Mitig Adapt Strateg Glob Change (2016) 21:81–99
DOI 10.1007/s11027-014-9571-6

ORIGINAL ARTICLE

Adaptation to climate change impacts on water demand

Xiao-jun Wang · Jian-yun Zhang · Shamsuddin Shahid · En-hong Guan · Yong-xiang Wu · Juan Gao · Rui-min He

Received: 18 September 2013 / Accepted: 30 April 2014 / Published online: 1 June 2014

Abstract Research on climate change impacts and related adaptation to water demand is still very limited. A review summarising the findings related to climate change impacts on water demand is carried out in this article. A water management strategy is also proposed, which would help with adaptation to growing pressure on water resources due to climate change and socio-economic development. The study reveals that climate change will increase global water demand, though this will vary widely with geographic location and climatic conditions. Water demand in agriculture will be affected more heavily than will demands in other sectors. As irrigation comprises the major portion of global consumptive water use, increased water demand in irrigation may cause severe stress on water resources. Studies suggest that water demand management or water supply management alone will not able to adapt to mounting water stress. A combination of both water supply and water demand management strategies is necessary in order to adapt to varying environmental and associated uncertainties. A case study from the Haihe River basin of China is presented, to illustrate the effectiveness of water demand management strategies used alongside water supply management in adapting to environmental changes. It is expected that the study will help guide policy responses, with the goal of mitigating the impacts of climate change on water resources.

Keywords Climate change · Water demand · Adaptation · Water resources management

X.-j. Wang · J.-y. Zhang · Y.-x. Wu · R.-m. He
State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing Hydraulic Research Institute, Nanjing, China 210029

X.-j. Wang (✉) · J.-y. Zhang · Y.-x. Wu · R.-m. He
Research Center for Climate Change, Ministry of Water Resources, No. 225 Guangzhou Road, Nanjing 210029, People's Republic of China
e-mail: nhri501@yahoo.com.cn

X.-j. Wang
State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China

S. Shahid
Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

E.-h. Guan · J. Gao
Department of Water Resources, Ministry of Water Resources, Beijing 100053, China

1 Introduction

Water plays a major role in economic development and food security (Ringler et al. 2011; Anseeuw et al. 2012). However, ever-increasing water demand in recent decades, resulting from population growth, economic development and urbanisation, has caused water scarcity and has restricted economic development in many countries across the world (Gowing 2003; Qadir et al. 2007; Blignaut and van Heerden 2009; Wang et al. 2013). It has been reported that approximately 2.4 billion people, or 36 % of the global population, are already experiencing water scarcity, and that 22 % of the world's gross domestic product (GDP) is produced in water-scarce regions (IFPRI 2012). The global water demand will continue to grow, making water a critical component of socio-economic development (IWMI 2007; Anseeuw et al. 2012). It has been projected that by 2050 the world's population will reach more than 9.6 billion people (United Nations 2013), its GDP will be almost quadruple what it is now (OECD 2012), and about 70 % of the global population will be living in urban areas with different lifestyles and consumption patterns (FAO 2009). Food production will have to increase by 70 % in order to feed the growing population, which will cause a vast expansion of irrigated agriculture globally (FAO 2009). Consequently, there will be a rapid growth in domestic, irrigation and industrial water demand across the world (Mote et al. 1999; Döll 2002; Downing et al. 2003; Rosenzweig et al. 2004; Elgaali et al. 2007; Koch and Vögele 2009; Shahid 2011; Pohle et al. 2012; Jakimavičius and Kriaučiūnienė 2013; Price et al. 2014). It has been predicted that global water demand will increase by 55 % by 2050, and that the greatest increases will be in the emerging economies and developing countries that are already under water stress (Vörösmarty et al. 2005 Butler and Memon 2006; OECD 2012; Wang et al. 2013). As potential sources of water are limited, the growing demand for water will make water resources scarcer in the developing regions. According to IFPRI (2012), approximately 45 % of the global GDP and 52 % of the world's population will be exposed to severe water scarcity by 2050 if proper adaptation measures are not taken.

Water resources are not affected only by population and economy. There are many other factors that have an influence on water supply and demand (Downing et al. 2003; Alvisi et al. 2003; Babel et al. 2007). Besides population and economy, climate is considered to be a deciding major factor in the water balance of a region (Middelkoop et al. 2001; Chen and Xu 2005; Bates et al. 2008; Zhang et al. 2008; Elmahdi et al. 2009; Wang et al. 2013). Therefore, changes in climate due to global warming could have severe implications for water resources.

Climate change will cause sharp increases in temperature, which in turn is likely to affect evapotranspiration and atmospheric water storage, thereby potentially changing the magnitudes, frequencies and intensities of rainfall as well as its seasonal and inter-annual variabilities and geographical distributions (Arnell 1999; Middelkoop et al. 2001; Chen and Xu 2005; Akhtar et al. 2008; Bates et al. 2008; Zhang et al. 2008; Elmahdi et al. 2009; Wang et al. 2013). Increased temperatures and variable precipitation may change regional water supplies and demands and, consequently, aggravate the condition of water scarcity. Parry et al. (2009) projected that the number of people at risk of hunger will increase by 10–20 % by 2050 because of climate change.

Climate change is inevitable, and it is already evident in many parts of the world (Ren et al. 2002; Fang et al. 2007; Chen and Xu 2005; Shahid 2010; Wang et al. 2010; Shahid et al. 2012). Therefore, it is very urgent to consider climate change issues in the planning and management of water resources, in order to be able to adapt to the changing environment. Understanding how water demand changes in response to variations in the environment is an essential component of water resources planning, development and management (Belton and Miller 2014; Wang et al. 2014). As the long-term outlook on environmental changes is uncertain, water management strategies in times of global change need to be developed within a complex and uncertain environment (Pahl-Wostl et al. 2007). Numerous studies have been carried out so far for the purposes of understanding the impacts of climate change on rainfall, river discharge and availability of water resources (Shahid and Hazarika 2010; Ahamad et al. 2013; Razafindrabe et al. 2014; Wang et al. 2014). However, research on climate change impacts on water demand is still limited. Lack of understanding has increased uncertainty in matters of impact assessment and managing water resources in the context of global change (Pahl-Wostl et al. 2007). Current water management practices are very likely to be inadequate in reducing the negative impacts of climate change on water resources and ensuring a continuous supply of water for food production, power generation, sanitation and public health, and aquatic ecosystems (IPCC 2007). It is very urgent that more attention be given to dealing with uncertainties related to sustainable water management resources in the context of climate change (Wang et al. 2012a; Wang et al. 2012c).

The objective of the present study is to understand the possible impacts of climate change on water demands and to identify possible water management strategies that can deal with uncertainty in managing water resources in the context of climate change. The study has been carried out through a review of the existing literature. The available literature is classified according to its relevance to climate change impacts on water demand in various sectors, such as agriculture, industry, domestic and environment; each classification is reviewed separately. Existing water management strategies are also reviewed, with the goal of proposing a water management system that can adapt to changes in climate and socio-economic functioning. Finally, a case study of China's Haihe River basin is presented, in order to show the efficacy of a proposed water management system in adapting to environmental changes. It is expected that the study will help development and planning authorities as well as policymakers to improve their understanding of climate change impacts on water resources, and will also assist them in adopting policy responses.

2 Research methodology

2.1 Climate change impacts on water demand

A short but systematic review is carried out here, in order to summarise the knowledge gathered by researchers in different parts of the world regarding climate change impacts on water resources. For this purpose, relevant studies from recent years are identified and thoroughly reviewed, in order to assist in understanding the direct and indirect impacts of changing patterns of temperature and rainfall on water demand within the sectors of agriculture, industry, domestic affairs and ecology. In some cases, published data are reanalysed for the purpose of better understanding the changes reported on.

