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Evaluation of desalination and other strategic management options using multi-criteria decision analysis in Kuwait

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ABSTRACT

Water is essential to life sustainability and the development of industry and agriculture in Kuwait. Kuwait is faced with water shortages, because of the scarcity of the natural water resources; well-developed supply infrastructure; and the practice of expanding irrigated agriculture and industrialization. This paper describes how to evaluate different management options and policies on the strategic level that can lead to secure and sustainable water resources management in the future for all water users in Kuwait. Possible interventions/management options are identified and evaluated using a decision- support tool based on a multi-criteria decision analysis (MCDA) methodology. This paper is the first of its kind to use trade-off between different management options and strategic policies in Kuwait. The results showed that desalination using renewable energy technologies was ranked highly, despite its economic cost and environmental impact but there is also a need to implement widely other options. Wastewater Reuse for agriculture was ranked first overall in the MCDA. Most brackish water supply to the agricultural sector should be replaced by treated wastewater. Other options such as virtual water, water demand management and changes in agricultural policies should be prioritized because of their socio-economic and environmental benefits.

1. Introduction

Ensuring the availability of reliable water resources and the use of good quality water without threatening the public health in Kuwait has become a critical issue. Kuwait is faced with water shortages, because of the scarcity of natural water resources, population growth, higher standards of living, lack of well-developed supply infrastructure, and practice of expanding irrigated agriculture and industrialization without a proper link between livelihood and water security. In addition to that the nonconventional water resources in Kuwait are fragile and expensive. In countries like Kuwait water resources sustainability and security are interrelated and the main concern for socio-economic development. Both water sustainability and security are about providing viable access to sufficient quantities of tolerable quality water for sustaining livelihoods and socioeconomic development while ensuring protection against pollution and preserving ecosystems [1]. In this paper, the emphasis is on how to develop and evaluate suitable policies and management options in response to the economic, environmental, financial, and cultural conditions in Kuwait in order to secure water supplies for the future and achieve sustainable water resources management.

Water shortages, if not met in a timely and sustainable manner, will inevitably have serious adverse effects on socioeconomic and commercial development [2]. Water sustainability is essential to the population of Kuwait for its people to live in a healthy and productive manner while maintaining the natural environment [3]. Water plays a fundamental role in the security of food and energy as well as in economic growth, maintaining health, and reducing poverty. The challenges of water sustainability in Kuwait were addressed by Al-Otaibi and Kotwicki [4]; and Al-Qunaibet and Johnston [5]. Kuwait is ranked among the world's highest consumers of domestic water, with per capita water use well above international standards [6,7]. There is an ever increasing demand for brackish groundwater for oil processing/injection into oil fields to maintain reservoir pressure. The sustainable exploitation of brackish groundwater has become recently an issue in Kuwait [8]. The rapid increase in oil field-produced polluted water caused by the maturity of oil production wells has become a major disposal/pollution problem threatening the groundwater environment in in the country. Sustainability of oil production, including enhanced oil recovery, poses new challenges, as ever larger quantities of processed water will be needed, and more polluted oil-field water will be produced [9]. In Kuwait, water produced from desalination plants is pumped to blending stations, to underground reservoirs, and then to networks and elevated towers as an efficient means of maximizing the benefits from desalinated water [10]. However, this imposes a heavy fiscal burden of water subsidies that is presently 5.9% of the oil export revenues and 2.4% of Kuwait's

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gross domestic product (GDP) (Table 1), which is projected to increase to 10% in the near future [9]. As an example, the subsidies of the Government of Kuwait for the water sector may reach US$4 billion per year in the near future [9]. This is because the construction and operating costs of desalination plants are very high [11]. Despite all the environmental problems associated with desalination, such as brine discharges and carbon dioxide emissions, high cost, and elevated consumption of energy, there is an ever increasing demand for desalinated water in Kuwait. It is expected that the production of desalinated water will increase by 75% above the current level in the near future [9]. Also, in Kuwait, agriculture consumes 60 to 90% of the groundwater produced and provides a low contribution to the GDP. This practice has led to the rapid depletion of aquifers, and raises the question of whether it would be better to import food and embedded 'virtual water', thus releasing groundwater for more strategic use.

The concept of 'virtual water' is not well-recognized in Kuwait. This concept is about trade in embedded water when food or other commodities are imported/exported from one country to another. The concept was introduced by Allan [12] to support the idea that countries like Kuwait can save their scarce water resources for more critical needs by relying more on imported food. The virtual water includes by definition quantity of water needed to produce and to process a commodity. For example, If 3500 l of water is used by a person in the UK, only 150 l is used within the home, the rest in embedded (hidden as virtual water) in food and goods consumed. The idea (for countries that lack natural water resources) is to import food with its hidden (impeded) water (which is a large percentage of water needs) and leave the rest to be supplied by local water resources. Later, Zubari [13] envisaged that Virtual Water Trade should be adopted as a Policy Instrument to contribute to food security in countries like Kuwait.

