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ORIGINAL ARTICLE

Water resources management strategy for adaptation to droughts in China

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Abstract Water Scarcity and drought are recurrent phenomena in China. In the context of environmental change, an increasing tendency in drought frequency and severity is observed in China in recent years. Therefore, it is imperative to take necessary initiatives to reduce the impacts of drought. In this paper, an attempt is made to identify the best water management strategies to cope with droughts. For this objective the records of historical droughts and their impacts in China over the period of 1950–2009 are analyzed. It is observed that the drought affected area has increased nearly by 12 folds and the drought damaged area has increased by about 22 times in China in last 60 years. Over 87,000 reservoirs were built with a total water storage capacity of about 7,064 billion m^3 to cope with droughts. However, this structural supply-based management strategy was not enough to meet the increasing water demand caused by rapid economic development and population growth. A typical relationship between socio-economic development and water resources management strategy to attain sustainability in water management is developed in this study. The relationship shows that the demand-side water management strategies can be the best option to meet the challenges posed by increased severity of drought, population growth, economic development and

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possible climate change. The concept is later verified through the analysis of changing pattern of water consumptions by different sectors in last 60 years.

Keywords Drought · Drought management · Water demand management · China · Environmental change

1 Introduction

Population growth, rise in water per capita use, urbanization and economic development are considered the main water crises factors that lead to increasing the gap between water supply and demand in all over the world (Wang et al. 2011a; Elmahdi et al. 2006a, b, 2007). Increased frequency of hydrological disasters (i.e. droughts, storm, and other precipitation and temperature related extreme events) due to global environmental and climate changes have exacerbated the water shortage problem in recent years. Drought is a creeping phenomenon which affects a wide range of social, economic, and environmental sectors compared to any other natural disaster (Wilhite 2000; Elmahdi 2008; Shahid 2008; Elmahdi et al. 2009). Droughts become a severe disaster when water supplies are overburdened and families, communities, and governments lack the capacity to effectively plan to respond to droughts. In the past years, a series of severe droughts have been recorded in different parts of the world, particularly, Africa (Dai et al. 2004; Touchan et al. 2008; Shanahan et al. 2009; Touchan et al. 2011; Elagib and Elhag 2011). Asia, Australia, Europe and America also experienced a number of severe droughts in recent years that caused serious damage to livelihood and economy (Nicholls 2004; Andeadis and Lettenmaier 2006; Lloyd-Hughes and Saunders 2002; Shahid 2008; Sheffield and Wood 2008; Shahid and Hazarika 2010; Bordi et al. 2009).

There is an increasing trend in drought frequency and severity in all over the world. Touchan et al. (2008) analyzed the drought variability in northwestern Africa over the last nine centuries and remarked that the most recent drought (1999–2002) appears to be the worst. Elagib and Elhag (2011) reported an increasing trend in Palmer Drought Index in Sudan. Dai et al. (2004) found that large multi-year oscillations in Sahel appeared to be more frequent and extreme after the late 1980s than previously. According to Touchan et al. (2011), the latest generation of state-of-the-art climate models project future widespread drying in the subtropical Africa. Shanahan et al. (2009) reported that the monsoon is capable of longer and more severe future droughts in West Africa. In Asia, Dulamsuren et al. (2010) reported increasing aridity during the 21st century in Mongolia. Pai et al. (2011) reported increasing trends in drought severity index in the western part of India. Shahid (2010) envisaged that droughts in Bangladesh might be more severe in near future. Nicholls (2004) suggested that drought conditions in Australia were worse than in previous recent periods with similarly low rainfall. In the global scale, Dai (2011a) studied the trends in various forms of the Palmer Drought Severity Index (PDSI) during 1900–2008 and reported that global percentage of dry areas has increased by about 1.74% (of global land area) per decade from 1950 to 2008. Widespread drying is observed over Africa, East Asia and South Asia and most of this drying is due to recent warming. In a recent research, Dai (2011b) reviewed literatures on droughts of the last millennium and predicted increased aridity in the 21st century over most of Africa, southern Europe and the Middle East, most of the Americas, Australia, and Southeast Asia.

