

Year	P_r	W_a	Q_t	Q_a	Q_i	Q_d	Q_e	GDP_1	GDP_2	GDP_3	P_t	P_s	P_u	A_a	A_i
1980	380.7	20.0	46.3	31.8	13.8	3.7	—	6.1	95.8	37.2	904.3	383.2	521.1	4260	3403
1981	393.2	22.5	—	—	—	—	—	6.6	92.5	40.1	919.2	385.9	533.3	4250	3413
1982	544.4	36.7	—	28.8	—	—	—	10.3	99.8	44.8	935.0	391.0	544.0	4240	3394
1983	489.9	26.0	—	—	—	—	—	12.8	112.7	57.6	950.0	393.0	557.0	4230	3433
1984	488.8	24.7	—	26.8	—	—	—	14.8	130.7	71.1	965.0	395.0	570.0	4220	3426
1985	721.0	34.2	—	—	—	—	—	17.8	153.7	85.6	981.0	395.0	586.0	4210	3384
1986	665.3	29.9	36.6	19.5	9.9	7.2	—	19.1	165.8	100.0	1028.0	407.0	621.0	4190	3379
1987	683.9	37.6	34.7	—	—	—	—	24.3	182.6	119.9	1047.0	410.0	637.0	4180	3379
1988	673.3	35.1	42.4	22.0	14.0	6.4	—	37.1	221.3	151.8	1061.0	411.0	650.0	4160	3381
1989	442.2	23.4	44.6	24.4	13.8	6.5	—	38.5	252.2	165.3	1075.0	411.0	664.0	4140	3384
1990	697.3	35.9	41.1	21.7	12.3	7.0	—	43.9	262.4	194.5	1086.0	288.0	798.0	4130	3351
1991	747.9	42.3	42.3	22.7	11.9	7.4	—	45.5	291.5	261.9	1094.0	286.0	808.0	4110	3287
1992	541.5	22.4	46.4	19.9	15.5	11.0	—	48.7	345.9	314.5	1102.0	283.0	819.0	4090	3311
1993	506.7	19.7	45.2	20.4	15.3	9.6	—	53.1	419.6	413.5	1112.0	281.0	831.0	4060	3147
1994	813.2	45.4	45.9	20.9	14.6	10.4	—	66.8	517.6	560.9	1125.0	279.0	846.0	4020	3234
1995	572.5	30.3	44.9	19.3	13.8	11.8	—	72.2	645.8	789.7	1251.1	304.9	946.2	3940	2924
1996	700.9	45.9	40.0	19.0	11.8	9.3	—	73.4	714.7	1001.1	1259.4	301.5	957.9	3440	3019
1997	430.9	22.3	40.3	18.1	11.1	11.1	—	74.0	781.9	1219.7	1240.0	291.7	948.3	3420	3233
1998	731.7	37.7	40.4	17.4	10.8	12.2	—	74.9	840.6	1460.5	1245.6	287.9	957.7	3410	3237
1999	266.9	14.2	41.7	18.5	10.6	12.7	—	77.1	907.3	1693.2	1257.2	285.5	971.7	3380	3221
2000	371.1	16.9	40.0	16.5	10.5	13.4	—	78.6	1033.3	2049.1	1363.6	306.2	1057.4	3290	3027
2001	338.9	19.2	38.9	17.4	9.2	12.4	0.3	80.8	1142.4	2487.3	1385.1	303.9	1081.2	2920	2527
2002	370.4	16.1	34.6	15.5	7.5	11.6	0.8	84.0	1250.0	2996.4	1423.2	305.2	1118.0	2750	2197
2003	444.9	18.4	35.8	13.8	8.4	13.0	0.6	89.8	1487.2	3446.8	1456.4	305.1	1151.3	2600	1789
2004	483.5	21.4	34.6	13.5	7.7	12.8	0.6	95.5	1853.6	4111.2	1492.7	305.5	1187.2	2360	1867
2005	410.7	23.2	34.5	13.2	6.8	13.4	1.1	98.0	2026.5	4761.8	1538.0	251.9	1286.1	2330	1815
2006	318.0	24.5	34.3	12.8	6.2	13.7	1.6	88.8	2191.4	5580.8	1581.0	247.7	1333.3	2330	1815
2007	483.9	23.8	34.8	12.4	5.8	13.9	2.7	101.3	2509.4	6742.6	1633.0	253.1	1379.9	2320	1736
2008	626.3	34.2	35.1	12.0	5.2	14.7	3.2	112.8	2693.2	7682.0	1695.0	255.9	1439.1	2320	1718
2009	636.0	35.0	35.8	12.0	5.2	15.3	3.3	118.3	2743.1	9004.5	1755.0	263.2	1491.8	2310	1730

