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Domestic water demand in Saudi Arabia: assessment of desalinated water as strategic supply source

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ABSTRACT

Kingdom of Saudi Arabia (KSA) is the largest desalinated water producer in the world, and it currently produces about one-fifth of the world productions. KSA government considers seawater desalination as the strategic option to alleviate water scarcity problem, and to meet the country's ever-growing domestic water demand. This research reviews the KSA desalination industry performance since inception to date; forecasts desalination water demand up to year 2040 in the context of three scenarios optimistic, moderate, and pessimistic; discusses the future of desalination industry as a strategic domestic water supply source and highlights its challenges. Results show that KSA will need about 2.0, 3.2, and 4.5 billion m^3/year of desalinated water in the year 2040 based on optimistic, moderate, and pessimistic scenarios, respectively. The review of Saudi initiatives shows that KSA government effectively considered seawater desalination as strategic option, and implemented a comprehensive set of initiatives to realize this option. Moreover, the on-going desalination industry initiatives, coupled with some improvements, will satisfy the desalinated water demand on short-term basis. However, the long-term ability of desalination industry to meet the ever-increasing domestic water demand remains a valid concern, especially, if the moderate or pessimistic scenario is realized.

Keywords: Desalination; Saudi Arabia; Water demand; Water supply; Scenarios; Forecast

1. Introduction

Water scarcity in the Middle East region is a well-known and alarming problem. Rainfall is well below the world average, and 87% of the region is a desert [1]. This region faced water scarcity problems since early 1970s [2]. The average person in the Middle East accesses one-eighth of the renewable water that an average global citizen enjoys. Additionally, 14 of the world's 20 most water-stressed countries are located in the Middle East [1]. Many countries are unable to achieve food self-sufficiency using renewable water resources [3]. National governments and research institutions are increasingly concerned about water scarcity that is threatening the economic development and political stability of many parts of the Middle East [4–8]. The Gulf Cooperation Council (GCC) countries, including the Kingdom of Saudi Arabia (KSA), are located in the driest spot of the Middle East. Furthermore, all GCC countries except Oman figure in the 20 most water-stressed countries in the world [1,9,10]. Urbanization, population, standards of living growth, and climate change exacerbate the region's natural water scarcity, and widen the gap between supply and demand [11]. KSA is located in arid to semi-arid area, and occupies about 70% of the Arabian Peninsula with very limited water resources [12–14]. The country has an average yearly rainfall of about 100 mm [14–17]. The annual per capita water share from natural water resources was about 188 m^3 in 2010, whilst the average water a consumer used is about 650 m^3 per year [18]. This fact puts the country far below the World Health Organization threshold for severe water scarcity of 500 m^3 per year [1]. The water demand exceeds the sustainable yields of conventional and non-conventional water resources in the country [15,17]. The gap between sustainable water resource yields versus total demand was about 11.5 billion m^3 in 2010, and was historically bridged through groundwater resources depletion [15]. KSA population grew from about 7 million to about 27 million in the last 40 years with an average growth rate of 3.4%, whilst urbanization level increased from about 50 to 80% of total population in the same period [19]. The high crude oil revenue since early 1970s has resulted in widespread development and better standards of living [5,6,15]. In 2012, KSA produced about 955 million m^3 of desalinated water which constitutes about 18% of the world desalinated water production [20–23]. KSA government considered seawater desalination as strategic option to meet the growing domestic water demand in the country [21]. This option has rarely been scientifically studied or evaluated. This research reviews the KSA desalination industry performance since inception to date; forecasts desalination water demand up to year 2040 in the context of three scenarios optimistic, moderate, and pessimistic; discusses the future of desalination industry as a strategic domestic water supply source and highlights challenges.

2. Water resources

KSA has an extreme desert environment and very limited natural water resources. Groundwater is the main natural water resource in KSA, and the country does not have surface water sources such as rivers or lakes [14,24–26]. KSA utilizes two conventional and two non-conventional water resources to satisfy expanding domestic, industrial, and agricultural water demands. Conventional sources include groundwater and surface water, whilst non-conventional sources include treated wastewater and desalinated seawater [15]. In the following sub-sections, the status of the four resources will be presented with emphasis on seawater desalination.