Drought trend in China is similar to global trend. Drought has become a common phenomenon in China in recent years, especially in southern China like Yunan, Guizhou, Jiangsu and other provinces. In 2010, drought in Southwest China caused serious water shortage and resulted in about 18.9 million people and 11.7 million animals out of sufficient water supply for drinking (FAO 2011). In 2011, China experienced such as a server drought that the Poyang Lake in Jiangxi province and the Dongting Lake of Hunan province was completely dried up. Droughts in consecutive 2 years indicate an increase of its frequency and severity. Wang et al. (2011d) analyzed the drought trends and concluded that China has become slightly drier in terms of soil moisture. He also suggested that soil moisture droughts have become more severe, prolonged, and frequent during the past 57 year, especially for northeastern and central China. Gong et al. (2010) analyzed the occurrence regularity of agricultural drought affected area in China during 1978–2006 and found that China will be in the state of agricultural drought in a long term, and the degree of disaster caused by drought will be exacerbated. Zhai et al. (2010) studied the dryness variations in ten large river basins of China and commented that in the next half century, the Haihe River basin, northeast China, is expected to show a significant trend towards drier conditions. Xu et al. (2011) analyzed the spatial patterns and trends of drought in the Han River Basin of China and found growing trend in drought severity in most parts of the basin.

Typically, whenever there is a water shortage issue, the solution mostly relies on the capital investment in supply system (i.e. a new water treatment and distribution networks) to meet the growing demand. This has caused huge construction of hydraulic structures in China to meet the increasing trend of water consumption (Stephenson 1999; Gumbo et al. 2005; Zhang 2005). This supply-driven approach is now considered as an unsustainable way of water management. Expansion of infrastructure and development of new water sources have become more expensive and require public acceptance (Elmahdi and MCFarlane 2009). Besides that, many researches revealed that development projects (dams and diversions) destroy aquatic and land habitat and made it ultimately unsustainable from both economic and environmental prospects (Stephenson 1999; Huang and Chen 2000; Butler and Memon 2006; Qian et al. 2009). Therefore, supply-driven approach such as by building more dams and drilling more boreholes cannot be a sustainable option for water resources management. It is very clear that increasing water demand due to population growth and economic development will make drought management more challenging in future than before. Identification and adaptation to sustainable water management practices are essential for drought management in the context of changing environment. The main objective of this paper is to identify the water management strategies for adaptation to water scarcity and drought in China in the context of growing severity of droughts, rising population, rapidly developing economy and changing climate.

2 Materials and methods

The study is carried out through the analysis of secondary data collected from government reports and bulletins. Time series data of population growth, economic development, investment in water sector, drought affected and damaged areas, losses in food yield due to droughts, and water consumptions by different sectors are collected from the China water resources bulletins (MWR 2004, 2007, 2010). Data of drought affected and damaged areas as well as losses in food yield due to water crisis in last 60 years are used to show the trend in drought impacts in China. Data of population growth and economic development are used to anticipate the possible change in water demand in China. Water resources management strategies in different stages of socio-economic development are recognized to draw a typical relationship between socio-economic context and water resources management strategy. The relationship is used to identify the suitable water resources management practices in the present socio-economic context. Trends in water consumptions by different sectors over the last 60 years are analysed to show the effect of water management policies on water consumptions in China.

Change of water demand is a complex procedure. There are many factors that influence water supply and demand. In the present study, only a qualitative analysis of data is carried out to envisage the growing pressure on water and to identify the best management practices to adapt with water stress caused by droughts in the changing environment. The analysis is done on the basis of historical supply and demand situations in China, and the strategies applied to date to adapt with water shortages. Quantitative analysis of changing pattern of droughts, population growth, economic development and water consumption to numerically quantify the gap between demand and supply, and measure the quantitative impacts of water management practices on this gap is out of scope of this paper. It is expected that the qualitative analysis proposed in this paper to identify the water management strategies to reduce the gap between water supply and demand will help in mitigating droughts and water scarcities in China.

3 Drought management in China

3.1 Drought impacts in China

China is a country with plenty of water resources. However, due to its natural characteristics, water resource is distributed unevenly between the south and the north. This caused flood in South and drought in North of China almost every year (Qian and Zhang 2001; Cosier and Shen 2009). Due to the population growth and economic development, total water consumption in China has increased from $1{,}031\times10^8$ m^3 to $5{,}965\times10^8$ m^3 over the period of 1950–2009. This means that water consumption has increased by 5.8 folds in last 60 years. This caused a reduction of the annual per capita renewable freshwater resources availability in China to 1/4 of the world's average (Qian and Zhang 2001; Blanke et al. 2007; Cosier and Shen 2009; MWR 2010). On the other hand, drought severity and impacts are increasing in China.