P_r: precipitation (mm/a); W_a: amount of water resources (10^8 m^3/a); Q_t: total water consumption (10^8 m^3/a); Q_a: agricultural water consumption (10^8 m^3/a); Q_i: industrial water consumption (10^8 m^3/a); Q_d: domestic water consumption (10^8 m^3/a); Q_e: environmental water consumption (10^8 m^3/a); GDP_1: gross domestic product of primary industry (10^8 yuan); GDP_2: gross domestic product of secondary industry (10^8 yuan); GDP_3: gross domestic product of tertiary industry (10^8 yuan); P_t: total population (10^4); P_s: suburb population (10^4); P_u: urban population (10^4); A_a: area of arable land (km^2); A_i: area of irrigated area (km^2).

2.3 Method

Water demand forecasting methods can be categorized into six classes (Mohamed and Aysha, 2010). These methods include (1) Judgmental Forecasting (JF): which is a statistical forecasting method that can be used when no data is available. It includes manager's opinion, jury of executive opinion, consumers' market survey, and Delphi method. (2) Regression Forecasting (RF): this approach is based on regression analysis. The concept is simply based on statistically estimated historical relationships between different independent variables and, water consumption is the dependent variable assuming that those relationships keep continuing in the future. As a result, the forecaster is able to obtain forecasts of the factors related to water consumption such as income, population, location and others. This method is valid for both short and long term forecasts. (3) Time Series Forecasting (TSF): this is a direct forecast method and it forecasts water consumption directly without having to forecast other factors on which water consumptions depend. This method is based on an assumption that historical trends in water consumption continue along the same path, with no structural changes taking place. This method is based on a statistical breakdown of the various trends that contribute to water consumption over time. (4) Cascade Forecasting (CF): this approach is a combination of both time series analysis and regression analysis. It is named cascade because during the model development, four sequential steps are involved in transforming the water demand time series which are de-trending, de-seasoning, autoregressive filter and climatic regression (Jain *et al*., 2001). (5) Artificial Neural Networks (ANNs) forecasting: this method is a set of mathematical models that work similar to biological processes of the brain. ANNs models consist of user defined inputs (e.g. rainfall, temperature, etc.) and desired outputs (e.g. prediction of peak demand). These inputs and outputs are connected by a set of highly interconnected nodes arranged in a series of layers (Bougadis *et al*., 2005). (6) Support Vector Machine Forecasting (SVMF): this approach is a classifier derived from statistical learning theory.

Time Series Forecasting Method is used in this paper for analysis. As a common and effective method for water demand forecasting, this method has at least two advantages: (1) it is the most simple method among the above six methods, and this method is based on an assumption that historical trends in water consumption continue along the same path, with no structural changes taking place; (2) it is a direct method which forecasts water consumption directly without considering factors on which water consumptions depend, and these factors are very complex and uncertain.

3 Results and discussion

3.1 Evolution of water consumed structure during the past 30 years

Classified by socio-economic sectors, social water composition of Beijing was ever divided into agricultural water consumption (Q_a), industrial water consumption (Q_i) and domestic water consumption (Q_d). Since environmental water consumption increases year by year, the environmental water consumption (Q_e) as a part of social water consumption has been taken into account since 2000. In this paper, Q_t represents total water consumption.

3.1.1 Q_t increasing firstly and decreasing subsequently

Overall, from 1980 to 2009, the annual total water consumption of Beijing has experienced an increasing process firstly and a decreasing process subsequently, then reaches a relatively stable process latterly (Figure 2). It is more than 40×10^8 m^3/year during the first 20 years accounting for two thirds of the whole period; it generally shows a rising trend from the late 1980s to the mid-1990s and reaches the peak value (45.9×10^8 m^3) in 1994, which is followed by a relatively fluctuant process. Since 2001, the annual total water consumption has maintained at about 35×10^8 m^3. The total annual water consumption has reduced from 46.3×10^8 m^3 in 1980 to 35.8×10^8 m^3 in 2009 with average annual reduction of 0.36×10^8 m^3, and it decreases by 7.8×10^8 m^3 in the 2000s compared with that of the 1990s.