2.1. Groundwater system

The groundwater aquifer system consists of deep rock non-renewable and shallow alluvial renewable aquifers [15,27]. The deep rock aquifers are sedimentary in origin and include at least seven non-renewable aquifers, which extend from the northern boundary southwards to the Empty Quarter, and eastwards from the central area to the Arabian Gulf [6,15,27]. The aquifer's water is generally brackish with total dissolved solid values range from 300 to more than 10,000 ppm. Isotopic analysis showed that the non-renewable groundwater in the upper aquifers is 10,000–32,000 years old [28]. The renewable groundwater system consists of shallow alluvial aquifers located mostly in the mountainous south-western and western regions. They recharge from the infiltration of the annual orographic rainfall in the coastal mountains and exist under major valleys within the coastal mountains [4,15,18]. The renewable aquifer water quality is potable and the water is utilized for domestic, industrial, and agricultural purposes [15,28,29]. The groundwater system annual recharge rate is estimated to be 3.85 billion m^3 [4,15,18,28]. Literature documented a wide range of values for the total groundwater reserves in KSA from about 259 billion m^3 to about 760 billion m^3 [12,27,30–33].

2.2. Surface water

The country's average yearly rainfall is less than 100 mm with an occasional maximum annual rainfall of 550 mm in the south-western region [4,6,14,15,18,33–35]. The average evaporation rate ranges from about 2,500 mm/year in the eastern and western coastal areas to about 4,500 mm/year in the central parts of the country [28]. The only surface water bodies in Saudi Arabia are intermittent flash floods in valleys, which run following heavy rainfall events in the months of November to April [24,28]. The run-off flow rate ranges from 2 to 2,400 million m^3/year and is governed by rainfall patterns and land surface topography [14,28]. The number of surface water regulation dams has increased from 210 to 302 from the year 2004– 2009 [28]. Dams holding capacities increased from 0.8 to 2.3 billion m^3/year during the same period [28,35,36]. The KSA government is planning to increase surface water dams holding capacity to 2.5 billion m^3/year by the end of year 2014 [36]. If achieved, the surface water run-off will be completely regulated, and the captured surface water will be used for the irrigation purposes.

2.3. Treated wastewater

Wastewater system currently services about 42% of KSA's urban areas, and the government is planning to increase its coverage to about 60% by the end of 2014

[36,37] and to 100% for every city with population above 5,000 by the year 2025 [13]. Septic tanks and cesspools are currently utilized by residents in areas not covered by wastewater collection system for wastewater disposal [29]. In 2010, wastewater generation rate was about 2 billion m^3/year, 51% was discharged via septic tanks and cesspools, 16% was collected but not treated, 33% was treated, and 12% was reused [13,36,38]. KSA existing wastewater treatment plants have treatment capacity of about 730 million m^3/year [37]. In 2010, about 240 million m^3/year of treated wastewater was used for urban area landscape and municipal parks irrigation. KSA government is planning to increase treated wastewater reuse to a 400 million m^3/year by the end of 2014 [36].

2.4. Desalinated water

2.4.1. Desalination background

Desalination of seawater is currently practiced in many countries that have water scarcity problem across the globe. The KSA experience with seawater desalination can be traced back to early 1900s with the coal-fired water distillation unit of a capacity of 300 m^3/d that was operated in Jeddah city on the Red Sea coast by non-governmental organization [21]. The first formal step in establishing the desalination industry in KSA's occurred when KSA's founder, the late King Abdulaziz, ordered the importation of two distillation condensers with a capacity 135 m^3/d each to relieve the problem of water shortage in Jeddah city especially during the Hajj (pilgrimage) season. The two condensers were installed and operated in the year 1926 [28,39]. The successful operation of the two condensers encouraged the KSA government to install more units in Yanbu and Jazan coastal cities. The first Desalination Directorate was established in 1940 with mandate to manage the condensers operation in accordance with the approved regulations. The mandate gave the Desalination Directorate the right to supply distilled water, sell it, collect payments, and install special meters to measure the quantity of desalinated water, and store it in dedicated tank storage [28,39]. The initial step toward modern desalination industry was initiated with the Royal Decree No. 360 in 1965 that gave the Minister of Agriculture and Water the authority to develop plans and construct desalination plants in the Eastern Province and in Jeddah city. Additionally, an agreement was signed with the USA to support the KSA seawater desalination in the same year [28,39]. The General Directorate of Saline Water Conversion Corporation (SWCC) was established in 1966 as part of Ministry of Agriculture and Water. The successful development of desalination projects has encouraged the Saudi government to declare desalination as strategic water supply option for the Kingdom in 1971. The 1974 Royal Decree No. R/49 has mandated the creation of SWCC as an independent public body. A governor was appointed for the Corporation and the Minister of Agriculture & Water was made chair of its board of directors. The charter of the corporation stated its objectives to construct more desalination plants whether single-purpose plants producing only desalinated water or cogeneration plants producing water and electric power. By early 1990's, the production of desalinated water in KSA increased more than a 100-fold [28,39].