A total of 140 papers were preliminarily selected for screening. The quality of the papers was assessed based on the methods they used for analysing data and interpreting the results. Only those studies that were carried out using field data and reliable methods were selected. Studies based on a qualitative analysis of the information were excluded. At the end of this process, 76 papers were selected to assist in understanding the impacts of climate change on water demand. The papers were classified according to their relevance to climate change impacts within various sectors, and each classification was summarised separately. Finally, the summarised results are interpreted here for the purpose of understanding the impacts of climate change on water demand within the sectors of agriculture, industry, domestic affairs and ecology. Similarly, strategies that are used for the management of water resources are reviewed. Based on this analysis of the literature, a management strategy for adapting to ever-increasing water demand is proposed.

Changes in water demand depend on many factors, including population growth, economic development, climate change, lifestyle changes, technological advances, etc. It has become increasingly clear that the pressing problems in this field have to be tackled from an integrated perspective, taking into account environmental, human and technological factors as well as their interdependence (Pahl-Wostl 2007). However, the present study concentrates only on the influence of climate change on water demand. It is very clear that climate change will affect both water availability and water demand, and therefore it is necessary to consider both together when proposing adaptation measures. In the present study, adaptation measures are proposed in light of the considerations that potential sources of water are limited and will become scarcer as a result of climate change.

2.2 Water management strategies for adaptation to changing environments

Environmental conditions that become warmer and drier due to climate change will further aggravate the water crisis in many regions of the world that are already facing water shortages due to growth in the economy and in population. Increased water demand might increase conflicts between different water uses, including in-stream needs for retaining ecosystem sustainability. Managing water resources will become a major challenge and an important priority across the world, as the growing and conflicting demand for water will appear as a major threat to economic development (Abu-Taleb 2000; Leipprand et al. 2008; Wang et al. 2012b). Therefore, adaptation through water management practices is essential in order to mitigate the negative impacts of climate change.

Water management strategies can be divided into three broad classes, namely, supply side management, demand side management and business-as-usual management (Wang et al. 2012a; Wang et al. 2014). Water supply management focuses on increasing the amount of water available, in order to keep pace with increases in water demand; this is to ensure adequate water availability and acceptable water quality. It is the most traditional approach to water resources management. Supply-side approaches include changes in structures, operating rules and institutional arrangements; increasing flood defences; building weirs and locks to facilitate navigation; and modifying or expanding infrastructure for water collection and distribution.

Water demand management (WDM) refers to any technical, economic, administrative, financial or social approaches to reducing the quantity or quality of water required to accomplish a specific task (Brooks 2006; Butler and Memon 2006; Wang et al. 2011; Wang et al. 2012c). In light of economic development, population growth and climate change, needs for efficient water demand management increased significantly (Global Water Partner 2012). On the other hand, business-as-usual management refers to managing water resources without considering possible future circumstances that may have a negative impact on these resources. The business-as-usual approach to water management is not suitable in the context of climate change, as it is very certain that fresh water will be scarcer in the future. It has been projected that 4.8 billion people, or more than half of the world's population, as well as approximately half of global grain production, will be at risk due to water stress by 2050 if status quo or business-as-usual management is practised (Global Water Partner 2012).

Institutions that govern water allocation play the most important role in determining overall climate and socio-economic impacts on water availability, as well as costs and benefits of different management options, in service of determining appropriate water management strategies (Kundzewicz et al. 2007). Both water supply and water demand management strategies have their own set of economic, environmental, and political advantages and disadvantages. However, potential sources of water are limited and are insufficient to meet increasing demand within a changing environment. Furthermore, financial resources in many developing countries are insufficient for making the water system investments that are required for supply augmentation. Water demand management, on the other hand, can reduce water demand, to a certain extent, without hampering economic development and without putting significant constraints on society. Therefore, either water supply or water demand management strategies alone will not be sufficient for adaptation to changing scenarios. Experience suggests that meeting the challenge of water scarcity requires both a supply management strategy, involving the highly selective development and exploitation of new water supplies (conventional and non-conventional), and a vigorous demand management strategy, involving comprehensive reforms and actions taken to optimise the use of existing supplies (Global Water Partner 2012). The appropriate mix of supply and demand management will vary depending on the level of development, governance structure and degree of water scarcity in each country.

Furthermore, a sustainable water management system should be able to deal with maximum uncertainty, arising not only from climate change but also from socio-economic development and emerging model projections. Uncertainty regarding needs for future water management manifests itself in several ways, such as natural variability or changes in water supply and demand that are due to climate change or other external pressures, socio-economic uncertainties or variability in socio-economic development, and uncertainty due to changing projections of water supply and demand (ten Brinke et al. 2010). Pahl-Wostl et al. (2007) distinguish among different types of uncertainty: uncertainty due to lack of knowledge, uncertainty due to difficulty understanding the system itself, uncertainty that is inherent in system behaviour and uncertainty that arises from the diversity of rules and underlying mental models determining stakeholder perceptions and actions. All types of uncertainty must be considered when addressing a management problem. Robust strategies that perform well under a wide range of uncertain but possible future circumstances should be chosen (Pahl-Wostl et al. 2007; van der Voorn et al. 2012).

Generally, a management system including a single operational strategy will be less capable of handling uncertainty, as compared to a system that relies on several alternative strategies. Therefore, a combination of water supply and water demand strategies is more sustainable than either strategy alone in adapting to increasing water demand within the contexts of climate change, population growth and economic development, as well as associated uncertainties. However, it should be implemented in different manners in different geographical conditions (Magini et al. 2008).

This paper proposes a water resource management system that combines both water demand and water supply management strategies in dealing with changes in the environment. The basic framework of the system is shown in Fig. 1. The system follows the adaptive management concept, proposed by Pahl-Wostl et al. (2007), of improving management policies and practices by learning from the outcomes of management strategies. The adaptive management cycle consists of five phases, namely, pre-assessment, goal formulation, policy development (option) implementation and monitoring. Understanding possible future scenarios within the context of environmental changes is essential for the formulation and implementation of adaptive water management strategies (van der Voorn et al. 2012). In the first, or pre-assessment, phase of the proposed system, forecasting models are employed to predict future changes in water supply and demand due to climate change as well as due to population growth and economic development. Model outputs are used in the second phase for goal formulation and policy development, including in the areas of improvement of water use

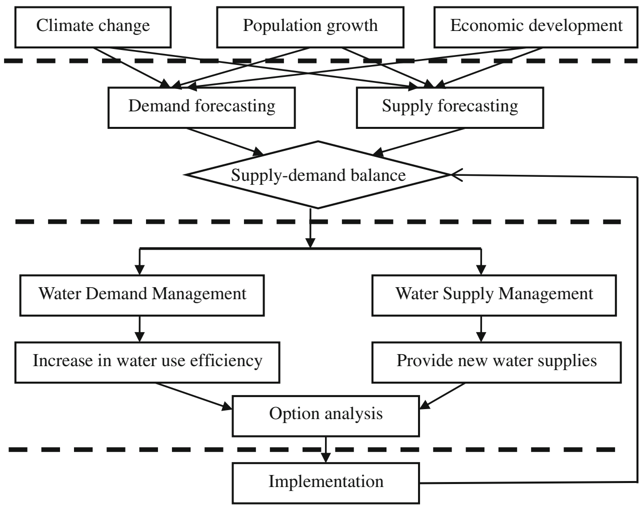

Fig. 1 The framework of a water management system that can adapt to a changing environment

efficiency and development of new water sources. In the third phase, practical measures are taken to implement the water supply and water demand management policies for the purpose of adapting to changing scenarios of water supply–demand balance. Improvement of the system's ability to adapt to changes in the environment is continuously monitored through a cyclic process.

According to Pahl-Wostl et al. (2007), an adaptive system should be able to process new information as it becomes available to the system, and should also be able to change itself based on the processing of new information. The proposed system will continuously monitor changes in the environment and will improve management policies and practices by learning from the outcomes of previously employed management strategies. Therefore, the system will be able to adapt to changes and will be prepared for future changes of an uncertain nature.