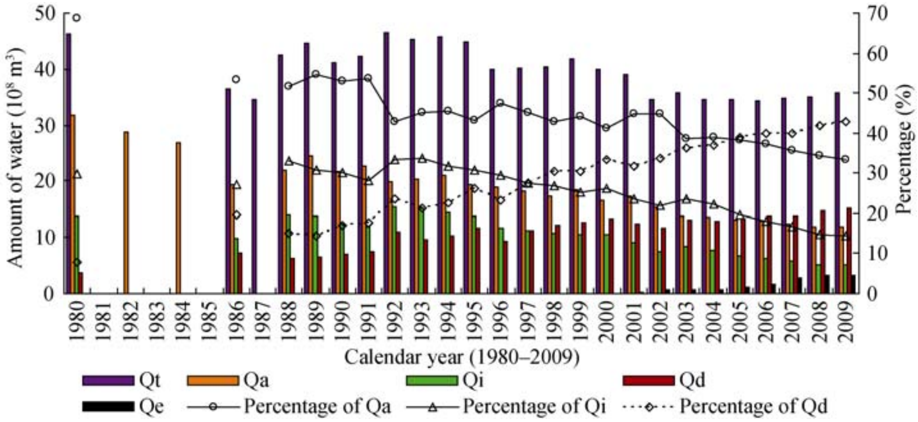


Figure 2 Changes of water consumed and ratios of different water consumed departments in Beijing during 1980–2009

The period from 1980 to 2009 can be divided into three parts according to percentage changes of water consumption of different socio-economic sectors (Table 2): (1) from 1980 to 1997, the agricultural sector is the largest water consumer with the industrial sector in the middle and the domestic sector as the last, the instance of which lasted until the latter two are generally equal in 1997; (2) the domestic water consumption exceeds the industrial water consumption in 1998 for the first time, followed by a process lasting seven years during which the domestic water consumption is more than industrial water consumption and less than agricultural water consumption, although increasing continuously; (3) the domestic water consumption surpasses the agricultural water consumption historically in 2005 and becomes the largest water consumer.

Table 2 Rank changes of different socio-economic sectors for percentages of water quantity consumed during 1980–2009

Period	Socio-economic sector		
	Agriculture	Industry	Resident
1980–1997	1	2	3
1998–2004	1	3	2
2005–2009	2	3	1
Change trend	↓	↓	↑

Notes: 1, 2, and 3 denotes rank; ↓ and ↑ denote decreasing trend and increasing trend, respectively.

The instance of water consumption of all socio-economic sectors during 1980–2009 can be sorted to the following four aspects.

3.1.2 Q_a decreasing gradually with proportion decreasing

Irrigated agriculture represents the bulk of the demand for water in most developing countries. It is also usually the first sector affected by water shortage and increased water scarcity. During the long historical period, the agricultural sector is always the first major water user, and the proportion of annual agricultural water consumption accounts for more than half of the annual total water consumption in the 1980s with its peak value of 68.75% in 1980. However, from 1980, the decreasing trend of the agricultural water consumption is obvious, and both it and the proportion of it always show a decreasing trend remarkably (Figure 2). In the 1990s, the average annual agricultural consumption and the annual proportion of it are 19.8×10^8 m^3/year and 46.28%, respectively. The latter drops by about 10% compared with that of the 1980s. Both of them reduce further to 13.9×10^8 m^3/year and 38.73% over the past ten years from 2000 to 2009, respectively. They are 5.9×10^8 m^3 and 7.55% less than those of the 1990s, respectively. Compared with 1980, the agricultural water consumption and the proportion of it of 2009 reduce by about half. From 2000 to 2009, the agricultural water consumption and the proportion of it reduce by about 0.45×10^8 m^3 and 0.77% yearly, respectively. Therefore, we have good reason to believe that this phenomenon will persist for a certain period in the near future.