2.4.2. Desalination industry present status

At present, KSA leads the production of desalinated water in the world and claims about 18% of the world production. About 50% of domestic water demand in KSA is supplied by desalination plants [20,21,40,41]. SWCC currently operates 30 publicly owned desalination plants located in the East and West coasts of KSA as listed in Table 1. Table 1 lists each plant's location, total annual production capacity, service area, date of commission, and designed end of life. It is worth to notice that 14 desalination plants, with a total production capacity of about 685 million m^3/year, have already reached their designed end of life. This condition raises concerns about the SWCC's ability to maintain the current level of desalinated water production without major investments in new plants development and maintain the existing ones. The total annual desalinated water production from the year 2000 to 2012 is presented by Fig. 1. The average desalinated water production was about one billion m^3/year, over the last decade. The figure shows a slight decline in annual production in the last two years which can be attributed to plant's aging. SWCC is operating a network of pumping stations, reservoirs and 4,400 km of pipes in diameters ranging from 300 to 2,000 mm to transport the water in bulk from the plants to the major in-land consumption centees, some of them located far in-land such as Riyadh and Maddina cities [20,21,37,40–44]. Desalinated water share for the major cities in KSA as per 2012 is presented in Fig. 2. Riyadh, the capital, and Jeddah, the commercial capital, consumed together about 45% of desalinated water production in 2012. The long-term average cost of desalinated water in KSA is about 0.8 US$/$m^3$ [20,40,41].

Table 1
Summary of desalination plants in Saudi Arabia

Plant	Location	Supply capacity (million m^3/year)	Plant total (million m^3/year)	Service area	Date of commission	End of life
Jubail 1	Jubail	42.23	368.31	Riyadh and Jubail	1982	2007
Jubail 2		297.54		Riyadh and Jubail	1983	2008
Jubail RO		28.54		Riyadh, Qassim, and Sudair	2000	2025
Khobar 2	Al-Khobar	70	157.89	Khobar, Dammam, qatif, Dhahran airport, Saihat, Safvi and Ras Tanura	1983	2008
Khobar 3		87.89		Khobar, Dammam, qatif, Dhahran airport, Saihat, Safvi, Ras Tanura, Abqaiq and Hofuf	2000	2025
Khafji	Khafji	7.18	7.18	Al-Khafji	1986	2011
Total east cost (million m^3/year)			533.38			
Jeddah 3	Jeddah	27.74	132.95	Jeddah	1979	2004
Jeddah 4		69.55		Jeddah	1982	2007
Jeddah RO1		17.83		Jeddah	1989	2014
Jeddah RO2		17.83		Jeddah	1994	2019
Shuaiba 1	Shauiba	70	212.68	Makkah and Taif	1989	2014
Shuaiba 2		142.68		Makkah, Jeddah and Taif	2001	2026
Yanbu 1	Yanbu	34.54	117.4	Yanbu, Medina and surrounding villages	1981	2006
Yanbu 2		43.84		Yanbu, Medina and surrounding villages	1998	2023
Yanbu RO		39.02		Yanbu, Medina and surrounding villages	1998	2023
Shuqaia	Shuqaia	30.45	30.45	Abha/Khais Mushait, Rafidah, military city, surrounding village	1989	2014
Haqi RO	Satellite	1.38	25.34	Field of surrounding villages	1990	2015
Duba RO		1.38		Duba and surrounding villages	1989	2014
Al Wajih		2.83		Face and surrounding villages	2009	2034
Umlujj		4.2		Troweland its villages	1986	2011
Rabigh		5.65		Rabigh and surrounding villages	1982	2007
Alazizia		1.41		Island Azizia	1987	2012
Farasan 1		2.83		Knights Island	1979	2004
Al Lith		2.83		Laith	2009	2034
Al-Qunfutha		2.83		Qunfudah, Al-Quoz-Costume	2008	2033
Total east cost (million m^3/year)			518.82			
Total SWCC (million m^3/year)			1,052.2			