3 Climate change and water demand

It is widely accepted that water demand will increase due to changes in temperature regimes and precipitation amount and distribution. A number of studies have been carried out to estimate the influences of climate variables on water demand (Graeser 1958; Maidment et al. 1985; Jain et al. 2001; Bougadis et al. 2005; Ghiassi et al. 2008; Zhou et al. 2000; Khatri and Vairavomoorty 2009; Caiado 2010). Various methods for understanding the impacts of climate variables such as rainfall, air temperature, sunshine duration, relative humidity, wind speed, etc. on daily, weekly, monthly, seasonal and annual water demands have been proposed, including linear regression (Graeser 1958), the Box and Jenkins model (Maidment et al. 1985), the use of artificial neural networks (Jain et al. 2001; Bougadis et al. 2005; Ghiassi et al. 2008; Adamowski 2008; Khatri and Vairavomoorty 2009), the use of system dynamics (Wang et al. 2011; Wang et al. 2013) and other methods (Alvisi et al. 2003; Altukaynak et al. 2005). The results of these analyses reveal that climatic conditions and water use are significantly correlated. A summarisation and interpretation of the results obtained by various authors regarding climate change impacts on water demand in various sectors are discussed below.

3.1 Irrigation water demand

A number of studies have been carried out for the purpose of understanding the impacts of climate change on irrigation water demand in various geographical and climatic regions (Harte et al. 1995; Herrington 1996; Brumbelow and Georgakakos 2001; Döll 2002; Izaurralde et al. 2003; Downing et al. 2003; Rosenzweig et al. 2004; Yano et al. 2005; Fischer et al. 2007 Mikhwanazi 2006; Rodriguez Diaz et al. 2007; de Silva et al. 2007; Elgaali et al. 2007; Yano et al. 2007; Shahid 2011; Safeeq and Fares 2012; Jampanil et al. 2012; Ashour and Al-Najar 2013; Wada et al. 2013). Generally speaking, different versions of the Penman-Monteith equation and of water balance models were used for the assessment of climate change impacts on irrigation demand. According to the Penman-Monteith model (FAO-PM), the change in evapotranspiration due to the change in temperature can be calculated as

$$ET_0 = \frac{0.408(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_2 - e_2)}{\Delta + \gamma(1 + 0.34 u_2)} \tag{1}$$

where ET_0 is the reference evapotranspiration (mm/d), R_n is the net radiation over the grass ($\mathrm{MJ} \times \mathrm{m}^{-2} \times \mathrm{d}^{-1}$), G is the soil heat flux density ($\mathrm{MJ} \times \mathrm{m}^{-2} \times \mathrm{d}^{-1}$), Δ is the slope of the saturation vapor pressure curve at the mean daily air temperature (kPa/°C), γ is the psychrometric constant (kPa/°C), u_2 is the wind speed measured at 2 m above the ground (m/s), e_0 is the saturated vapour pressure of the air (kPa), and e_a is the mean actual vapour pressure of the air (kPa).

On the other hand, water balance models estimate how irrigation demand changes when both temperature and rainfall change. The irrigation demand of crop land can be calculated using the water balance model below

$$I_N = ETc - Pe + \Delta W + G \tag{2}$$

where IN is the net water demand of the crop (mm), ETc is the reference crop evapotranspiration (mm), Pe is the effective precipitation (mm), G is the groundwater recharge during the growth of the crop (mm), and ΔW is the soil moisture storage capacity (mm).

Studies by different authors that are based on the above-mentioned methods reveal that changes in local weather, particularly changes in temperature and precipitation, affect the soil-water balance and hence irrigation needs. Herrington (1996) showed that an increase in temperature of 1.1 °C in the United Kingdom (UK) would cause an increase of 35 % in water used for lawn sprinkling. The study also showed that, due to an increase in temperature and a decrease in summer rainfall, irrigation demand in the UK could increase by 20 % in 2020 and 30 % in 2050. Harte et al. (1995) reported that a 3 °C rise in soil temperature would entail a 25 % decrease in soil moisture, which consequently would increase irrigation needs. Fischer et al. (2007) investigated potential changes in global and regional agricultural irrigation water demand that could occur in socio-economic scenario A2r; they suggested that climate change would cause a global increase in irrigation water requirements nearly as large as the changes projected as a result of socio-economic development in this century. Rodriguez Diaz et al. (2007) studied the climate change impacts on irrigation water requirements in the Guadalquivir river basin of Spain and estimated an average increase in demand of between 15 % and 20 % by 2050. de Silva et al. (2007) reported an average increase in paddy irrigation requirements of 13 % to 23 % in Sri Lanka, depending on climate change scenarios. Elgaali et al. (2007) predicted an increase in irrigation water demands in the Arkansas River basin of southeastern Colorado. Yano et al. (2007) showed that a water deficit could occur in the Mediterranean environment of Turkey, as precipitation might not adequately compensate for an increased evaporative demand due to a rise in temperature. Shahid (2011) reported an increase in daily irrigation demand in northwest Bangladesh due to climate change. Jampanil et al. (2012) estimated a 13.3 % increase in agricultural water demand in Thailand due to climate change. Ashour and Al-Najar (2013) reported that a temperature increase of 1–2 °C would cause an increase in annual average evapotranspiration of 45–91 mm relative to current climate conditions, leading to an increase in irrigation requirements of 3.28–6.68 % in the Gaza Strip, Palestine. Increased irrigation demand has also been reported in other parts of the world by Brumbelow and Georgakakos (2001), Döll (2002), Izaurralde et al. (2003), Rosenzweig et al. (2004), Yano et al. (2005), Mikhwanazi (2006), Yano et al. (2007), Safeeq and Fares (2012), Schewe et al. (2012) and Wada et al. (2013).

Based on the findings of the above studies, it can be concluded that irrigation water demand will certainly increase due to increases in evapotranspiration and reductions in soil moisture that occur under warmer climatic conditions. Irrigation water withdrawals account for almost 70 % of global water withdrawals and 90 % of global consumptive water use (Shiklomanov and Rodda 2003). Therefore, increased demand for irrigation will certainly intensify water competition among different sectors.

3.2 Industrial water demand

Industrial water demand includes water needs for fabrication, processing, washing, dilution and cooling. However, the majority of water withdrawn by industry is used for the cooling process (Koch and Vögele 2009). For example, about 43 % of water demand in the European Union (EU) is for cooling water for power authorities (EUREAU 2009). A thermal power plant generally draws cool water from a river and discharges hot water back to the river. It has been estimated that an average of 95 l of water is required to produce 1 kWh of electricity (Heiner 2010). Major changes in industrial water consumption will occur due to changes in the amount of water needed for cooling. Demand for cooling water in the once-through cooling system has been calculated by different authors (Koch and Vögele 2009; Rübbelke and Vögele 2011; Khan et al. 2012), using the following equation

$$Q = KW \cdot h \cdot 3.6 \cdot \frac{1-\eta_e}{\eta_e} \cdot (1-a) \cdot \frac{1}{p \cdot c \cdot AS} \tag{3}$$

where Q is the cooling water demand (m^3), KW is the installed capacity (kW), h is the operation hours (h), 3.6 is the factor used to convert kWh to megajoules, ηt is the total efficiency (%), ηe is the electric efficiency (%), α is the share of waste heat not discharged by cooling water (%), c is the specific heat capacity of water (MJ/t.K), ρ is the water density (t/m^3), and AS is the permissible temperature increase of the cooling water (k).

The maximum permissible water withdrawal in industry can be calculated as (Koch and Vögele 2009; Rübbelke and Vögele 2011)

$$Q_{max} = \frac{KW_{max} \cdot \lambda \cdot h \cdot 3.6 \cdot (1-\alpha)(1\eta_t)}{4.2 \cdot \eta_e \cdot AS_{max}} \tag{4}$$

where Q_{max} is the maximum permissible water withdrawal (m^3), AS_{max} is the maximum permissible temperature increase (K), and the other notations are the same as in Equation 3.