3.1.3 Q_i decreasing gradually with proportion decreasing

The industrial sector has ever been the second largest water user after agricultural sector in the history of Beijing. The industrial water consumption accounts for about 30% of the total water consumption from the 1980s to the mid-1990s, and it undergoes a little change (27.11%–33.79%) in this period. Similar to the change process of agricultural water consumption, the industrial water consumption and its proportion has presented a negative growth trend remarkably during 1980–2009 (Figure 2). The proportion of industrial water consumption has gone through "III→II→I" (indicating 30%, 20%, and 10%, respectively) change process from 1980 to 2009. In the first 16 years (from 1980 to 1995), the proportion of industrial water consumption is generally higher than 30% with few exceptions and a mean value of 30.86%. In the middle period from 1996 to 2004, it is generally higher than 20% with a mean value of 25.17%, which is 5% less than that of the first period. During the five years from 2005 to 2009, it is generally higher than 10% with a mean value of 16.76%, which is 8.41% less than that of the last period.

The number of industrial water consumption has undergone change from double digit to single digit (in units of $10^8 m^3$). In the first 11 years from 1980 to 2000, the annual industrial water consumption is always more than 10×10^8 m^3 with peak value of 15.5×10^8 m^3 in 1992 and mean value of 12.6×10^8 m^3. It decreases below 10×10^8 m^3 in 2001 for the first time and presents a declining trend in the successive eight years. The mean value of industrial water consumption of 2001 to 2009 is 6.9×10^8 m^3/year with decrement of 0.44×10^8 m^3 yearly.

3.1.4 Q_d increasing gradually with proportion increasing

In contrast with the instances of agriculture and industry, the domestic water consumption and its proportion of Beijing are growing rapidly from 1980 to 2009 (Figure 2). They increase from 3.7×10^8 m^3 in 1980 to 15.3×10^8 m^3 in 2009 and from 7.9% to 42.74%, respectively. The domestic water consumption becomes the largest water user. With a reverse change process of the industrial water consumption, the domestic water consumption experiences from single digit to double digits (in unit of 10^8 m^3). During the 12 years from 1980 to 1991, the annual domestic water consumption is always less than 10×10^8 m^3 with mean value of 6.4×10^8 m^3/year and the biggest value of 7.4×10^8 m^3 in 1991 which is two times of that in 1980. The value of it breaks through 10×10^8 m^3 historically in 1992 reaching 11×10^8 m^3, and presents a rising trend generally during the successive 17 years excluding 1993 (9.6×10^8 m^3) and 1996 (9.3×10^8 m^3). Its value in 2009 is two times that in 1991 and four times that in 1980.

3.1.5 Q_e increasing gradually with proportion increasing

Since the environmental water consumption is not listed in water resources statistics of Beijing until 2001, only data of 2001–2009 are analyzed here. From the data listed, the environmental water consumption of 2001 is only 0.3×10^8 m^3, which is only 0.77% of the total water consumption that year. It reaches 3.3×10^8 m^3 in 2009, but it is only 9.21% of the latter that year, and much smaller than those of other socio-economic sectors. However, both of the environmental water consumption and its proportion increase year by year from 2001 (Figure 2), and the increase of the environmental water consumption is the biggest among all of the socio-economic sectors during the past 10 years. In detail, the environmental water consumption increases by 10 times from 2001 to 2009, meanwhile the proportion of it increases by 11 times.

3.2 Evolution analysis of driving forces of water consumed structure

The preceding analysis shows that, from 1980 to 2009, the annual total water consumption and its structure change constantly, with the general decreasing trend of agricultural and industrial water consumption, and increasing trend of domestic and environmental water consumption. Influenced by these processes, the annual total water consumption of Beijing in recent years becomes generally stable (Figure 2).

3.2.1 Analysis of driving forces of changes of Q_t

The total water consumption is generally influenced by all of the socio-economic sectors directly, which can be depicted using formula as $Q_t=Q_a+Q_i+Q_d+Q_e$.

Generally speaking, the decreasing parts of Q_t (including Q_a and Q_i in detail) are mainly due to the adjustment of industrial structure and upgrading, while the increasing parts of Q_t (including Q_d and Q_e in detail) are mainly due to the continuing rapid population growth, followed by the growing importance of environmental issues. Details are further discussed in the following parts.