Note: Adapted after [20,40,41].

3. Desalinated water demand forecast

KSA has experienced widespread development in all sectors coupled with high growth in standard of living since the last four decades. This development has resulted in rapid increase in domestic water demand. Domestic water demand has increased from 200 million m^3/year in 1970 to 2,063 million m^3/year in 2010 [15]. In 2010, domestic water needs were met by desalinated water (1,050 million m^3/year) and ground water (1,050 million m^3/year). The substantial increase in domestic water demand resulted from high annual population growth rate of about 3.4%, and urbanization level growth from 50 to 80% in the last four decades. The 2010 average domestic water consumption was around 205 litres per capita per day (LCD) [28]. Other literature reported higher averages ranging from 260 to 300 LCD for earlier years [4,5,45].

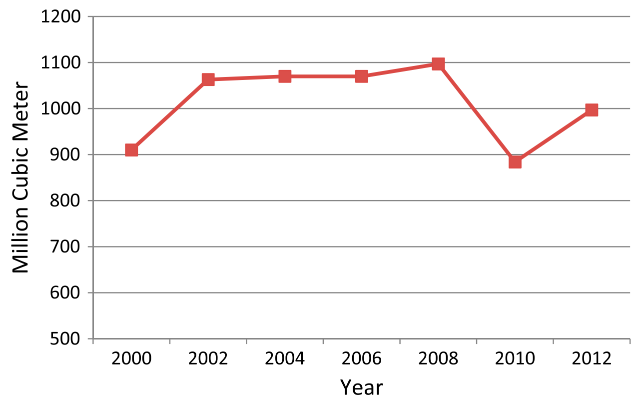


Fig. 1. Total annual desalinated water production [20,40,42,43,45].

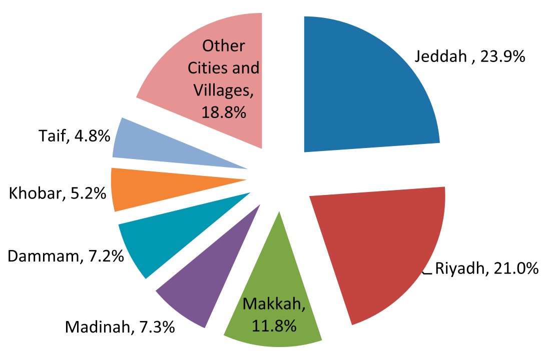


Fig. 2. Percentage distribution of water export to major cities in year 2012 [20].

The forecast of domestic water demand is highly dependent on population and standards of living, and per capita water demand growth.

3.1. Desalinated water demand forecast methodology

To forecast the future desalinated water demand three scenarios of domestic water demand were developed: optimistic, moderate, and pessimistic. The optimistic scenario was developed to match with the KSA government plan for the development of water sector as documented in the Saudi Ninth National Development Plan, 2010–2014 and the proposed national water strategy as presented in AlSaud [46]. The moderate scenario was based on comprehensive historical review of population, standards of living, and socioeconomic development growth trends. The scenario presents a midway between the government's optimistic vision of water demand development and the historical trend of water demand growth. The pessimistic scenario reflects the historical water demand trends over the last two decades to the future. Simply, the history repeats itself. The key assumptions for the three scenarios are presented in Table 2.