Compared to studies of climate change impacts on irrigation and domestic water demand, studies of climate change impacts on industrial water demand are very few. Among these, the studies by Mote et al. (1999), Protopapas et al. (2000), Downing et al. (2003), Koch and

Vögele (2009), Zachariadis (2010), Rübbelke and Vögele (2011), Jessberger et al. (2011), Averyt et al. (2011), Linnerud et al. (2011), Förster and Lilliestam (2010), Khan et al. (2012) and Jampanil et al. (2012) are most notable. It has been reported that if the maximum allowable heating temperature is 28 °C and the intake water temperature is 18°C, 1 m^3 of water is needed to dissipate 42 MJ of heat. If the intake water temperature increases to 23 °C and the maximum allowable temperature remains at 28°C, 2 m^3 of water is needed to dissipate 42 MJ of heat (Koch and Vögele 2009; Rübbelke and Vögele 2011; Khan et al. 2012). Förster and Lilliestam (2010) reported that production losses calculated at 87 GWh/a on average during baseline years would increase to an average of 1,350 GWh/a in the +5° scenario. Mote et al. (1999) and Downing et al. (2003) reported a small increase in industrial water demand due to climate change. Koch and Vögele (2009) and Downing et al. (2003) also projected an indirect but small (less than 5 % by the year 2050) secondary effect on water demand due to an increased summer energy demand for space cooling. Averyt et al. (2011) reported that water demands for industrial cooling and thermoelectric power production are likely to increase with warmer air and water temperatures. Jampanil et al. (2012) estimated an indirect increase in industrial water demand of 0.2 % in Thailand by the mid-twenty-first century. Jessberger et al. (2011) projected a change in industrial water usage ranging between −5.58 % and +11.64 % in 2025 (relative to the base year 2012) in the upper Danube River basin.

It can be stated, in summarising the above studies, that cooling water demand depends chiefly on local climate conditions, and especially on water temperatures. As there is a direct relationship between cooling water demand and temperature, water demand in power plants and manufacturing facilities will increase due to increases in temperature. Supplementary water supplies will be required in order to compensate for decreased efficiencies of cooling systems due to these rises in temperature. However, the impact of climate change on water demand in industry will be rather small compared to its impact on water demand in agriculture.

3.3 Domestic water demand

Domestic water demand includes water needs for all residential purposes, including in-house water use for drinking, preparing food, bathing, washing clothes and dishes, flushing toilets, etc., as well as outdoor water use for gardening, lawn watering, etc. (Alvisi et al. 2003; Alaa and Nisai 2004; Garcia et al. 2004; Blokker et al. 2009; Wang et al. 2011). Domestic water demand is usually calculated using the climatic elasticity of water use. Impacts of temperature on water demand are estimated using the temperature elasticity of water use,

$$e_t = -\Delta Q/\Delta T \tag{5}$$

where ΔQ is the percentage change in water demand and ΔT is the percentage change in temperature. Similarly, the impact of precipitation on water demand is estimated using the precipitation elasticity of water demand,

$$e_t = -\Delta Q/\Delta P \tag{6}$$

where ΔQ is the percentage change in water demand and ΔP is the percentage change in precipitation.

A number of studies focusing on climate change impacts on domestic water demand have been carried out (Mote et al. 1999; Protopapas et al. 2000; Downing et al. 2003; Gutzler and Nims 2005; Neale et al. 2007; Zachariadis 2010; Polebitski et al. 2011; Karamouz et al. 2011 Jampanil et al. 2012; Price et al. 2014). Frederick (1997) studied urban water use in four mountainous counties of Utah and suggested that a 1 % rise in temperature would cause an increase in residential water demand of between 0.02 % and 3.8 %, and that a 1 % decrease in precipitation would cause an increase in residential water demand of between 0.02 % and 0.31 %. A statistical analysis of water use in New York City showed that, above 25 °C, daily per capita water use increases by 11 l per 1 °C (Protopapas et al. 2000). Neale et al. (2007) studied climate change impacts on residential water demand in the Okanagan Basin of British Columbia, and reported that residential water demand increases by 0.0031 to 0.0111 ML for every 1 °C increase in monthly mean daily maximum temperature. Gutzler and Nims (2005) studied the effects of inter-annual climate variability on water demand in Albuquerque, New Mexico, and reported that over 60 % of year-to-year changes in summer residential demand is accounted for by inter-annual temperature and precipitation changes. Zachariadis (2010) studied residential water scarcity due to climate change in Cyprus and predicted that by 2030 climate change would aggravate the already-existing water scarcity in Cyprus. Price et al. (2014) examined the influence of climatic variables on annual residential water use in the city of Phoenix, Arizona, and reported that temperature, precipitation, and/or drought conditions all have a significant impact on residential water use. On the other hand, Karamouz et al. (2011) projected no appreciable change in average domestic water demand in the city of Tehran due to climate change. Mote et al. (1999) and Downing et al. (2003) also projected that any increases in household water demand due to climate change are likely to be rather small, i.e., less than 5 % by the 2050s. Jampanil et al. (2012) estimated an indirect increase in domestic water demand of only 0.3 % in Thailand due to climate change. An increase in water demand due to a rise in temperatures was also predicted by Kenney et al. (2008), Harlana et al. (2009), Polebitski et al. (2011) and Lott et al. (2013).

An analysis of the results of the above-mentioned studies reveals that domestic water demand will increase as a result of increased evapotranspiration caused by higher temperatures. However, changes in domestic water demand may not be significant in some regions, due to an increase in precipitation. Overall changes in domestic water demand will depend on how well increased rainfall balances water losses from increased evapotranspiration due to higher temperatures (Wiley and Palmer 2008).

3.4 Ecological water demand

Ecological water demand includes water demand for environmental and ecological system protection purposes. Usually, when supplies become scarcer, major adjustments in water use are required in order to maintain the minimum in-stream flows needed for the protection of endangered species and of the recreational benefits of an area. Ecological water demands are calculated by adding in-stream and out-stream water demands. There is no well-accepted method of estimating in-stream ecological water demand.

Out-stream water demand for environmental protection is usually calculated as

$$ET_c = \alpha D \tag{7}$$

where ET_c is the out-stream water demand for environmental protection (mm), α is a parameter (mm/hPa), and D is the aerial saturation deficiency (hPa). A comprehensive factor reflecting temperature change and air humidity can be obtained as

$$e = e_0 - e_a \tag{8}$$

where e_a is the mean actual vapour pressure of the air (kPa) and e_0 is the saturated vapour pressure of the air (kPa), which can be defined as

$$e_0 = e_1.10^{\frac{8.5t}{273+t}} \quad (9)$$

where t is air temperature and e_1 = 6.11 hPa.

The equations above show a direct relationship between out-stream water demand and air temperature. Therefore, increased temperatures will cause an increase in out-stream water demand. Mote et al. (1999) and Downing et al. (2003) predicted that increased temperatures would cause an increase in gardening water demand. They also predicted that there might be an increase in seasonal water demands associated with recreational uses such as swimming, boating and fishing.

Only a few studies have been carried out focusing on climate change impacts on in-stream water demand (Zhong et al. 2008; Hu et al. 2012; Barron et al. 2012; Piniewski et al. 2012; Spears et al. 2013). Piniewski et al. (2012) reported that climate change impacts on ecological water demand would be greater than impacts caused by other regional changes. Zhong et al. (2008) predicted that climate change would cause annual changes in eco-environmental water demand. A study by Barron et al. (2012) on climate change impact on water-dependent ecosystems in southwestern Australia showed that, in the context of climate change, more water will be required to keep the ecosystem healthy. Spears et al. (2013) reported a potential increase of in-stream water demand due to increases in ecosystem demands and recreational uses within climate change scenarios. They also reported that the water demands of endangered species and of other fish and wildlife could increase along with ecosystem impacts due to warmer air and water temperatures, as well as with resulting hydrologic impacts, e.g., runoff timing. Hu et al. (2012) also reported changes in stream flow and ecology in the North China Plain due to climate variability.

The studies above indicate that changes in the quantity, quality, and timing of runoff, stemming from greenhouse gas warming, would affect in-stream water uses for the maintenance of ecosystems. These changes might also affect in-stream water demands, directly or indirectly. Furthermore, an increase in air temperature would also lead to an increase in water temperature, which in turn would have a direct impact on cyanobacteria growth and water demand.

