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Impacts of climate change on the municipal water management system in the Kingdom of Bahrain: Vulnerability assessment and adaptation options

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ABSTRACT

An assessment of the vulnerability of the municipal water management system to the impacts of climate change in the Kingdom of Bahrain, manifested by the increase in demands due to increase in temperatures, is conducted using a dynamic mathematical model representing the water sector in the kingdom. The model is developed using WEAP software and was calibrated and validated by historical matching utilizing data for the period 2000–2012. The model is used in the evaluation of the municipal water sector performance in terms of municipal water demands and their associated cost without and with climate change impacts scenarios for the period 2012–2030. The impact of climate change on the municipal water system is quantified as the difference between the two scenarios in three selected cost indicators: financial (production, conveyance and distribution costs), economic (natural gas asset consumption by desalination plants), and environmental (CO2 emissions by desalination plants). The vulnerability assessment indicated that the current municipal water management system in Bahrain is generally inefficient and associated with relatively high costs, which are expected to increase with time under the current policies and management approach focusing on supply-side management. The increase in temperature will increase these already high costs, and would exacerbate the water management challenges in Bahrain. However, these mounting challenges also present an opportune moment for Bahrain to review its current water resources management approaches and practices and to integrate climate change adaptation measures into its water planning and policies. In order to build an adaptive management capacity of the municipal water management system in Bahrain, a number of management interventions are proposed and evaluated, individually and combined, for their effectiveness in enhancing the efficiency of the management system using the developed dynamic model. These are: reduction of the leakage percentage in the municipal water distributions network and reducing per capita water consumption by raising water awareness among consumers and installing water saving devices in residential units. The evaluation results indicate that there is a large potential for reducing the municipal water demand and its associated cost, especially when all the three are combined; by the year 2030 it is estimated that the cumulative financial saving would be about US$ 2.9 Billion, the cumulative reduction in CO2 emission would be about 19.7 Million tons, and the preservation of the kingdom's limited natural gas reserves would be about 4 Billion m^3. In addition, a major reduction in desalination brine discharge to the marine environment and reduction of generated wastewater and their associated collection and treatment cost could be achieved from the implementation of these interventions. Adopting such management interventions will not only enhance the efficiency of the municipal water management system, but it will also help the Kingdom in its efforts in reducing its

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greenhouse gasses emissions. It is recommended that similar climate change vulnerability and adaptation analysis is extended to the whole water sector in Bahrain to include other major water consuming sectors (i.e., agricultural, industrial, and tourism sectors) and their sources of water (i.e., groundwater and wastewater) in Bahrain.

1. Introduction

Situated in one of the most arid regions of the world, the Kingdom of Bahrain has an extremely poor endowment of water resources. Taking population into consideration under this climatic setting, the kingdom has one of the lowest per capita freshwater availability in the world, and is considered one of the world's most water-stressed countries; due to rapid population growth per capita freshwater share has been continuously declining from 525 m^3/yr in 1970 to less than 100 m^3/yr in 2010, which is much less than the absolute water poverty line of 500 m^3/capita/yr (Fig. 1). Worse still, and without taking into account the future impacts of climate change, the per capita freshwater availability could fall by more than half in the next two decades if Bahrain current population trends continue.

Like most of the other Gulf Cooperation Council States, Bahrain has experienced an accelerated socio-economic development growth since the mid 1970s. This occurred as a direct result of the sudden increase in the country's oil revenues, which led to fast increase in its economic base and an improvement in its population's living standards, resulting in a rapid increase in the country's population. A significant portion of the oil revenues has been used to modernize infrastructure and improve the living standards of the population; water supply and sanitation services have been made accessible to a large percentage of the population, and now have reached commendable levels of almost 100% and more than 95% in these two categories, respectively (WHO and UNICEF, 2014).

To meet rising demands, water authorities have focused their efforts mainly on the development and supply augmentation aspects of water resources management. Sectoral water demands are being satisfied by groundwater abstraction, installation of desalination plants, and expansion in wastewater treatment and reuse. These efforts, particularly the expansion in desalination plants, though at a significant cost, have improved the per capita water share considerably (Fig. 1). However, the adoption of the supply augmentation approach without giving adequate attention to the aspects of demand management, efficient use, and conservation have led to the emergence of a number of unsustainable water uses, such as low water use efficiency, growing of per capita water use, escalating sectoral water demands, deterioration of groundwater quality, and an overall increase in the costs of water production and distribution. Under such conditions, the heavy financial, economic, and environmental costs, as well as social costs and burden to be borne cannot be overemphasized.

If these current trends continue without management interventions, these costs are expected to increase in the future due to many pressing drivers, including sustained population and urbanization growth, changing lifestyle and consumption patterns, increasing food demand, prevailing general subsidy system, and many other drivers. These drivers will be forcing the water authorities in Bahrain into more expensive and costly investments in water supply sources and infrastructures, which are represented mainly by desalination, wastewater treatment and reuse, and groundwater over-abstraction and mining to meet spiraling water demands.

Moreover, located in an arid region it is expected that climate change, represented by the increase in temperatures, sea level rise, and increased frequency of extreme events, would further aggravate the water scarcity-related challenges and would add additional pressures on the currently stressed water management system in Bahrain (Bates et al., 2008; GCPMREW, 2005; PCPMREW, 2012). Therefore, it is imperative that Bahrain considers the potential impacts of climate change in its water resources planning and management process by integrating appropriate adaptation measures, particularly those related to demand management, conservation and water efficiency.

The anticipated direct and indirect impacts of climate change on water resources and water utilization in Bahrain are many, the most important of which are: increasing water demands in the municipal and agricultural sectors due to increasing temperature, seawater intrusion to groundwater due to sea level rise, less groundwater recharge due to decrease in rainfall, impact on inlets and

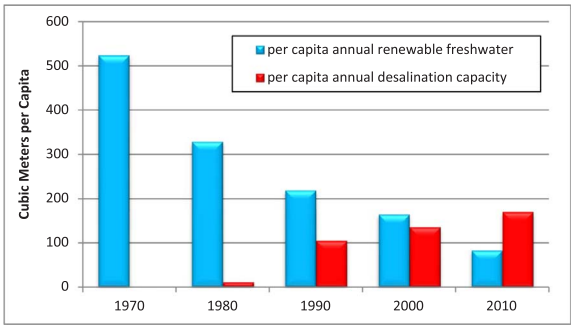

Fig. 1. Trends of availability of annual per capita renewable freshwater and desalination capacity in Bahrain, 1970–2010. Note: a value of 500 m^3/capita/year, i.e., absolute water poverty level, implies that water becomes a major constraint for development affecting the standard of living, health, and the environment (Falkenmark, 1989).