The year 2010 was considered as the starting year for scenarios developments. The population census conducted in 2010 and water demand and water resource yields information for 2010 are readily available from Saudi Ministry of Water and Electricity. The year 2040 was selected as the scenario's end of year. The optimistic scenario assumes an annual decrease in consumer water demand of 1% to reach about 150 LCD by the end of the forecast period. The moderate scenario assumes 0.5% diminishing rate, while the pessimistic scenario assumes no change on consumer water demand for the forecast period. The reduction of consumer water demand requires the implementation of intensive water demand management measures such as public awareness campaigns for water conservation, restructuring the current water tariffs system, and increasing the performance of the water distribution system. It has been assumed that 1,100 million m^3/year of groundwater will be readily available for domestic water supply during the forecasted period. This value is equal to groundwater contribution to domestic water demand in 2010. Any major change in this value is not an option, given the substantial gap of about 11.5 billion m^3/year between total demand and natural water resources availability. Additionally, in-land area in KSA, 400 km plus from coastal areas, will continue to depend on groundwater for domestic water supply due to high water transportation costs from coastal areas, and the agricultural water demand is mainly supplied by groundwater sources. The following formula was utilized to calculate the annual desalination water demand for the three scenarios.

$$\mathrm{DesWD_i} = \frac{\left(P_0(1+G_{\mathrm{D}})^{N_i}\right) \times \left(\mathrm{LCD}_0(1+G_{\mathrm{w}})^{N_i}\right) \times 365}{1,000} - \mathrm{GWS_i} \quad (1)$$

where $\mathrm{DesWD_i}$ is the desalinated water demand in the ith year in million m^3/year, P_0 is the 2010 population (start year) in million, N_i is the number of year in future from the start year, $G_{\mathrm{D}}$is the population growth rate %, LCD_0 is the consumer water demand at the start year (205 LCD)), $G_{\mathrm{w}}$is the consumer water demand growth rate %, and $\mathrm{GWS_i}$ is the groundwater supply in the ith year in million m^3/year.

Domestic water demand forecast is a sophisticated exercise that may influence by many factors like population growth, per capita water demand, climatic

Table 2
Forecast scenarios assumptions

No.	Assumption	Unit	Optimistic	Moderate	Pessimistic
1	Forecast start year	Year	2010	2010	2010
2	Forecast end year	Year	2040	2040	2040
3	Start year population	Million	27.6	27.6	27.6
4	Population growth rate	%	2.5	3.0	3.4
5	Consumer domestic water demand	LCD	205	205	205
6	Consumer water demand annual growth rate	%	−1	−0.5	0

change, change in technology, social behavior, and standards of living of the different classes of the population, water supply system performance, and water tariff. The proposed domestic water demand model considers the population growth model and per capita water demand as the key inputs for the forecast. This fact may impact the forecast accuracy of Eq. (1). The development of three scenarios aims to consider this uncertainty in the model accuracy and to give in-depth to the results. Additionally, considering these factors in the model will result in other sources of uncertainties to the forecast results. Accordingly, the proposed model satisfied the research objectives. Future research is highly recommended to develop a comprehensive model for domestic water demand forecast in the country.

3.2. Desalinated water demand forecast results

The population forecast for the three scenarios is presented in Fig. 3. The population is projected to increase by twofolds based on the optimistic scenario and three folds based on the pessimistic scenario. This is a substantial increase in population and surely expected by Saudi officials given that the demographic trend in the last four decades and the Saudi culture favoring large families. Currently, the average family size in KSA is about seven people [19].

The domestic water demand forecast results for the three scenarios are presented in Fig. 4, whilst the desalinated water demand forecast results are presented in Fig. 5. The optimistic scenario, if realized, shows a total domestic water demand of about 3.1 billion m^3/year and desalinated water demand of about 2.0 billion m^3/year in the year 2040. This amount is double the current production capacity of the existing desalination plants. The moderate scenario, if realized, shows a total domestic water demand of about 4.3 billion m^3/year in 2040 which is about two fold higher than the 2010 domestic water demand. Desalinated water demand based on the moderated scenario will be about 3.2 billion m^3/year in the year 2040. This amount is threefolds higher than the current production capacity of the existing desalination plants. The pessimistic scenario, if realized, shows a total domestic water demand of about 5.6 billion m^3/year in 2040 which is almost three folds higher than the 2010 domestic water demand. Desalinated water demand based on the pessimistic scenario will be