Finally, it can be concluded without any doubt that climate change will increase water demand. Increases in water demand within agriculture will primarily be due to higher irrigation demand caused by warmer and drier conditions. In industry, increases will be due to increases in cooling water demand for power generation under higher atmospheric temperatures. On the other hand, in domestic and ecological sectors, water demand will increase due to increases in temperature. Overall, water demand will increase more significantly within agriculture than it will within other sectors.

4 Adaptive water resources management in the Haihe River basin of China

The Haihe River basin, as one of the fastest-developing regions in China, is facing a huge challenge in managing its water resources to support its economic development under the pressures of both climate change and population growth (Allan et al. 2013). Following the economic development of the late 1980s, the urban areas of the basin expanded greatly. With the influx of migrants from various regions of the country, especially from rural areas, the population of the basin increased rapidly. Huge industrial growth also occurred in the basin after the early 1980s (Yang et al. 2010; Ji et al. 2012). Population growth and economic development in the Haihe River basin during the time period 1980–2004 is shown in Fig. 2. Rapid population growth and economic development caused changes in water demand in the

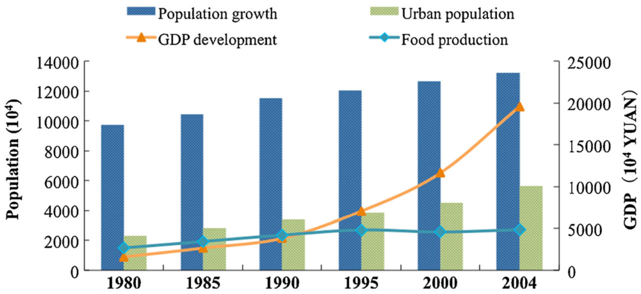

Fig. 2 Population growth and economic development in the Haihe River basin during the time period 1980–2004

basin, which are shown in Fig. 3. It can be seen from the figure that water demand, especially in domestic and industrial sectors, increased rapidly in the eighties and early nineties. Traditionally, the Haihe River basin has been one of the most water-scarce river basins in China. Water is usually transferred from the Yellow River to the Haihe River in order to mitigate water crises. The annual amount of water transferred from the Yellow River increased rapidly in the eighties, in order to meet the water demand of the growing economy in the Haihe River basin; in 1989, the amount reached 65×10^8 m^3 (Wang et al. 2013). Meeting an ever-increasing water demand through augmentation of the water supply became very difficult, as the resultant pressure on the Yellow River ecosystem raised concern. Water demand management, along with water supply management, was emphasised, in order to manage the increasing water demand in the Haihe River basin (Wang et al. 2012c). The government introduced a series of national water strategy actions. Initiatives to increase water use efficiency in industry and irrigation were created; these imposed water prices and water quotas (Pang and Zhang 2001; Yang 2002; Wu et al. 2007; Yang et al. 2010; Wang et al. 2013).

Agricultural areas declined significantly in response to the increase in water prices (Wu 2010; Xiao and Shen 2008; Yang et al. 2010). At the same time, water use efficiency in agriculture increased, due to the adoption of new irrigation technology. According to Pang and Zhang (2001) and Yang (2002), by the year 2000, water use per unit of land in the Haihe River basin had decreased by 20 %. Therefore, the governmental initiatives of adopting new irrigation technology and of turning paddy fields into other less water-intensive operations were successful in reducing agricultural water consumption in the Haihe River basin (Ji et al. 2005; Wu et al. 2007; Ji et al. 2012; Wang et al. 2013).

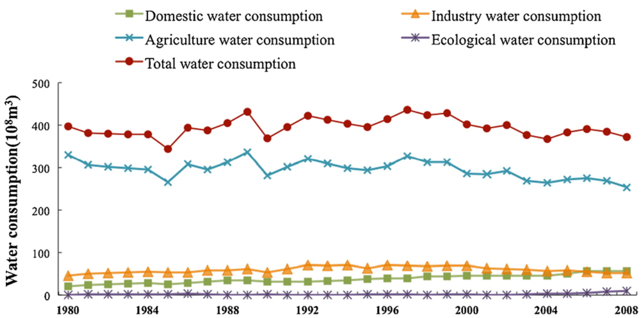

Fig. 3 Changes in water consumption in the Haihe River basin during the time period 1980–2008

It was also possible to keep industrial water demand stable, despite the industrial growth in the basin (Wang et al. 2013). The Haihe River basin achieved high efficiency in industrial water consumption by adjusting industrial structures and arrangements, limiting high levels of water consumption in production, adopting water-saving technology and gradually increasing the proportion of new technology industries that use less water (United Nations 2005). This caused the average water consumption quantum for every RMB 10,000 output value to decrease from 160 m^3 in the early 1990s to 51 m^3 in 2004. In Beijing, a water quota, along with high rates for exceeding the water quota, led to a 37 % reduction in industrial water use in the 1980s (Bhatia and Falkenmark 1992). Tianjin was able to increase its rate of industrial output per cubic metre of water from \$18.5/m^3 in 1981 to \$45.5/m^3 in 1988, a reduction of 14 % per year in average industrial water consumption per unit of industrial output (Bhatia et al. 1995). Consequently, water consumption in the industrial sector stabilised, even with the continuous industrialisation in the basin. It can be concluded from the above analysis that water demand management strategies have successfully reduced the total water demand of the Haihe River basin.

In spite of a decrease in total water consumption, water shortage is still a problem in the Haihe River basin. On average, about 44.7×10^8 m^3 of water still needs to be transferred every year from the Yellow River to the Haihe River (Wang et al. 2012d). However, reduced water demand in the Haihe River basin, due to strict water demand management strategies, has reduced the need for water transfer from the Yellow River. The lower part of the Yellow River dried up several times in recent years (Wang et al. 2012d). Due to a reduction in river flow, the ability to make huge water transfers from the Yellow River, in the context of a changing environment, became uncertain. Reduction in total water demand after the adoption of water demand management strategies has made the water management system in the Haihe River basin more robust and better able to handle uncertainties in the changing environment.

Therefore, it can be concluded that the adoption of water demand management strategies along with water supply management strategies is necessary in order to adapt to environmental changes. Although both water supply and water demand management are equally important, in consideration of the available options for achieving water resource sustainability in the contexts of population growth, economic development and climate change, as well as of the fact that sources of water are limited, it is recommended that more emphasis be given to water demand management.

It can be learnt from this study that climate change will be a major threat to water resources which are already under stress due to huge population growths and economic booms. Temperature increases due to climate change will increase water demand in all sectors of water use. However, the impact will be much higher in agricultural and domestic sectors. Water supply management or water demand management alone will not be able to meet the growing demand, considering that sources of water are limited. A management system that considers both water demand and water supply management strategies, one that can adapt to the changing environment and to related uncertainties, should be employed. The system should be cyclic, so that it can improve management policies and practices by learning from the outcomes of previously employed management strategies.

5 Discussion and Conclusions

The sustainable management of water resources in the context of a changing environment is a growing concern among policymakers. It is certain that climate change will increase water demand and will put global freshwater resources under pressure. As climate change is inevitable, the sustainable management of water resources is essential in order to adapt to changing scenarios. A review has been carried out in this paper, summarising the possible impacts of climate change on water demands as well as identifying the best water management strategy for mitigating the negative impacts of climate and socio-economic changes on growing water demands and of consequent water stress.

The study reveals that there will likely be an increase in water demand in all sectors due to climate change. Water demand is likely to increase in agriculture primarily due to an increase in irrigation demand, while in industry it will increase in order to meet an increasing need for cooling water, and in domestic and ecological sectors it will increase due to higher water needs resulting from higher temperatures. However, the impact of climate change on water demand is projected to be more significant in agriculture than it will be in other sectors. The world's population is expected to reach more than 9.6 billion people by 2050, and food production must be increased by 70 % in order to feed the growing population (United Nations 2013; FAO 2009). It can be anticipated from present trends that a major part of the supplementary food will come from irrigated agriculture. This means that increased irrigation demand due to climate change might have severe implications for water resources, especially in regions already under water stress.