The area affected and damaged by droughts in China from 1950 to 2009 is shown in Fig. 1. It can be seen from the figure that the drought affected and damaged areas are increasing in China. The drought affected area has increased from $2{,}398\times10^3$ ha in 1950 to $29{,}258\times10^3$ ha in 2009 which is nearly 12 folds. The drought damaged area has increased more as compare to drought affected area. The damaged area has increased by about 22 times from 1950 to 2009. This caused a sharp decrease of food yield in drought affected regions of China (Fig. 2).

3.2 Drought management in the past years

In order to deal with the drought, many hydraulic structures were built during the past years which greatly benefited the economic development of China. The scheme is known as Water Supply Management (WSM) and was the main way of water resources management in

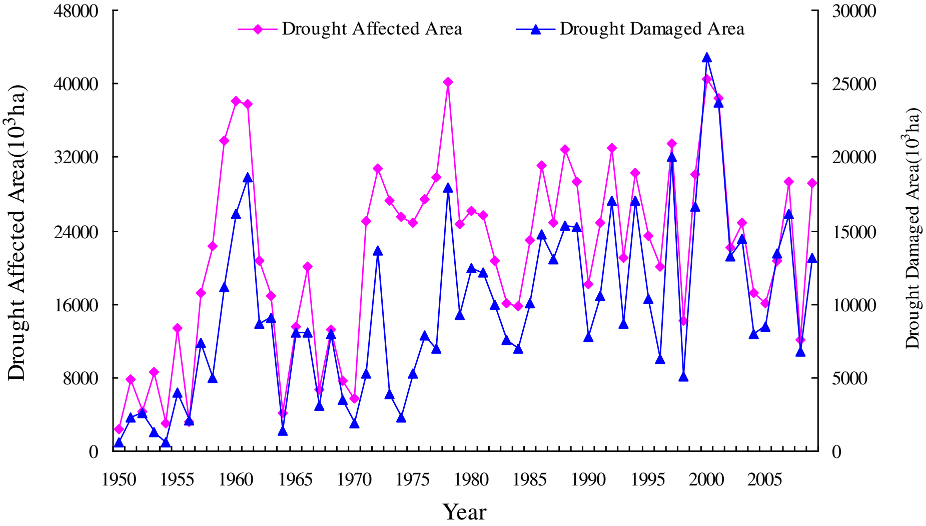

Fig. 1 Drought affected area and damaged area during 1950–2009

China in the past century. The investment for water in China over the past few years is shown in Fig. 3.

Figure 3 shows an increasing trend in water investment in China. Approximately 87,151 reservoirs were built with a total water storage capacity of over 7,064 billion m^3 (MWR 2010). These engineering constructions benefited the country's water resource management planning tremendously during the past years.