3.2.2 Analysis of driving forces of changes of Q_a

The agricultural water consumption can be classified into two parts, the irrigation water consumption and the forest, stock raising, and fishery water consumption, with the former accounting for more than 90% of the total agricultural water consumption. Therefore, the amount of agricultural water consumption depends mainly on irrigation water use, which is further determined by the irrigative area, the crop planting structure, the irrigation technology and so on.

(1) The continuing decrease of agricultural water consumption is attributed radically to the decreasing of the area of arable land and the area of effective irrigated arable land (Figure 3), both of which are due to the urbanization process. The area of the city zone of Beijing is more than 660 km^2 within the Fifth Ring Road and 2200 km^2 (accounting for 35.5% of the plain area) within the Sixth Ring Road, while it is only 63 km^2 which is mainly distributed in the Second Ring Road at the beginning of the founding of new China. At the same time, the urbanization processes of the peripheral urban and suburban districts and counties always develop very rapidly, in which arable land is mainly distributed. The cultivated area in Beijing reduces from 4260 km^2 in 1980 to 2310 km^2 in 2009, the irrigated area reduces from 3403 km^2 to 1730 km^2, and the agricultural water consumption reduces from 31.8×10^8 m^3/year to 12×10^8 m^3/year correspondingly. The decreasing of the agricultural water consumption is also due to other two main factors in the following.

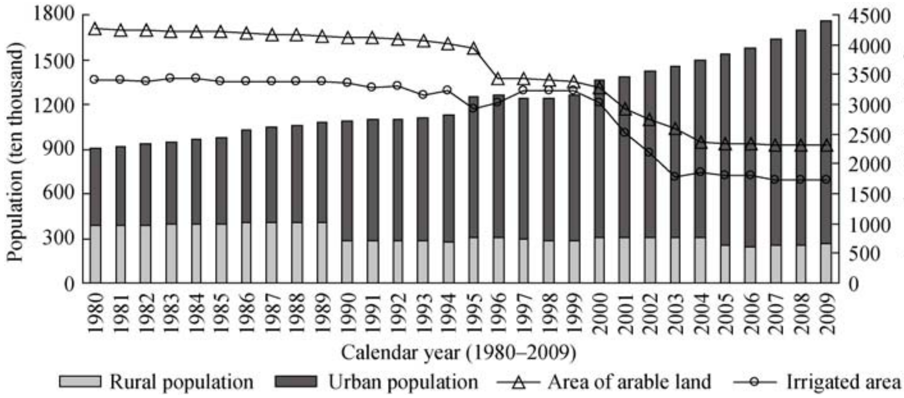


Figure 3 Changes of population and areas of cultivated lands in Beijing (1980–2009)

(2) The promotion of agricultural water saving technologies is the second important reason explaining the decreasing of Q_a. In recent years, water saving irrigation technologies have been developed and promoted in Beijing, resulting the eliminating of unreasonable irrigation methods, such as channeling flood irrigation and paddy irrigation. Especially since the late 1980s, the percentage of the irrigation area using sprinkler irrigation technology accounting for the total irrigated area has increased year by year, which induces that the agricultural water consumption decreases from 74.65×10^4 m^3/km^2 in 1980 to 51.95×10^4 m^3/km^2 in 2009.

(3) The adjustment of rural industrial structure is another factor influencing the changing trend of Q_a. The adjustment of rural industrial structure includes the restructuring of the rural economy and the adjustment of agricultural production structure. The former refers to the relationship among the primary industry, secondary industry, and the tertiary industry of the national economy. The latter refers to the output ratios of different socio-economic sectors (planting, forestry, livestock, fisheries, and so on) of the primary industry. The adjustment of industrial structure in rural areas inevitably leads to changes of agricultural water consumption and changes of water consumed structure in agricultural industry sector, because water consumption between various economic sectors of agriculture varies widely. From 1980 to 2009, the industrial structure in rural areas shows the following characteristics: 1) the output percentage of agriculture shows gradually rising trend, while the output percentage of non-agricultural increases continuously (Liu *et al*., 2003); 2) in the composition of agricultural output, the output proportion of forestry and animal husbandry (low water consumption) increases year by year (forestry from 1.73% to 6.75%, livestock from 20.87% to 46.23%), while the output proportion of planting agriculture (high water consumption) decreases continuously (from 77.39% to 42.15%); 3) planting (high water consumption) acreage decreases gradually, and the corn and wheat acreage reduces from 3610 km^2 to 2100 km^2.