Business-as-usual strategies manage water resources without considering possible future circumstances; therefore, they will not be able to adapt to the negative impacts posed by climate change. It will not be possible to meet the increasing demand using supply augmentations alone, as potential sources of water are limited. Water demand management alone will also be unable to reduce demand that has increased due to climate change and socio-economic development. Therefore, the present study proposes a framework for a water management system that combines water demand and water supply management strategies, with an aim of creating a system that is more able to adapt to changing states of water balance, due not only to climate change but also to rapid growths in populations and economies. Furthermore, having multiple strategy options available is likely to improve the capability of a water management system to deal with the uncertainties in a changing environment.

Future studies can be carried out in order to gain more insight into climate change impacts on water demand. The impacts of other climatic variables such as sunshine duration, relative humidity, wind speed, etc. on water demand can be studied for the purpose of gaining more insight into changing states of water balance. Most of the studies that have been carried out so far have focused on future water demand without considering the impact of uncertainties. Further research can be carried out which would quantify the uncertainty of water demand due to climate change. Changes in water balance depend on the combined effects of many factors. Therefore, the impacts of climate change must be considered in combination with potential future socio-economic impacts, including future changes in infrastructure, land use, technology and human behaviour. Extreme weather events (such as drought or flood) will have considerable impacts on future water demand; therefore, the impacts of extreme events and resulting changes on water demand are very important to understand. Finally, as both water demand and water supply management strategies are essential components of any adaption to future scenarios, more research focusing on the field implementations of these strategies within different geographical regions is necessary.

Acknowledgments We are grateful to the National Natural Science Foundation of China (No. 51309155), the National Basic Research Program of China (No. 2010CB951104 and 2010CB951103), the China Postdoctoral Science Foundation (No. 2013 M530027), the Central Public-interest Scientific Institution Basal Research Fund (No. Y513004), the Open Research Fund of State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin (China Institute of Water Resources and Hydropower Research Project No. IWHR-SKL-201212) and the Asia-Pacific Network for Global Change (Grant No. ARCP2013-25NSY-Shahid) for providing financial support for this research. We are also thankful to anonymous reviewers and editors for their helpful comments and suggestions.

References

Abu-Taleb MF (2000) Impacts of global climate change scenarios on water supply and demand in Jordan. Water Int 25(3):457–463
Adamowski JF (2008) Peak daily water demand forecast modeling using artificial neural networks. J Water Res Plan 134(2):119–128
Ahamad MG, Khondker RK, Ahmed ZU, Tanin F (2013) Seasonal food insecurity in Bangladesh: evidences from northern areas. Mitig Adapt Strateg Glob Chang 18(7):1077–1088
Akhtar M, Ahmad N, Booij MJ (2008) The impact of climate change on the water resources of Hindukush-Karakorum-Himalaya region under different glacier coverage scenarios. J Hydrol 355:148–163
Alaa HA, Nisai W (2004) Short-term forecasting for urban water consumption. J Water Res Plan 130(5):405–410
Allan C, Xia J, Pahl-Wostl C (2013) Climate change and water security: challenges for adaptive water management. Curr Opin Environ Sustain 5(6):625–632
Altukaynak AS, Özger M, Çakmakci M (2005) Water consumption prediction of Istanbul city by using fuzzy logic approach. Water Resour Manag 19:641–654
Alvisi S, Franchini M, Marinelli A (2003) A stochastic model for representing drinking water demand at residential level. Water Resour Manag 17:197–222
Anseeuw W, Alden Wily L, Cotula L, Taylor M (2012) Land rights and the rush for land: findings of the global Commercial Pressures on Land research project. ILC, Rome, p 72
Arnell NW (1999) Climate change and global water resources. Glob Environ Chang 9:31–50
Ashour EK, Al-Najar A (2013) The impact of climate change and soil salinity in irrigation water demand on the Gaza Strip. J Water Clim Chang 4(2):118–130
Averyt K, Fisher J, Huber-Lee A, Lewis A, Macknick J, Madden N, Rogers J, Tellinghuisen S (2011) Freshwater use by U.S. power plants: electricity's thirst for a precious resource. A report of the Energy and Water in a Warming World initiative. Union of Concerned Scientists, Cambridge, MA
Babel MS, Das Gupta A, Pradhan PA (2007) Multivariate econometric approach for domestic water demand modeling: an application to Kathmandu, Nepal. Water Resour Manag 21:573–589
Barron O, Silberstein R, Ali R, Donohue R, McFarlane DJ, Davies P (2012) Climate change effects on water-dependent ecosystems in south-western Australia. J Hydrol 434:95–109
Bates BC, Kundzewicz ZW, Wu S (2008) Climate change and water demands. Intergovernmental Panel on Climate Change, Geneva
Belton V, Miller KA (2014) Water resource management and climate change adaptation: a holistic and multiple criteria perspective. Mitig Adapt Strateg Glob Chang. doi:10.1007/s11027-013-9537-0
Bhatia R, Falkenmark M (1992) Water resource policies and the urban poor: innovative approaches and policy imperatives. Background paper for the ICWE, Dublin, 26–31 January 1992
Bhatia R, Cestti R, Winpenny J (1995) Water conservation and reallocation: best practice cases in improving economic efficiency and environmental quality, A World Bank-ODI joint study. The World Bank, Washington, DC
Blignaut J, van Heerden J (2009) The impact of water scarcity on economic development initiatives. Water SA 35(4):415–420
Blokker EJM, Vreeburg JHG, van Dijk JC (2009) Simulating residential water demand with a stochastic end-use model. J Water Res Plan 136(2):19–26
Bougadis J, Adamowski K, Diduch R (2005) Short-term municipal water demand forecasting. Hydrol Process 19(1):137–148
Brooks DB (2006) An operational definition of water demand management. Water Resour Dev 22(4):521–528
Brumbelow K, Georgakakos A (2001) An assessment of irrigation needs and crop yield for the United States under potential climate changes. J Geophys Res Atmos 106:27383–27405
Butler D, Memon FA (2006) Water demand management. IWA Publishing, London
Caiado J (2010) Performance of combined double seasonal univariate time series models for forecasting water demand. J Hydrol Eng 15(3):215–222
Chen YN, Xu ZX (2005) Plausible impact of global climate change on water resources in the Tarim River basin. Sci China Ser D, Earth Sci 48(1):65–73

