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Analytical and forecasting study for wastewater treatment and water resources in Saudi Arabia

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ABSTRACT

Water treatment is a strategic solution to resolve the water shortage in agriculture and industrial sectors in Saudi Arabia. Rainfall which is not a reliable water source varies from 50 mm in most of the country to 500 mm per year in the southwest region. Lack of incentive and poor water treatment level were the main challenges in the water treatment industry. The water consumption in 2018; around 3360 million m^3, was almost 70% higher than it was in 2007. Similarly, the total municipal wastewater increased steadily and it is predicted to rise dramatically between 2025 and 2050 to reach 5090 million m^3. Treated water rose by nearly 200 % between 2007 and 2018 and is expected to grow annually by 4% between 2025 to 2050.

1. Introduction

In the absence of permanent water resources in Saudi Arabia such as rivers or water bodies. Surface water, groundwater and desalinated water are the only water resources that supply the country's needs. Water shortage with limited water resources in an arid climate is a serious problem. The population rate went up from 25 million in 2007 to about 33 million in 2018 with an average growth rate of 3% per year. Additionally, the fresh water demand over the past 20 years has risen dramatically. As a consequence, reclaimed wastewater and water conservation should be considered as strategic solutions for arid and semi-arid countries such as Saudi Arabia. Water treatment and reuse has many advantages such as minimizing environmental pollution and groundwater demand. It is predicted that, the total sewage effluent by the end of 2019 would cross 830 million m^3/day. Nationally, several new wastewater treatment plants will be established to take their total number to about 95 by 2019. These treatment plants will be able to treat about 2.8 billion m^3/year of sewage. For instance, Riyadh city has six centralized treatment plants and more than 77 decentralized wastewater treatment plants [1]. A decentralized system is an onsite wastewater system that is used to treat and dispose of relatively small volumes of wastewater. Also, about 200,000 m^3/d of the treated water in Riyadh city is employed for landscaping and irrigation. Industry sectors exploit about 20,000 m^3/d and the remaining is discharged into groundwater recharge [1].

Due to the lack of incentives and poor levels of treatment In the 1990s, wastewater could not be used as an alternative to natural water. Also, the infrastructure of the wastewater treatment was inadequate to cover all needs. As a result, the reuse of treated wastewater was relatively unpopular in Saudi Arabia. Chowdhury and Al-Zahrani [2] reported that, about 40% of wastewater was discharged into the environment without treatment. In addition, Secondary treatment technology was the most commonly used in Saudi Arabia at that time [3].

Tertiary treatment is currently applied for all types of wastewater such as domestic, industrial and agricultural with governmental decision. Several methods for water treatment are utilized to produce treated water. For instance, activated sludge, trickling filters, and rotating biological contactors, followed by sand filters to achieve tertiary treatment. Furthermore, Media filtration and disinfection by chlorination have been utilized widely in tertiary treatment technology. Reverse Osmosis (RO) is also used for advanced wastewater treatment. Recently, Yaser and Shafie [4] reported that, cost-effective bioaugmentation with microalgae would be promising technology in the future.

The treated wastewater by tertiary technology is suitable for various

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reclamation applications. Treated wastewater has been successfully used in agriculture, landscaping activities, industrial and commercial enterprises and groundwater recharge. It is essential to mention that, the length of the wastewater network and the number of regulation reservoirs play a considerable role to the quality of treated wastewater [1].

This paper attempts to address the wastewater problem and industrial water demand in Saudi Arabia. In addition, the water resources and trends of consumption were discussed. This paper also analyses and forecasts fresh water consumption, treated water and industrial water demand until 2050.

2. Methodology

Forecasting is a planning process, which historical and present information are collected and analysed to predict the future trends direction with using one or more forecast techniques. Governmental institutes use forecasting to allocate their plan and make correct decisions, which is typically based on the estimated demand in the future. Several issues such as historical data reliability, the period to be forecasted, and the accurate desirable affect forecasting method selection.

Quantitative category is a major forecasting approach. It is divided into two main categories which are; Time series methods and Explanatory methods. Explanatory methods seek to identify the pattern of the past then applying those relations to future. On the other hand, time is used as a reference to identify the historical relationships in time series methods [5–7]. The Exponential smoothing method is one of the time series methods. Regression method; which is widely preferred to find out the relationship between the variables for prediction purposes, is considered as a type of Explanatory forecasting methods.

Exponential Smoothing can be estimated by [5,6]:

$$F_{t+1} = F_t + \alpha(x_t - F_t)$$

Where x_t, F_t and α are actual value, forecast value and constant respectively.

The value of α varies between 0 and 1 and estimated to be 0.5 based on the actual values between 2007- 2017.