In addition, the rural population shows a decreasing trend during this period, which also contributes to the decreasing of Q_a clearly.

Affected by impacts of these factors above, the annual agricultural water consumption presents a continuous declining trend year by year.

3.2.3 Analysis of driving forces of changes of Q_i

The industrial water consumption refers to the general water which includes the water consumption during processes of manufacturing, processing, cooling, air conditioning, washing, water boilers, etc. in (or during) the industrial production process and the water which is used by the factory workers. The industrial water consumption is mainly determined by the industrial output, the water use efficiency (water consumption per unit of output), the recycling rate and so on. The relationship between them can be expressed as $Q_i = q \times G \times (1 - \lambda)$ (q, G and λ denote water consumption per unit of output, industrial production and water recycling rate, respectively, the units of which are $m^3/10^4$ yuan, 10^8 yuan/year and %, respectively). From 1980 to 2009, the industrial output maintains a rapid increasing trend with the average annual growth rate of 9.3%, and increases nearly 30 times (according to comparable price). At the same time, the water consumption of 10 thousand GDP decreases rapidly because of the rapid improvement of production technology and the scientific adjustment of industrial structure, resulting in the water consumption of 10 thousand GDP in 2009 being only 2.28% of that in 1980. Furthermore, the increasing of industrial water recycling rate year by year also ensures the continuing decline of industrial water consumption.

3.2.4 Analysis of driving forces changes of Q_d

The domestic water consumption includes urban residents water consumption and rural living water consumption. The former includes family, business, institutions, universities, tourism, social service water consumption and so on, and the latter includes farmer family, domestic livestock water consumption and so on concretely. In current Beijing, household water use predominantly consists of bathing and toilet flushing water use, though faucet and clothes washing water use was ever the predominant use (Chu *et al.*, 2009). The continuous increasing of population (Figure 3) during the past decades is the root cause for the increasing of domestic water consumption (Figure 2). The improvement of living standards which often is due to the increasing of per capita water consumption consequentially is the secondary cause.

Due to the continuous urbanization (i.e. reduce the proportion of rural population) and the increasing influx of adventitious population (Figure 3), the residents increases from 9.043 million in 1980 to 17.55 million in 2009 with average annual increase of 293 thousand and average annual growth rate of 3.24%. Meanwhile, as the improvement of living standards, the per capita water consumption increases from 45.6 to 87.2 m^3/year. In addition, the water consumption of the service sector also increases rapidly because of the rapid development of service industry.

3.2.5 Analysis of driving forces changes of Q_e

The environmental water consumption refers to the essential water quantity whose existence is to maintain a certain capacity of water environment on the purpose of maintaining the ecological balance, protecting and improving the landscape. However, the long-term water supply-demand system of China only includes traditional agricultural, industrial and domestic sectors excluding the water consumption of ecological environment. In recent years, the environmental water consumption is taken into account in water statistics of Beijing, and it increases 10 times from 2000 to 2009, which fully reflects that the emphasis on ecological environment from residents increases rapidly. Taking the urban green area as an example, it increases from 40.74 km^2 in 1980 to 500 km^2 in 2009, and the per capita of it increases from 4.5 to 28.5 m^2 in the same period.

Moreover, considering the gradual implementation of “Overall Urban Planning of Beijing

(2004–2020)", in which the constructing of livable city, tourism city, ecological city, and the environment construction and protection are highlighted in detail, we have good reason to believe that the environmental water consumption will continue to maintain the increasing trend in the next period of time.