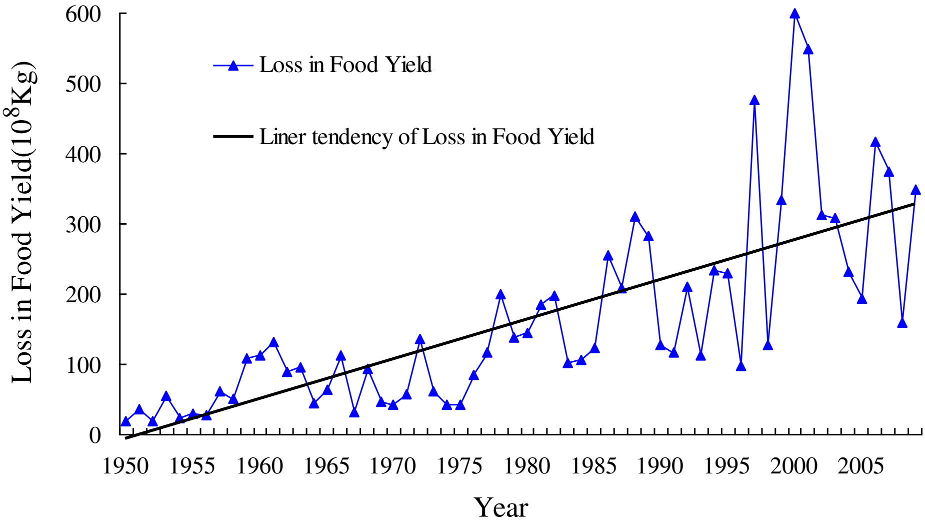

Fig. 2 Loss in food yield by drought during 1950–2009 in China

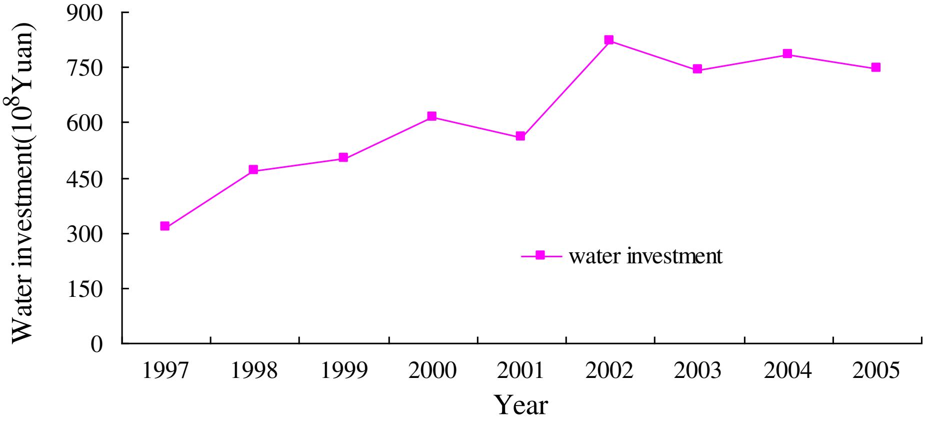

Fig. 3 Water investments in China in recent years

3.3 Challenges for drought management

3.3.1 Economic development

Economic development is the main factor for increasing water demand in China. Figure 4 shows total GDP growth during 1980–2005 in China. It can be seen from the figure that the Chinese economic growth in the recent years is much faster than ever before.

According to the twelfth five-year plan, the Chinese government will pay more attention on economic development to keep the GDP growth rate at 7%.

3.3.2 Population growth

Population growth is another main driving factor of increasing domestic water consumption. Rising Chinese population is the main cause of increasing consumption of water and exacerbating the drought situation. The growth of population from 1980 to 2005 in China (Fig. 5) shows that total population of China has grown from 982.2 million in 1980 to 1307.5 million in 2005. With the rapid urbanization, urban population is growing quickly