Also, the reuse of treated wastewater in irrigation is still low at only 36% ([9]. Al-Jarallah [14] highlighted the potential of using grey wastewater to enhance water security in Kuwait. In addition, the rate of unaccounted- for-water (UFW) such as leakages is high. The World Bank [15] reported the level of UFW in Kuwait as 40%. However, Azrag et al. [16] gave much lower values for UFW in freshwater networks in Kuwait. The high values of UFW and excessive wastes have led to rising groundwater tables in urban cities, threatening the stability of building foundations and roads [8]. The lack of implementation of the principles of Integrated Water Resources Management (IWRM), including weak institutions and weak operational services, makes the water sector of Kuwait far from being sustainable. Moreover, using desalination as the prime development and management solution also requires an investigation of what other solutions can be offered in meeting the future water needs of Kuwait, as the gap between total water demand and renewable natural water resources is still large [17]. When these other solutions are planned for, there is an imminent need to evaluate and compare these solutions from the socioeconomic and environmental-technical points of view. This issue is addressed in this paper.

It seems that Kuwait is producing water as much as it is consuming. According to the records of the Ministry of Electricity of Water [7] about 630 Mcm/yr is generated from desalination plants and 8 Mcm/yr is generated from groundwater resources as freshwater. All other quantities of groundwater (about 89 Mcm/yr) are produced as brackish and used for agriculture and oil industry. Kuwait receives some 160 Mcm/yr as recharging water from rainfall to the aquifers which mix with brackish to saline groundwater resources. Also, Kuwait generates some 110 treated wastewaters for greenery use. Kuwait produces some 120 Mcm/yr as Reverse Osmosis Treated Wastewater for crops agriculture. In summary water supplies and resources in Kuwait without desalination are not sustainable because of the scarcity of natural water resources and because of the high rate of water consumption that Kuwait enjoyed throughout the past few decades. The concept of meeting water deficits in Kuwait through desalination while groundwater resources continue to be used for low value agriculture will not be a strategic solution. The objective of this paper is to highlight and evaluate the related strategic solutions/policies that might be used to achieve integrated and sustainable development and management of the water sector in Kuwait. These solutions/policies, when evaluated from the socioeconomic and environmental-technical standpoints using the multi-criteria decision analysis (MCDA) methodology presented in this paper, will help identify how water sustainability and security in the domestic and agricultural sectors can be achieved. This paper is the first of its kind to use such methodology to trade-off between different management options and strategic policies in Kuwait.

The development of a water sustainability strategy for Kuwait follows a strategic vision that each citizen has the right to a sufficient quantity of water of a required quality at an affordable cost for the purpose of use. However, when water resources are being developed, then the larger ecological system needs to be conserved. Water therefore has socioeconomic and environmental values.

Table 1
Water subsidies in the GCC countries (El-Sayed et al., [9]).

Country	Produced desalinated water (Mcm/yr)[a]	Cost ($/m^3)	Revenue ($/m^3)	Subsidies		
				1×10^6 ($)	% of GDP	% of oil export revenues
Kuwait	520	1.98	0.19	832	2.4	5.9
Saudi Arabia	2500	1.35	0.08	3175	1.7	7
UAE	831	1.16	0.13	856	1.2	2.1
Qatar	132	1.31	0.42	117	0.7	1.3
Bahrain	115	0.65	0.17	55	0.7	1.4
Oman	169	1.34	0.84	85	0.4	1.1

[a] Mcm/yr: million cubic meter per year.

2. Desalination in Kuwait

Kuwait over the past half century has been fully dependent on the conventional steam -boiler-turbine-generator (SBTG) and the multi-stage flash (MSF) seawater desalination technologies for the supply of its needs for electricity and freshwater. This so-called cogeneration scheme was encouraged by the immediate availability of fossil fuel oils and the direct easy access to the Gulf seawater. This scheme helped Kuwait to grow and expand in different ways at different levels to continuously improve the standard of living for its people. The downside of this situation is the reckless attitude towards the natural resources (specifically, fossil fuel oils) and the environment as well as the irrational consumption of electricity and water. The latter may be attributed mainly to the lack of appropriate policies, sound codes of practice and proper decisions by the governing and legislative bodies in a way that would reward conservation and safeguard against misuse of such resources. Only lately; however, soaring fuel prices and rising concerns over global climate changes and increased atmospheric pollution made it impossible to continue turning a blind eye to this situation. On the supply side, the Ministry of Electricity and Water (MEW) has already started modernizing its technology base. Since 2005, projects for major power generation installations based on the open cycle gas turbine (OCGT) and the combined cycle gas turbine (CCGT) have either been completed or moving ahead. Construction of the first seawater reverse osmosis (RO) plant is already in progress. Furthermore, blueprints for construction of new mega capacity power generation and water desalination plants based on better and more efficient technologies continue to evolve. Prospects for adoption of alternative-energy-based power generation and water desalination technologies have better chances than ever.

Meanwhile; on the demand side, MEW conducted massive public campaign over the past few years aiming to create a culture of partnership with the consumers for the sake of encouraging and stimulating conservation of electricity and water. The last strategic aspect where MEW needed to work on in order to deal with the downside of the