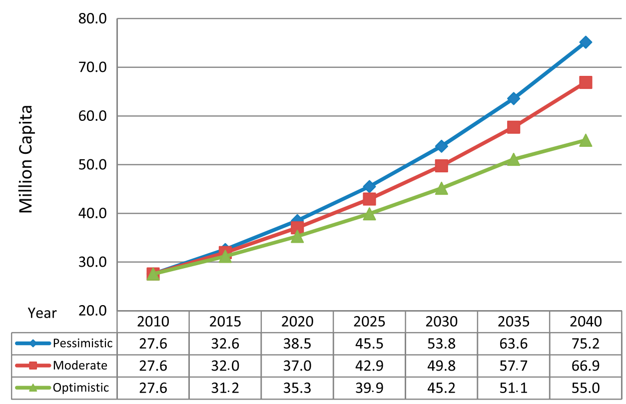


Fig. 3. Population forecast results.

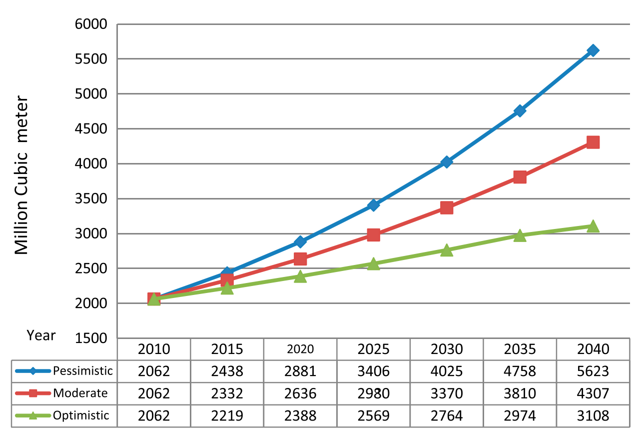
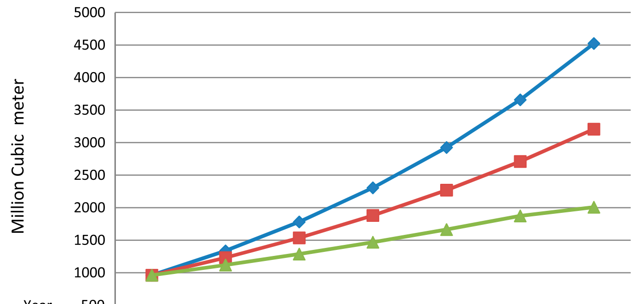


Fig. 4. Domestic water demand forecast results.



Year	2010	2015	2020	2025	2030	2035	2040
Pessimistic	962	1338	1781	2306	2925	3658	4523
Moderate	962	1232	1536	1880	2270	2710	3207
Optimistic	962	1119	1288	1469	1664	1874	2008

Fig. 5. Desalinated water demand forecast results.

about 4.5 billion m^3/year in 2040. This amount is four folds higher than the current production capacity of the existing desalination plants. The forecast results pose a huge challenge to Saudi water officials. In the following section, the main challenges to Saudi desalination industry will be discussed and the Saudi initiatives to handle these challenges will be highlighted.