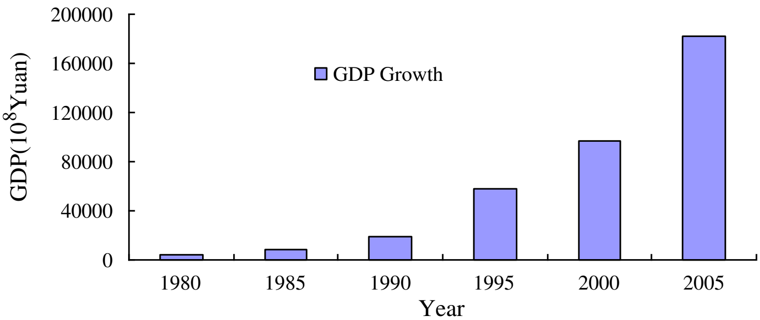

Fig. 4 Economic developments in China from 1980 to 2005

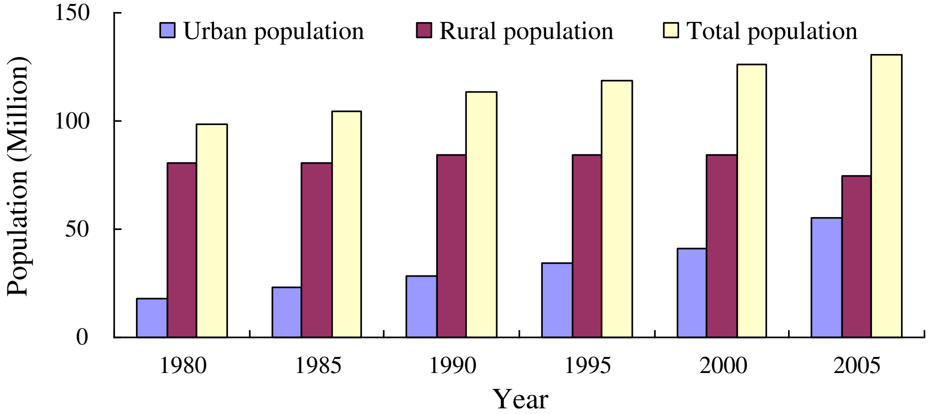

Fig. 5 Population growths in China from 1980 to 2005

compared to rural population. According to the twelfth-year plan, total population will continue to increase in the future.

3.3.3 Climate change

China is a country with vast area and widely varying climate. Tremendous differences in latitude, longitude, and altitude give rise to sharp variations in precipitation and temperature within China. Rainfall decreases from southeast to northwest. Year to year variation of rainfall is also very high, especially in the dry northwest. According to recent IPCC report, climate models project that global warming will change spatial and temporal extents of precipitation which may cause to more frequent droughts in north China (IPCC 2007). It has been observed that annual average air temperature has increased by 0.5~0.8°C in China during last 100 years, which is higher than the average global temperature rise (CNCCP 2007). On the other hand, no obvious change in annual precipitation is observed in China in last 100 years. However, there exists considerable variation among regions. The regional distribution of precipitation trends showed significant decrease in annual precipitation in most of northern China, eastern part of the northwest, and northeastern China, and increase in southern China and southwestern China (CNCCP 2007). With the change of rainfall and temperature, the frequency and intensity of extreme climate/weather events have also changed significantly throughout China. Drought in northern and northeastern China, and flood in the middle and lower reaches of the Yangtze River and southeastern China have become more severe. Number of researches showed that climate change will lead to more frequent extreme events in China (Zhang 2005; Zhang et al. 2009).

4 Adaptation strategy under changing environment

4.1 Socio-economic vulnerability to droughts

The societies and ecosystems are appeared increasingly vulnerable to economic uncertainty due to water scarcity in past years. Wada et al. (2011) estimated that global population under water-stressed condition has increased from 800 million or 27% for 1960 to 2.6 billion or

43% for 2000. Pandey and Bhandari (2007) found that incidence of poverty increases substantially during drought years in India, China and Thailand. Shahid and Behrawan (2008) reported that losses from drought are likely to be more severe than from floods in Bangladesh. Severe episodes of devastating famines provoked by droughts drove massive livestock losses, human migration and mortality in the history of Africa and India (Sendzimir et al. 2011; Davis 2001). Kampragou et al. (2011) estimated that an average of 15% of the total EU area and 17% of the EU population were affected by drought during the period 2000–2006 (CEC 2007). It caused economic damages of $37.2billion accounting for nearly 40% of the total economic damages from droughts over the last 30 years (CEC 2007). Examining the past episodes of droughts, Kampragou et al. (2011) remarked that drought can have severe impacts even in comparatively water rich countries and river basins, which were not considered drought-prone in the past. As a result, the challenge of water resources management for mitigating drought has begun to receive increasing attention by researchers and policy makers in all over the world.

4.2 Sustainable water resources management

Water is a limited resource. With the economic development and population growth, total water consumption is increasing in all over the world (Elmahdi et al. 2009). Though a number of hydraulic infrastructures have been built to increase water supply, those were not enough for mitigating droughts. Drought still causes huge economical losses in China. Massive engineering constructions caused a number of environmental and ecological problems in many river basins of China, such as the drying-up of the river system, subsidence of the land surface due to over-exploitation of groundwater, degradation of the lake and wetland, etc. (Downing et al. 2003; IPCC 2007; Wang et al. 2010; Wang 2010). Continuous population growth, economic development and climate change will pose further challenges on drought mitigation in future. To meet the future challenges, consensus has grown among scientists and water managers to manage droughts in sustainable ways by not only increasing the water supply, but also through the management of water demands.