3.3 Forecasting

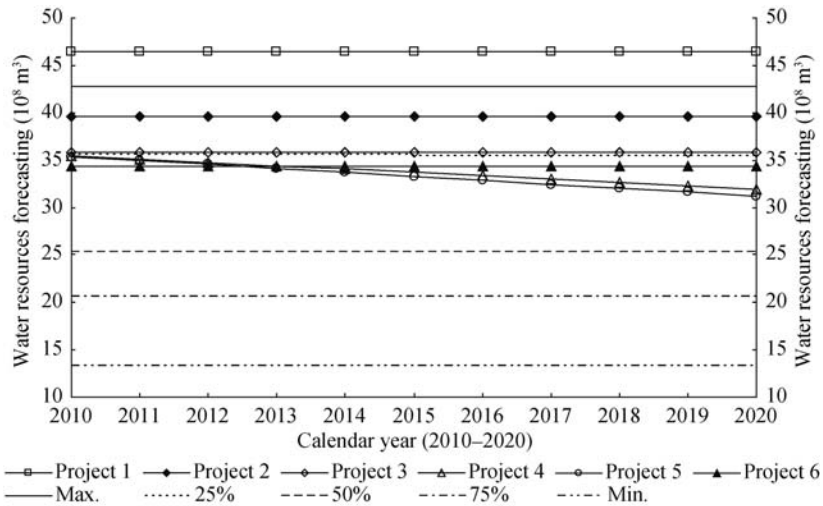
The time series forecasting method is a direct forecast method forecasting water consumption directly without having to forecast other factors on which water consumptions depend and a lot of work has been reported in literature on short-term water demand forecast modeling using time series analysis. According to the future development planning, the urban functional orientation (political and cultural center of China) and the natural conditions of Beijing, the future scale of development and production value of agriculture will maintain its decline trend. With the technological development of agricultural water resource utilization, the agricultural water consumption will continue to maintain its decline trend in the near future based on the level of 2009 (12×10^8 m^3). Benefited from the adjustment of industrial structure, which refers to the transformation from the high water and energy consumed structure to the environment-friendly energy and resources saving consumed structure, rather than the scale expansion which has been proved to be true in the past years, the industrial water consumption will also continue to fall from the third place to the fourth place before long on the basis of 2009 (5.2×10^8 m^3).

In the foreseeable future, the population of Beijing will continue to grow, and the size of the floating population will continue to expand, coupled with the increasing of the per capita consumption, all of which will lead to the continuous increasing of the domestic water consumption. With environmental issues growing in popularity and the construction of livable city and ecological city, the environmental water consumption will maintain an increasing trend and occupy the third place by exceeding the industrial water consumption. On the whole, the proportion of agricultural and industrial water consumption will continue to decrease, while the proportion of domestic water consumption will continue to rise.

The shortage of water resources of Beijing in recent years is mainly caused by the insufficient supply of water resources available and the continuous expansion of water resources demand (Huang *et al*., 2009). Generally, the water resources in Beijing have been in the overexploitation state during the past decades. The current composition of water resources available in Beijing includes surface water, groundwater, and reclaimed water (accounting for 17.66%, 65.24% and 17.09%, respectively, 2009). The former has no longer potential to be tapped, and the water resources deficit during the past decades has always been made up by the long-term overexploitation of groundwater. Only the reclaimed water resource continues to increase, and rises to a level equal to surface water supply in 2009. From this point of view, both of the surface water and groundwater resources have no longer potential to exploit unless the annual precipitation will increase evidently in the near future. For reclaimed water resource, because its quality cannot meet the requirement of some water demand sectors, especially the domestic water users, it cannot play a major role in water supply system. Therefore, the water supply gap will still be made up by groundwater overexploitation before the water inflowing of South-to-North Water Transfer Project in 2014 as planned, and after that time, the water inflowing (10×10^8 m^3/year as planned, Cui *et al*.,

2009) will not only greatly ease the contradiction between water supply and demand, but also can change the long-term overexploitation circumstance of groundwater gradually.

However, because the precipitation of Beijing has a large interannual variation impacted by climate change radically, which further affects the forming of water resources definitively, the water resources available of the coming years are full of great uncertainty. The annual water resources of the coming 10 years is calculated here under some assumptions designed based on the data of 1980–2009 (Figure 4). From this figure, we can see that the results calculated under different assumptions are different from each other very much with 42.8×10^8 m^3/year and 13.3×10^8 m^3/year as the biggest and smallest amounts of water resources available, respectively. The former is more than 2.2 times of the latter. That is to say, Beijing always faces a huge risk of water supply security. In the current case (with the annual water consumption of about 35×10^8 m^3/year), the deficit of water supply is about 10×10^8 m^3 in average year, which may be much more in dry year (Figure 4). Rigorously speaking, only in rainy year, the water resources formed can meet the water demand all the year round narrowly. However, if the water demand increases greatly and reaches the peak value of 1980–2009 (as shown in Figure 4, Project 1), the water resources may not meet the requirements in any case. Thus, water transfer from other places is likely to be the most effective and efficient way. From this point of view, the South-to-North Water Transfer Project is also the fundamental measure to resolve the water demand problem.