4. Desalination challenges and initiatives

4.1. Desalination challenges

The scenario results show that KSA will need desalinated water capacity of about 2.0, 3.2, and 4.5 billion m^3/year based on optimistic, moderate, and pessimistic scenario, respectively, in 2040. The production of this huge amount of desalinated water will produce substantial fiscal budget burden. Huge capital investments are needed to build the new desalination plants coupled with substantial annual operation and production costs. Given the fact that the average production cost of desalinated water from existing plants is about 0.8 US$/$m^3$ [20,40,41], and KSA currently implements water tariff system that are heavily subsidized by the government where people pay less than 5% of the water production cost [16]. Additionally, about 50% of the existing desalination plants have exceeded their useful life, and need either complete replacement or major rehabilitation and maintenance to improve their production efficiency and to extend their useful life. This situation will result in substantial fiscal budget burden in KSA unless effectively mitigated. The existing desalination plants are solely depending on crude oil for energy. The country is currently using about 1.5 million barrel/d for desalinated water production, which constitutes about 15% of the country crude oil production [22]. The increase in desalination capacity will be matched by the increase in energy demand from the country's major revenue source: crude oil. The energy conversion efficiency of the existing desalination plants is about 25% in comparison with the planed new one in Yanbu of about 35% [21]. Low energy conversion efficiency coupled with the increase in energy demand will add extra pressure on the country precious natural source: crude oil. Improving energy conversion efficiency and developing renewable energy sources such as solar energy are major challenges for desalination industry in KSA. The desalination industry potential environmental impact on the sensitive marine ecosystem is another concern. The desalination industry in KSA is largely dependent on international expertise for desalination plant development, operation, and maintenance. Improving Saudi capacity, skills, and expertise is highly needed given the fact that KSA is the largest desalinated water producer in the world at present, and will most likely keep this status in the future. Public awareness about the chronic water shortage problem in the KSA and water conservation practices are low. This condition has resulted in over consumption causing the Saudi average water consumption to be among world's highest [47–49].

4.2. Desalination initiatives

KSA has taken major initiatives to tackle the desalination industry current and future challenges. In 2008, the KSA government announced plans to privatize SWCC by transforming it to a holding company. The holding company would initially supervise affiliated production firms that would run the desalination plants and develop new plants. Subsequently, it would sell-off the whole industry to the private sector. The privatization of SWCC aims to improve the efficiency of desalination industry and alleviate the fiscal budget burden of the government. Accordingly, the Electricity & Co-Generation Regulatory Authority (ECRA) was initiated. ERCA is a financially and administratively independent Saudi organization, which regulates the electricity and water desalination industry in Saudi Arabia to insure provision of adequate, high quality, and reliable services at reasonable prices. ERCA's mission is to develop and pursue a regulatory framework, in accordance with government laws, regulations, policies, and standards, as well as international best practices, in order to guarantee the provision of safe, reliable, reasonably priced and efficient electric power and desalinated water to the consumers of Saudi Arabia.

The private sector participation in developing desalination plants was fruitful. Three major desalination plants were developed by independent private sector as based on independent power and ater projects approach. Shuaibah 3 and Shuqaiq Phase II desalination projects were developed on the West Coast and started commercial operations recently. Marafiq (Jubail) were developed on the East Coast and started commercial operations recently The Shuaibah 3 desalination plant has a total production capacity of 365 million m^3/year and serves Jeddah, Makkah, Taif, and Albaha cities. Shuqaiq Phase II desalination plant has a total production capacity of about 77.4 million m^3/year and serves Asir and Jazan cities [28,50]. Marafiq (Jubail) desalination plant has a total production capacity of about 290 million m^3/year, and serves both the Jubail Industrial city and the Eastern Province area [51]. Three desalination plants are under development in Jeddah and Yanbu 3 in the West Coast and Ras Alkair in the East Coast by SWCC. These plants will have a total production capacity of about 654 million m^3/year upon commercial operation [22,52]. The three plants are expected to be commercially operated in 2018 [21]. Upon the completion and commercial operation of all previously mentioned projects in 2018, the KSA desalination plants capacity will be increased by about 1,390 million m^3/year. The new capacity will facilitate the upgrading and/or decommissioning of the 14 existing plants that have exceeded their designed operation life. The involvement of private sector in desalination industry has accelerated the developments of new plants and partially improved the fiscal burden in the country. Desalination industry is still heavily depending on government financial support given the low water revenue due to sub-optimal water tariff system.

SWCC established the Saline Water Desalination Research Institute to conduct research studies in different fields of desalination technologies. The institute signed a number of research agreements and memorandum of scientific understanding with many national and international organizations that focus on desalination technologies development and reducing desalination cost. The main objectives of this initiative are to improve performance of the operating plants, find appropriate solutions for their operational problems, and extend the operational life of plants for as long as possible, develop renewable energy utilization in desalination industry, and improve conversion efficiency. These efforts have resulted in the first solar-powered desalination plant operated by a 10 megawatts PV solar system with a capacity of 30 thousand m^3/year that has been developed in Al-Khafji town near the Kuwait border in 2013 [21,52]. Additionally, three solar powered desalination plants will be developed in Hagel, Dhuba, and Farasan areas [22]. The research institute has produced many scientific achievements, such as development of membrane nanotechnology, for which it obtained an international patent [28]; improving the designed energy conversion efficiency of Yanbu new plant to 35% in comparison with 29% in the older one.