4.3 Socio-economic development and water resources management

Trends of economic development, population growth and climate reveal an ongoing socio-economic transformation and great uncertainty in water availability. To attain sustainability in water resources, it is necessity to know the relationship between socio-economic development and the state of water resources. The sustainability in water resources refers to the continuity of water supply more or less indefinitely into the future. This can only be obtained when the water need of a growing socio-economy can be kept below the water availability. Therefore, the fundamental measures to attain sustainability in water resources are related with the water management strategies to down the water demand below the water availability. Typical relationship between socio-economic development and water resources management strategies to attain sustainability in water management under changing environment is shown in Fig. 6. The curve depicts the empirical pattern between socio-economic development and water demand under different water management policies. Similar curve of relationship between economic growths and the environment, water pollution and economic development, etc. are already available and being widely used for a long time in different countries (Cole et al. 1997; Yandle et al. 2004).

It is well established fact that water resources management strategy should be different at different periods of economic development and every option for water management need to

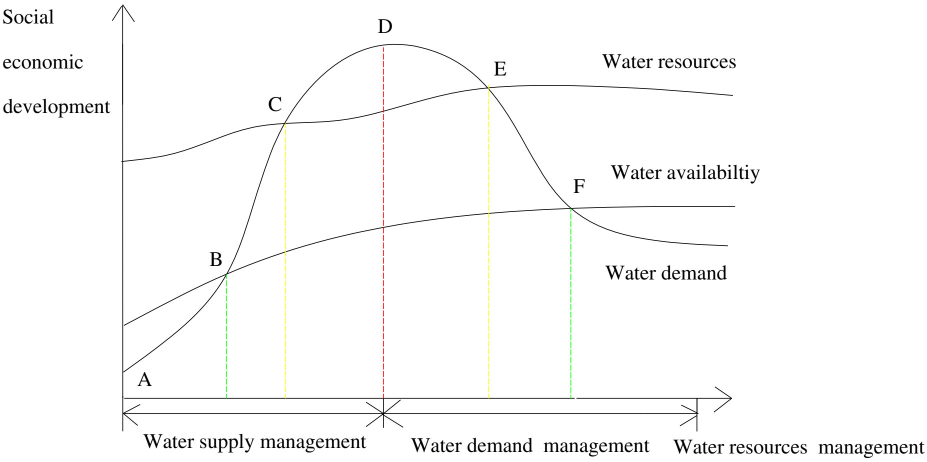

Fig. 6 Relationship between social development and water management

be revisited with time taking into account other factors (environment, social, economic, etc. Figure 6 shows that water management strategies can be divided into six stages in the process of economic development. Water management strategy of each stage is discussed below:

(1) A→B: In the beginning of the social development, the total water resources is abundant and there is no water shortage. Therefore, no actions are needed to increase the supply or control the demand.

(2) B→C: As the economic development continues, the water demand curve reaches to point B. At this point water shortage starts to build up as the supply is not enough to meet the demand. Hydraulic structures are built to increase the water supply for meeting the growing demand during this period which is known as water supply management;

(3) C→D: Continuous economic growth and environmental concerns raise the question of technical reliability and institutional capacity of water supply management. This finally leads the water managers and planners slowly shift towards water demand management approach;

(4) D→E: Lower costs and better environment protection make the water demand management approach widely acceptable for water resources management instead of water supply management. Water saving technology, water price, water rights and water markets are the main ways for water management during this period;

(5) E→F: With the implementation of demand management measures, total water demand decreases, the harmony between ecology and the human activity attains, and the other benefits of water demand management emerges. Public awareness about water saving techniques increases during this period.

(6) F: At this point of management, water resources comes under full control of the economic development and population growth. Therefore, the sustainable use of limited water resources is attained.

It can be concluded from the above discussion that more investments in water increase the water supply to meet the water need of developing society and economy. However, the increase of water demand grows more rapidly compared to water supply as water availability in time and space is limited. This creates a huge gap between water supply and demand.

Shifting the focus of water management from supply-driven management to demand side management reduces the water demand. Sustainability is obtained when water demand comes down to water supply. Population growth, economic development and climate change will certainly increase the water demand. Therefore, the demand-side water management strategies can be the best option to meet the challenges posed increased frequency and severity of droughts.

4.4 Total demand control

China's total water demand increased almost 6 folds during the past 60 years. This has caused serious concerns among the government agencies working on water resources management. After initiation of total demand control strategy, the water demand has started to become stable in China (Huang and Chen 2000; Qian et al. 2009). Changes in water consumptions by different sectors of China from 1949 to 2009 are shown in Fig. 7.