Scenarios of supply forecasting:
Max., **25%**, **50%**, **75%** and **Min.** represent the maximum water resources, the water resources in rainy year, the average year, the dry year, and the minimum water resources of the past 30 years (1980–2009), respectively.
Scenarios of demand forecasting:
Project 1: maximum water consumption of the past 30 years (1980–2009); **Project 2**: mean water consumption of the past 30 years (1980–2009); **Project 3**: mean water consumption of the past ten years (2000–2009); **Project 4**: changing trend of the past 30 years (1980–2009); **Project 5**: changing trend of the past ten years (2000–2009); **Project 6**: minimum water consumption of the past 30 years (1980–2009).

Figure 4 Forecasting of water resources supply and demand for the coming ten years under different assumptions

4 Conclusions

The main objective of this research is to estimate future needs of water in Beijing for the coming years using Time Series Forecasting Method. The water consumption data from 1980 to 2009 obtained from Yearbooks of Statistic of Beijing are used as the evidence.

(1) From the beginning of reform and opening up 30 years ago, the annual total water consumption and the water consumed structure of Beijing changes continually, and the changing pattern has the following characteristics: 1) the annual total water consumption during the former 15 years has been increasing, which can be defined as the high-level-water-consumption in Beijing historically, while during the latter 15 years is becoming stable with slightly decreasing; 2) the agricultural water consumption and industrial water consumption always decreases gradually, the former of which has relegated to the second place since 2005, the latter of which has relegated to the third place from the second place since the early 1998, and both of which have further degressive trends; 3) the domestic water consumption increases year by year, and has jumped to the first place as a water user after exceeding the industrial water consumption in 1998 and agricultural water consumption in 2005, respectively; 4) although both the amount of water consumption and its percentage are small, the environmental consumption has increased 10 times and will be increasing in the near future.

(2) The evolution of changes of annual total water consumption and water consumed structure of Beijing from 1980 to 2009 can be generally attributed to the following facts: 1) both of the total area of arable land and the area of effective irrigated arable land decreases rapidly; 2) water-saving irrigation technologies, such as drip and sprinkler irrigation are used widely; 3) the industrial structure in rural areas is adjusted constantly, all of which above have greatly contributed to the decreasing of agricultural and rural water consumption; 4) the industrial structure and layout is adjusted with decreasing of high energy and water resource consumption enterprises; 5) quota system of water consumption is carried out successfully and the rate of water recycling is increased, both of which finally lead to the decreasing of industrial water consumption year by year with the increasing of industrial output; 6) the population is always being grown and living standards are being developed (leading to the increasing of per capita water consumption), which result in the sustaining increasing of domestic water consumption; 7) the environmental water consumption increases sharply from 2001 to 2009.

(3) Changes of the total water consumption and its structure in the near future will present the following trends: 1) the annual total water consumption will maintain its declining trend steadily based on the nowadays level (about 35×10^8 m^3/year) and will not change obviously in short term; 2) both of the agricultural and industrial water consumption will go on decreasing slowly and steadily; 3) the domestic water consumption and its percentage will increase steadily, and its first rank status as water consumer will be strengthened as time goes on; 4) the environmental water consumption and its percentage will also increase steadily and exceed the industrial water consumption before long.

(4) The water resources of Beijing are in short supply in recent years mainly because of the decreasing of annual total water resource induced by climate change. The remedy for this gap is being depended mainly on the groundwater overexploitation, which has caused the groundwater level continuing to decline and further forming regional cone of groundwater table depression. However, with the smooth landing and even further decline of the total water consumption (about 35×10^8 m^3/year), and the increasing utilization of reclaimed water and rain & flood resources as time goes on, if the total water resource (about 28×10^8 m^3/year)

changes slightly in the near future, the supply gap will become narrow gradually. In addition, the inflow of water from South-to-North Water Transfer Project to Beijing in 2014 (10×10^8 m^3/year as planed) will not only further fill this gap and relieve water supply pressure, but also can renew surface water bodies and supplement groundwater, finally promoting the ecological and geological environment.

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