de Silva CS, Weatherhead EK, Knox JW, Rodriguez-Diaz JA (2007) Predicting the impacts of climate change—a case study of paddy irrigation water requirements in Sri Lanka. Agr Water Manag 93(1):19–29
Döll P (2002) Impact of climate change and variability on irrigation requirements: a global perspective. Clim Chang 54:269–293
Downing TE, Butterfield RE, Edmonds B (2003) Climate change and the demand for water, Research report. Stockholm Environment Institute Oxford Office, Oxford
Elgaali E, Garcia LA, Ojima DS (2007) High resolution modeling of the regional impacts of climate change on irrigation water demand. Clim Chang 84:441–461
Elmahdi A, ElGafy I, Kheireldin K (2009) Global warming-water Shortage and Food Security future planning interaction, System Analysis Approach (WBFSM). WRM 2009. Water Resource Management, Malta, pp 9–11, Sept 2009
EUREAU (2009) Statistics overview on water and wastewater in Europe 2008, Brussels
Fang CL, Bao C, Huang JC (2007) Management implications to water resources constraint force on socioeconomic system in rapid urbanization: a case study of the Hexi Corridor, NW China. Water Resour Manag 21: 1613–1633
FAO (2009) How to feed the world in 2050, Proceedings of the expert meeting on how to feed the world in 2050. FAO Headquarters, Rome, pp 24–26, June 2009
Fischer G, Tubiello FN, van Velthuizen H (2007) Climate change impacts on irrigation water requirements: effects of mitigation, 1990–2080. Technol Forecast Soc 74:1083–1107
Förster H, Lilliestam J (2010) Modeling thermoelectric power generation in view of climate change. Reg Environ Chang 11:211–212
Frederick KD (1997) Adapting to climate impacts on the supply and demand for water. Clim Chang 37(1):141–156
Garcia VJ, Garcia-Bartual R, Cabrera E, Arregui F (2004) Stochastic model to evaluate residential water demands. J Water Res Plan 130(5):386–394
Ghiassi M, Zimbra DK, Saidane H (2008) Urban water demand forecasting with a dynamic artificial neural network model. J Water Res Plan 134(2):138–146
Global Water Partner (2012) Water demand management: the Mediterranean experience. Technical focus paper 1, Blue Plan and Global Water Partnership
Gowing J (2003) Food security for sub-Saharan Africa: does water scarcity limit the options? Land Use Water Resour Res 3:2.1–2.7
Graeser HJ (1958) Meter records in system planning. J Am Water Work Ass 50(11):1395–1402
Gutzler DS, Nims JS (2005) Interannual variability of water demand and summer climate in Albuquerque, New Mexico. J Appl Meteorol 44(12):1777–1787
Harlana SL, Yabikub ST, Larsenc L, Brazeld AJ (2009) Household water consumption in an arid city: affluence, affordance, and attitudes. Soc Nat Resour 22(8):691–709
Harte J, Torn MS, Chang FR, Feifarek B, Kinzig A, Shaw R, Shen K (1995) Global warming and soil microclimate: results from a meadow warming experiment. Eco Appl 5:132–150
Heiner M (2010) Power generation and water reuse – urgent, equal global priorities. http://www.spectrum.ieee.org/energy/environment/how-much-water-does-it-take-to-make-electricity
Herrington P (1996) Climate change and the demand for water. Department of the Environment, HMSO, London
Hu S, Liu C, Zheng H, Wang Z, Yu J (2012) Assessing the impacts of climate variability and human activities on streamflow in the water source area of Baiyangdian Lake. J Geogr Sci 22(5):895–905
IFPRI (2012) 2012 Global Hunger Index, chapter 3: sustainable food security under land, water, and energy stresses. International Food Policy Research Institute, Washington, DC
IPCC (2007) Climate change 2007: impacts, adaptation, and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge
IWMI (2007) Water for food, water for life: a comprehensive assessment of water management in agriculture. Earthscan, and Colombo, International Water Management Institute, London
Izaurralde RC, Rosenberg NJ, Brown RA (2003) Integrated assessment of Hadley Center (HadCM2) climate-change impacts on agricultural productivity and irrigation water supply in the conterminous United States: part II. Regional agricultural production in 2030 and 2095. Agric For Meteorol 1117:97–122
Jain A, Varshney AK, Joshi UC (2001) Short-term water demand forecast modelling at IIT Kanpur using artificial neural networks. Water Resour 15:299–321
Jakimavičius D, Kriaučiūnienė J (2013) The climate change impact on the water balance of the Curonian Lagoon. Water Resour 40(2):120–132
Jampanil D, Suttinon P, Nasu S, Koontanakulvong S (2012) Application of input–output table for future water resources management under policy and climate change in Thailand: Rayong Province case study. PAWEES

2012: International Conference on Challenges of Water & Environmental Management in Monsoon Asia, Royal Irrigation Department (Pakkred), Thailand, 27–29 Nov 2012

Jessberger C, Sindram M, Zimmer M (2011) Global warming induced water-cycle changes and industrial production—a scenario analysis for the upper Danube River basin. J Econ Stat 231(3):415–439

Ji X-B, Kang E-S, Chen R-S, Zhao W-Z, Xiao S-C, Jin B-W (2005) Analysis of water resources supply and demand and security of water resources development in irrigation regions of the middle reaches of the Haihe River basin, Northwest China. Agric Sci China 5(2):130–140

Ji Y, Chen L, Sun R (2012) Temporal and spatial variability of water supply stress in the Haihe River basin, northern China. J Am Water Resour Assoc 48(5):999–1007

Karamouz M, Zahmatkesh Z, Nazif S (2011) Selecting a domestic water demand prediction model for climate change studies, Proceedings of the 2011 World Environmental and Water Resources Congress: Bearing Knowledge for Sustainability. Palm Springs, California, pp 1338–1346, May 22–26, 2011

Kenney DS, Goemans C, Klein R, Lowrey J, Reidy K (2008) Residential water demand management: lessons from Aurora, Colorado. J Am Water Resour Ass 44(1):192–207

Khan I, Chowdhury H, Alam F, Alam Q, Afrin S (2012) An investigation into the potential impacts of climate change on power generation in Bangladesh. J Sustain Energy E 3:103–110

Khatri KB, Vairavomoorty K (2009) Water demand forecasting for the city of the future against the uncertainties and the global change pressures: case of Birmingham. EWRI/ASCE 2009 Conference, Kansas City, Missouri, USA, 17–21 May 2009

Koch H, Vögele S (2009) Dynamic modeling of water demand, water availability and adaptation strategies for power plants to global change. Ecol Econ 68:2031–2039

Kundzewicz ZW, Mata LJ, Arnell NW, Döll P, Kabat P, Jiménez B, Miller KA, Oki T, Sen Z, Shiklomanov IA (2007) Freshwater resources and their management. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability. Cambridge University Press, Cambridge, UK, Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change, pp 173–210

Leipprand A, Dworak T, Benzle M (2008) Impacts of climate change on water resources: adaption strategies for Europe. Federal Environmental Agency, Sachsen

Linnerud K, Mideksa T, Eskeland G (2011) The impact of climate change on nuclear power supply. Energy J 32: 149–168

Lott C, Tchigriaeva E, Rollins K (2013) The effects of climate change on residential municipal water demand in Nevada. A technical report for the Nevada EPSCoR Project: vulnerability and resilience of urban water systems under a changing climate. http://epscorspo.nevada.edu/nsf/climate1/awards.html

Magini R, Pallavicini I, Guercio R (2008) Spatial and temporal scaling properties of water demand. J Water Res Plan 134(3):276–284

Maidment DR, Miaou SP, Crawford MM (1985) Transfer function models of daily urban water use. Water Resour Res 21(4):425–432

Middelkoop H, Daamen K, Gellens D (2001) Impact of climate change on hydrological regimes and water resources management in the Rhine basin. Clim Chang 49:105–128

Mikhwanazi M (2006) Assessment of climate change impacts on irrigation requirements and productivity of sugarcane in Swaziland. MSc thesis, Cranfield University, UK

Mote P, Canning D, Fluharty D, et al. (1999) Impacts of climate variability and change, Pacific Northwest. National Atmospheric and Oceanic Administration, Office of Global Programs, and JISAO/SMA Climate Impacts Group, Seattle, WA

Neale T, Carmichael J, Cohen S (2007) Urban water futures: a multivariate analysis of population growth and climate change impacts on urban water demand in the Okanagan basin, BC. Can Water Resour J 32(4):315–330

OECD (2012) The OECD environmental outlook to 2050: the consequences of inaction. OECD and the PBL Netherlands Environmental Assessment Agency

Pahl-Wostl C (2007) Transitions towards adaptive management of water facing climate and global change. Water Resour Manag 21(1):49–62

Pahl-Wostl C, Craps M, Dewulf A, Mostert E, Tabara D, Taillieu T (2007) Social learning and water resources management. Ecol Soc 12(2)

Pang JZ, Zhang ZZ (2001) Issues on rational allocation of water resources in Northern China and South–north water transfer. China Water Publishing House, Beijing

Parry M, Evans A, Rosegrant MW, Wheeler T (2009) Climate change and hunger: responding to the challenge. World Food Programme, Rome

Piniewski M, Laize CLR, Acreman MC, Okruszko T, Schneider C (2012) Effect of Climate Change on Environmental Flow Indicators in the Narew Basin. Poland J Environ Qual. doi:10.2135/jeq2011.0386

Pohle I, Koch H, Gruenewald U (2012) Potential climate change impacts on the water balance of subcatchments of the River Spree, Germany. Adv Geosci 32:49–53

Polebitski AS, Palmer RN, Waddell P (2011) Evaluating water demands under climate change and transitions in the urban environment. J Water Res Plan 137(3):249–257