It can be seen from the figure that total water demand in China is going to be more or less stable in the recent years. There are two reasons behind the stability of water demand in China: the change of the water consumption structure, and the increase of water use efficiency (Qian et al. 2009). It has been anticipated that the total water demand in China can be limited to $6{,}700\times10^8$ m^3 by 2020.

4.5 Quota management

Ecological deterioration in the recent years compelled the Chinese government to pay more attention on the sustainable use of water resources. The basic principle of present water management policy of Chinese government is to meet the needs of the present without compromising the ability of future generations to meet their needs. With the change of traditional water management system, more attentions are now being paid on ecological water consumption (Zhang 2005; Macleod et al. 2007; Cosier and Shen 2009). Water consumption efficiency in agriculture and industrial sectors has improved greatly in the recent years (Wang et al. 2011c). Changes in water consumption efficiency in industrial and agriculture sectors of China from 1980 to 2005 are shown in Figs. 8 and 9, respectively. The

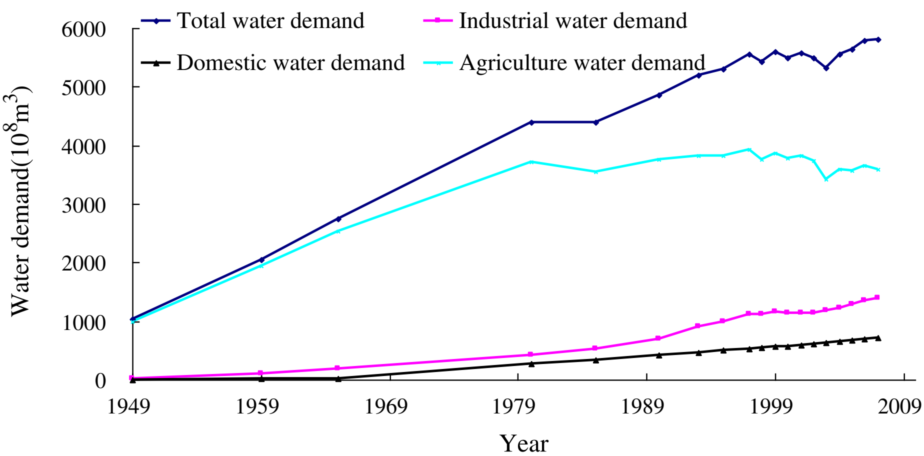

Fig. 7 Water consumptions by different sectors during 1949–2009

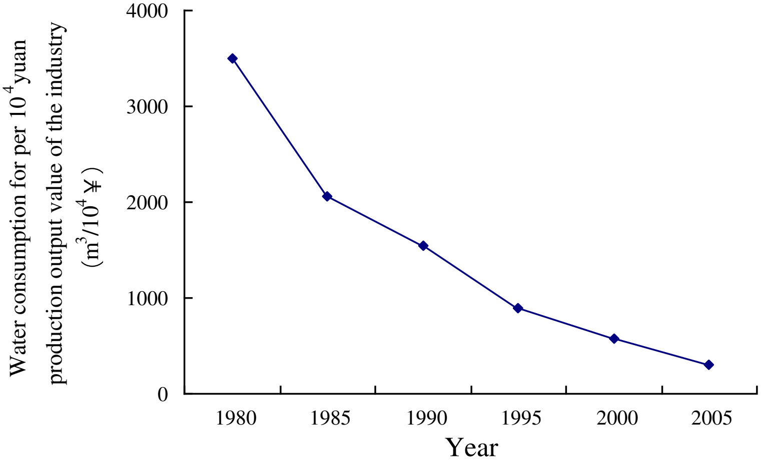

Fig. 8 Changes in water consumption per 10^4 Yuan industrial production during 1980–2005

figures show that agricultural water consumption has reduced by two-third and overall industrial water consumption has reduced by many folds over a short period of time.