For the regression method, it is assumed to be a linear relationship which indicates the pattern changes of Y (forecasted value) when X (time) changes.

$$Y = a + bX$$

The Exponential Smoothing method and the Linear Regression method have been used in this study to predict the treated and industrial water demand between 2007-2017 (known values). Linear Regression reflects excellent prediction results to the actual values between 2007- 2017 for both treated and industrial water. Also, Exponential Smoothing method shows good performance in predicting industrial water demand for the same period.

Absolute Percentage Error (APE) and Mean Absolute Percentage Error (MAPE) for treated and industrial water are calculated and shown in Table 1. MAPE for treated and industrial water were 2.4 and 1.7 respectively. As a result, Linear Regression is used in this study to predict the fresh water consumption and treated water until 2050. The yearly increases in the population and the new plants that will be established are considered in this study. The demand of industrial water is predicted until 2050 via the Exponential Smoothing method.

APE and MAPE can be calculated by [6,7]:

$$APE = \left|\frac{x_t - F_t}{x_t}\right| X100$$

$$MAPE = \frac{\sum_{i=1}^{n} APE_i}{n}$$

Where n is the time periods.

Table 1
Absolute Percentage Error (APE) and Mean Absolute Percentage Error (MAPE) for treated and industrial water.

	Treated water		Industrial demand	
year	APE for Smoothing	APE for Regression	APE for Smoothing	APE for Regression
2007	3.525	0.002	0.704	3.139
2008	1.801	0.000	1.688	1.018
2009	2.120	0.009	2.384	5.017
2010	2.840	3.710	5.516	2.587
2011	9.244	1.455	3.328	0.004
2012	15.777	3.936	0.001	3.544
2013	6.939	3.596	0.006	3.529
2014	17.475	5.842	3.741	0.418
2015	8.302	0.226	3.247	0.005
2016	12.278	3.129	3.152	0.008
2017	3.181	5.228	3.068	0.001
MAPE	**7.589**	**2.467**	**2.440**	**1.752**

3. Standards and policies for treated water

In general, industrial wastewater has organic and inorganic compounds due to the industrialization growth. There are several styles of industries, accordingly, the type of pollutants and concentration vary for each waste. For example, textile waste contains mainly dyes. Leather industry contains zinc, copper, lead and arsenic. These pollutants exceeded the limit allowable by the government. Moreover, the average industrial wastewater temperature, salinity, turbidity and pH are also high. Therefore, onsite treatment for the industrial influent such as filtration or neutralization is essential before discharge to the wastewater network.

The Ministry of Municipal and Rural Affairs issued the first standards and policies of wastewater treatment and reuse in 2001 and which was amended by The Ministry of Water and Electricity (MWE) in 2006 (Table 2). In addition, treated water standards for irrigation in Gulf Cooperation Council (GCC) are illustrated in Table 3.

Generally, biochemical oxygen demand (BOD), chemical oxygen

Table 2
Maximum allowable contaminant levels for irrigation and industrial water [modified] [8].

Standards of sewage entering treatment plants		Standards of treated water (Tertiary)	
Chemical & Physical Parameters		Chemical & Physical Parameters	
Floatable materials	Absent	Turbidity - NTU	5
Biochemical oxygen demand (BOD) - ppm	500	Biochemical oxygen demand (BOD) - ppm	10
Chemical oxygen demand (COD) - ppm	1000	Chemical oxygen demand (COD) - ppm	20
Total suspended solids (TSS) - ppm	600	Total suspended solids (TSS) - ppm	40
Oil and grease- ppm	100	Oil and grease- ppm	Absent
pH	6-9	pH	6-8
Total organic carbon (TOC) - ppm	400	Total dissolved salt (TDS) - ppm	2500
NH3-N - ppm	80	Floatable materials	Absent
PO4- ppm	25	NO3-N - ppm	10
Pesticides	Absent	NH3-N- ppm	5
Detergents- ppm	15	Phenol- ppm	0.002
Heavy metals		**Heavy metals**	
Arsenic (As) - ppm	0.1	Arsenic (As) - ppm	0.1
Lead (Pb) - ppm	1	Lead (Pb) - ppm	0.1
Mercury (Hg) - ppm	0.05	Mercury (Hg) - ppm	0.001
Zinc (Zn) - ppm	2.6	Zinc (Zn) - ppm	0.2
Aluminum (Al) - ppm	-	Aluminum (Al) - ppm	4
Iron (Fe) - ppm	-	Iron (Fe) - ppm	5
Silver (Ag) - ppm	-	Silver (Ag) - ppm	0.2
Copper (Cu) - ppm	1.2	Copper (Cu) - ppm	0.4
Chromium (Cr) - ppm	1.2	Chromium (Cr) - ppm	0.1

Table 3
Treated water standard for irrigation in Gulf Cooperation Council [modified] [9].