Price JI, Chermak JM, Felardo J (2014) Low-flow appliances and household water demand: an evaluation of demand-side management policy in Albuquerque, New Mexico. J Environ Manag 133:37–44

Protopapas A, Katchamart S, Platonova A (2000) Weather Effects on Daily Water Use in New York City. J Hydraul Eng 5(3):332–338

Qadir M, Sharma BR, Bruggeman A, Choukr-Allah R, Karajeh F (2007) Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agric Water Manag 87:2–22

Razafindrabe BHN, Kada R, Arima M, Inoue S (2014) Analyzing flood risk and related impacts to urban communities in central Vietnam. Mitig Adapt Strateg Glob Chang 19(2):177–198

Ren LL, Wang MR, Li CH (2002) Impacts of human activity on river runoff in the northern area of China. J Hydro l261:204–217

Ringler C, Karelina Z, Pandya-Lorch R (2011) Emerging country strategies for improving food security: linkages and trade-offs for water and energy security. Bonn 2011 Conference: The Water, Energy, and Food Security Nexus, Bonn, Germany, 17 Nov 2011

Rodriguez Diaz JA, Weatherhead EK, Knox JW (2007) Climate change impacts on irrigation water requirements in the Guadalquivir River basin in Spain. Reg Environ Chang 7:149–159

Rosenzweig C, Strzepek KM, Major DC (2004) Water resources for agriculture in a changing climate: international case studies. Glob Environ Chang 14:345–360

Rübbelke D, Vögele S (2011) Impacts of climate change on European critical infrastructures: the case of the power sector. Environ Sci Policy 14:53–63

Safeeq M, Fares A (2012) Hydrologic response of a Hawaiian watershed to future climate change scenarios. Hydrol Process 26:2745–2764

Schewe J, Wada Y, Wisser D (2012) Future irrigation water demand under climate change: regional variability and uncertainties arising from GHMs and CMIP5 climate projections. AGU Fall Meeting 2012, San Francisco, 3–7 Dec 2012

Shahid S (2010) Recent trends in the climate of Bangladesh. Clim Res 42(3):185–193

Shahid S (2011) Impact of climate change on irrigation water demand of dry season Boro rice in northwest Bangladesh. Clim Chang 105(3–4):433–453

Shahid S, Hazarika MK (2010) Groundwater droughts in the northwestern districts of Bangladesh. Water Resour Manag 24(10):1989–2006

Shahid S, Harun S, Katimon A (2012) Changes in diurnal temperature range in Bangladesh during the time period 1961–2008. Atmos Res 118:260–270

Shiklomanov IA, Rodda JC (2003) World water resources at the beginning of the 21st century. Cambridge University Press, Cambridge

Spears M, Harrison A, Sankovich V, Gangopadhyay S (2013) Literature synthesis on climate change implications for water and environmental resources. Technical Memorandum 86-68210-2013-06, U.S. Department of the Interior Bureau of Reclamation

ten Brinke WBM, Kolen B, Dollee A, van Waveren H, Wouters CAH (2010) Contingency planning for large-scale floods in the Netherlands. J Conting Crisis Manag 18(1):55–69

United Nations (2005) Good practices on strategic planning and management of water resources in Asia and the Pacific. United Nations Publications

United Nations (2013) World population prospects: the 2012 revision: highlights and advance tables. Department of Economic and Social Affairs, Population Division, United Nations, New York

van der Voorn T, Pahl-Wostl C, Quist J (2012) Combining backcasting and adaptive management for climate adaptation in coastal regions: a methodology and a South African case study. Futures 44: 346–364

Vörösmarty CJ, Douglas EM, Green PA, Revenga C (2005) Geospatial indicators of emerging water stress: an application to Africa. Ambio 34(3):230–236

Wada Y, Wisser D, Eisner S, Flörke M, Gerten D, Haddeland I, Hanasaki N, Masaki Y, Portmann F, Stacke T, Tessler Z, Schewe J (2013) Multimodel projections and uncertainties of irrigation water demand under climate change. Geophys Res Lett 40(17):4626–4632

Wang X-J, Zhang J-Y, Wang G (2010) Climate change and water management adaptation for China. Xth Kovacs Colloquium, Paris, France. IAHS-AISH, pp 258–259

Wang X-J, Zhang J-Y, He R, Amgad E, Sondoss E, Shang M (2011) A strategy to deal with water crisis under climate change for mainstream in the middle reaches of Yellow River. Mitig Adapt Strateg Glob Chang 16(5):555–566
Wang X-J, Zhang J-Y, Shahid S et al (2012a) Catastrophe theory to assess water security and adaptation strategy in the context of environmental change. Mitig Adapt Strateg Glob Chang. doi:10.1007/s11027-012-9443-x
Wang X-J, Zhang J-Y, Shahid S et al (2012b) Gini coefficient to assess equity in domestic water supply in the Yellow River. Mitig Adapt Strateg Glob Chang 17(1):65–75
Wang X-J, Zhang J-Y, Shahid S et al (2012c) Potential impact of climate change on future water demand in Yulin city, Northwest China. Mitig Adapt Strateg Glob Chang. doi:10.1007/s11027-013-9476-9
Wang X-J, Zhang J-Y, Shahid S et al (2012d) Water resources management strategy for adaptation to droughts in China. Mitig Adapt Strateg Glob Chang 17(8):923–937
Wang X-J, Zhang J-Y, Yang Z-F et al (2013) Historic water consumptions and future management strategies for Haihe River basin of Northern China. Mitig Adapt Strateg Glob Chang. doi:10.1007/s11027-013-9496-5
Wang X-J, Zhang J-Y, Wang J-H et al (2014) Climate change and water resources management in Tuwei River basin of Northwest China. Mitig Adapt Strateg Glob Chang 19(1):107–120
Wiley MW, Palmer RN (2008) Estimating the impacts and uncertainty of climate change on a municipal water supply system. J Water Res Plan 134(3):239–246
Wu B (2010) Ecological change detection using remote sensing in Hai Basin of China. Sino-French seminar on Biodiversity and management of natural resources 5–6 October 2010. http://www.cnrs.fr/inee/relationsinternationales/docs/WUBingfang_ SFseminarweb.pdf
Wu GH, Liu DW, Cong LM (2007) Management of water resources and water environment of Haihe River basin. Water Resour Prot 23(6):80–84
Xiao J, Shen Y (2008) Landscape pattern change and associated environmental implications in Haihe River basin, China. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol XXXVII part B4, Beijing
Yang H (2002) Water, environment and food security: a case study of the Haihe River basin in China. http://www.rioc.org/wwf/Water_in_China_Haihe.pdf
Yang B, Zhiyun O, Hua Z, Weihua X, Cheng Z, Changwei Z, Shuai C, Bo J (2010) Ecosystems patterns and dynamics in Haihe River basin. Acta Ecol Sin 30:327–334
Yano T, Koriyama M, Haraguchi T (2005) Prediction of future change of water demand following global warming in the Cukurova region of Turkey. In: Proceedings of the International Conference on Water, Land and Food Security in Arid and Semi-Arid Regions, Mediterranean Agronomic Institute Valenzano (CIHEAM-MAIB), Bari, Italy, 6–11 Sept 2005
Yano T, Aydin M, Haraguchi T (2007) Impact of climate change on irrigation demand and crop growth in a Mediterranean environment of Turkey. Sensors 7:2297–2315
Zachariadis T (2010) Residential water scarcity in Cyprus: impact of climate change and policy options. Water 2(4):788–814
Zhang L, Ma ZM, Kang SZ (2008) Analysis of impacts of climate variability and human activity on stream flow for a river basin in arid region of Northwest China. J Hydrol 352:239–249
Zhong P, Yang Z, Cui B, Liu J (2008) Eco-environmental water demands for the Baiyangdian wetland. Front Env Sci Eng China 2(1):73–80
Zhou SL, McMahon TA, Walton A, Lewis J (2000) Forecasting daily urban water demand: a case study of Melbourne. J Hydro l236:153–164