Beside the increase of water use efficient, Chinese government is also paying more attention towards water demand management (Zhang 2005; Wang et al. 2009). The national conference of water resources management in 2009 emphasized the importance of water demand management in China. China is carrying out the strictest water resource management measures to grapple with water shortages. The measures will focus on three "red lines" or security lines: to limit the scale of water exploitation, to improve the efficiency of water usage, and to curb water pollution. Water demand management can be a good option to comply with the strictest water resource management measures (Wang et al. 2009; Wang et al. 2011b). But as it is relatively new way for water management, system for Quota management should be setup with full consideration of the possible legislation, available water saving technology, metering

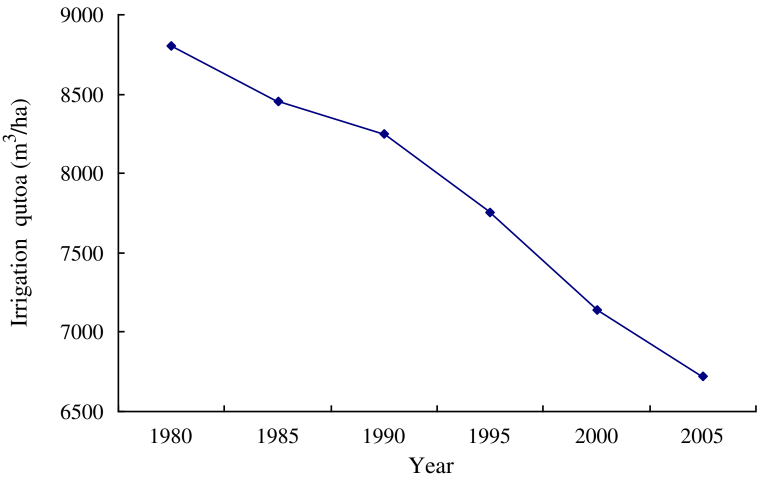

Fig. 9 Irrigation quota in China during 1980–2005

and leakages, wastewater reuse and water price, all of these are recognized around the world (Zhang 2005; Blanke et al. 2007; Liu and Speed 2009).

5 Conclusions and discussion

China is a country where drought is a recurrent phenomenon. Recent researches and the trends in drought affected and demanded areas indicate an increasing tendency in drought frequency and severity in China. Water supply management was the main way of handling drought and water crisis in China in the past century. Huge increase of water demand caused by high population growth and rapid economic development has made the drought management much more challenging in recent years. To adapt with the rapidly changing socio-economic scenario, China recently shifted the focus of water management policy from supply based management to demand based management. The study reveals that the demand based water management strategy particularly increasing efficiency in water use and imposing quota to control total water demand has successfully stabilized the water demand.

The main lesson learned from the present study is that structural supply based management alone is not capable to meet the growing demand of water even if the country or basin is affluent in water resources. Demand based management can improve water consumption efficiency and lessen the water crisis. Therefore, a non-structural demand-side management approach instead of structural supply-driven management can be the effective strategy to adapt with the growing severity of droughts as well as to attain sustainability in water resources management in the context of population growth and economic development.

Authors recommend that further research is required on the following issues:

(1) The study presented in this paper is based on the historical supply and demand situation in China and the strategies applied to date to adapt with water shortages. No analysis of effectiveness of demand based management in future has been carried out in this paper. A detailed study can be done to project demand and supply under various scenarios to measure the effectiveness of demand side management policy based on water use efficiency and water quota.

(2) Drought is a serious natural disaster causing great losses in lives and economy in different parts of the world. Though the present study has identified a concept for sustainable water resources management for adaptation with droughts or water scarcity in China, more researches are urgent to identify droughts mitigation strategies under different geographical, physical and socio-economic environments.

(3) Shifting from water supply management to water demand management would be a major challenge for the water resources mangers in near future. Further study is necessary to get a clear idea about the required amount for control and quota for management to achieve the target. More collaboration is essential between water users and water managers to cope with droughts and water scarcity.

China has gone through a big change in water management strategy to attain sustainability in water resources. Outstanding success in reduction of water consumptions is achieved through demand side water management. Therefore, it can be proposed that water demand management, particularly increasing efficiency in water use and imposing quota to control total water demand, could be the best water management strategies for mitigating droughts in China in the context of climate change, rapid economic development and large population growth. It is expected that the lesson learned from the study will help the stakeholders including policy makers and water managers to improve their understanding on changing pattern of water supply and demand situations in China and ways to adapt with the changing scenarios.

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