Human resources development in desalination industry is a key concern to Saudi government. SWCC has introduced intensive training programs for its employees in collaboration with universities, training institutes, and specialized organizations in KSA and internationally. A large number of fresh graduates have been recruited and given adequate training to prepare them for work challenges [21]. Additionally, the new plants are expected to generate about 3,000 new jobs to Saudis [52].

To increase Saudi public awareness of the country chronic water shortage problem and to improve water conservation practices in the country, Ministry of Water and Electricity (MOWE) launched a massive water conservation awareness program in 2005. The MOWE among other water awareness activities has introduced a four-stage program of free distribution of water conservation tools [47–49]. The program performance is sub-optimal and needs further improvement to meet the stated objectives [47,48].

4.3. Discussion

The review of Saudi initiatives shows that KSA government considers seawater desalination as strategic option for domestic water supply. The on-going initiatives are to tackle most of the challenges, including desalination capacity, fiscal burden, conversion efficiency, research and development, energy and renewable resources, human resource capacity building, and public awareness. The long-term performance of these initiatives is an on-going concern. The performance of the privatization initiative will be financially jeopardized if the current water tariff system is not updated to reflect the actual cost of water. The KSA currently implements water tariff system that is heavily subsidized by the government where people pay less than 5% of the water production cost [16]. The high crude oil demand for desalination industry is another long-term concern. Currently, desalination industry consumes about 15% of crude oil production in the country. Increasing desalinated water production to meet the forecasted domestic demand will result in a substantial increase in crude oil demand accordingly. Crude oil revenue constitutes about 90% of KSA GDP. Intensive initiatives and programs are needed to further improve conversion efficiency and to utilize renewable energy source for seawater desalination. The research and development initiative to date is not sufficient and more resource should be directed toward this field. KSA should not only lead the world in desalinated water production, but also should lead the world in research and development in this field. The public water awareness of water shortage problem in the country is sub-optimal given the fact that Saudi average consumer water demand is among the world's highest. The on-going public awareness campaign needs significant improvements to meet the Saudi officials target to reduce domestic water demand by 1% annually. Industrial water demand has not been considered in this research. The industrial water demand in 2010 was about 800 million m^3 [15]. This is a significant amount and will add extra pressure in the Saudi desalination industry. The environmental concern of seawater desalination is rarely considered in Saudi initiatives. In-depth research is needed to mitigate the potential environmental impacts of desalination industry on the sensitive marine ecosystem. Finally, the analysis shows that the on-going desalination industry initiatives, coupled with some improvements, will satisfy the desalinated water demand on the short-term. The long-term desalination industry's ability to meet the ever-increasing domestic water demand remains a valid concern, especially, if the moderate or pessimistic scenario is realized.

5. Conclusion

KSA water scarcity is a chronic problem and will potentially hurt the socio-economic development in the country if not problem managed. KSA government considers seawater desalination as strategic option to alleviate water scarcity problem, and to meet the country ever-growing domestic water demand. This research reviews the KSA desalination industry performance since inception to date; forecasts desalination water demand based on three scenarios optimistic, moderate, and pessimistic up to year 2040; discusses the future of desalination industry as strategic water supply source and the challenges facing this option. The scenario results show that KSA will need desalination water capacity of about 2.0, 3.2, and 4.5 billion m^3/year based on optimistic, moderate, and pessimistic scenario, respectively, in 2040. The KSA government develops initiatives to tackle most of desalination industry challenges. The long-term desalination industry's ability to meet the ever-increasing domestic water demand remains a valid concern, especially, if the moderate or pessimistic scenario realized. New initiatives are needed toward improving the desalination industry long-term financial sustainability and protecting the marine environment and ecosystem. Additionally, KSA needs to implement water demand management program to reduce per capita water demand. Domestic water demand program may include conducting public awareness campaigns, upgrading the current water tariff system, and minimizing the unaccounted water in the water supply system.

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