GCC Country	BOD (ppm)	COD (ppm)	TSS (ppm)	NH4-(ppm)	NO3-(ppm)	PO4 (ppm)	TDS (ppm)	pH
Kuwait	20	100	15	15	-	30	1500	6.5-8.5
Oman	15	150	15	5	50	30	1500	6-9
UAE (Abu Dhabi)	10	150	10	-	-	-	2000	6-8
Bahrain	10	40	10	1	10	1	-	6.5-9
Qatar	5	50	50	1	-	2	2000	6-9

demand (COD), total suspended solids (TSS), total dissolved solids (TDS), total nitrogen (TN) and nitrates (NO3–N) are important parameters which should be monitored regularly.

GWI [9] reported that, the actual water consumption amount of agricultural, domestic and industrial in 2010 were 15040, 2063 and 800 m^3 respectively. They also expect 9% reduction in agricultural demand and about 27% and 20% growth in domestic and industrial demand in 2020.

4. Wastewater and treated water

Municipal wastewater treatment is vital because it is considered as a renewable water resource and it is increasing as a population increases. General wastewater processing flow diagram in Saudi Arabia is presented in Fig. 1.

Municipal wastewater is expected to pass 2.7 km^3 in 2035. The Fig. 2 shows the changes in the wastewater effluent and treated water over an eleven year period. Also, it demonstrates forecast study to 2050. As can be seen from the figure, there were different trends for wastewater and treated water between 2007-2018. The total municipal wastewater increased steadily between 2007 and 2018, from about 2125 to 2884 million m^3 and it's predicted to rise dramatically between 2025 and 2050 to reach 5090 million m^3 due to the increases in population. Similarly, treated water rose by nearly 200 % between 2007 and 2018; from 811 to 1710 million m^3. Although, the growth of treated water is estimated to be annually about 4% between 2025 and 2050, the total effluent of wastewater still higher by average of 28% in the same period. The major wastewater plants in Saudi Arabia are presented in Table 4.

For example, in 2018 agricultal irrigation followed by landscape irrigation represent about two third of the treated water reuse. The industrial water is equivalent to 13% of total water reuse as it shown in Fig. 3.

Wadi Hanifa in Riyadh, which is considered as natural landmarks and recreation, becomes recycled water site. The discharged rate of treated sewage is about 450,000 m^3 /day. Al Hamid et al. [12] pointed out that, the water quality of the groundwater sample was better than the surface water due to the natural filtration. They also noticed that, the water quality became better as the water travels along the Wadi.

The overall cost of 1 m^3 of desalted water is about $ 6.0, while, the total cost of reused treated wastewater is less than $ 3.0. Therefore, water reclamation can be implemented to cover the water demand

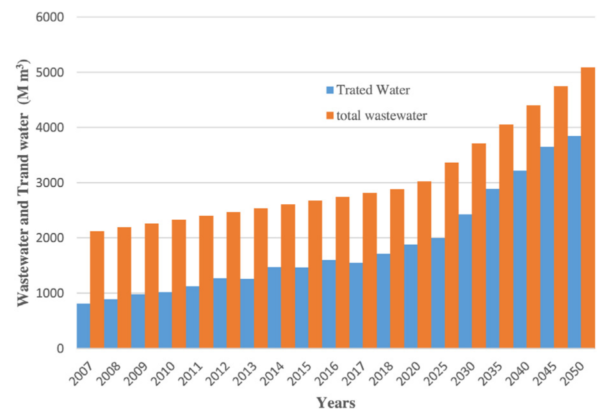

Fig. 2. Changes in the wastewater effluent and treated water to 2050.

especially in agriculture and industrial sectors [13]. Several studies illustrated that, the cost of water treatment in Saudi Arabia varies with the type of technology, from US$ 0.34–0.75 per m^3 for secondary treatment and US$ 1.19–2.03 per m^3 for tertiary treatment.

Reclaimed water is suggested to be a potential solution to address the water lack in Saudi Arabia. Reliable, efficient and cost effective water treatment processes are important to capitalize in the agriculture and industrial sectors. The demand management, monitoring and updating regulations are the main challenges phasing the water treatment industry.

It is worth noting that there are no health or environmental studies that have investigated the potential influence of using recycled water in the future. Moreover, there are insufficient economic and water management studies for wastewater treatment.

5. Industrial water demand

Industrial water is a significant requirement in the industrial environment. Usually, water is utilized in the industry for three main purposes, which are: cooling, manufacturing process, and steam generation (feed for boiler system). Water quality control is essential to prevent scaling, corrosion, and microbial formation.

In general, the industrial wastewater has organic and inorganic compounds due to the industrialization growth. As a result, onsite

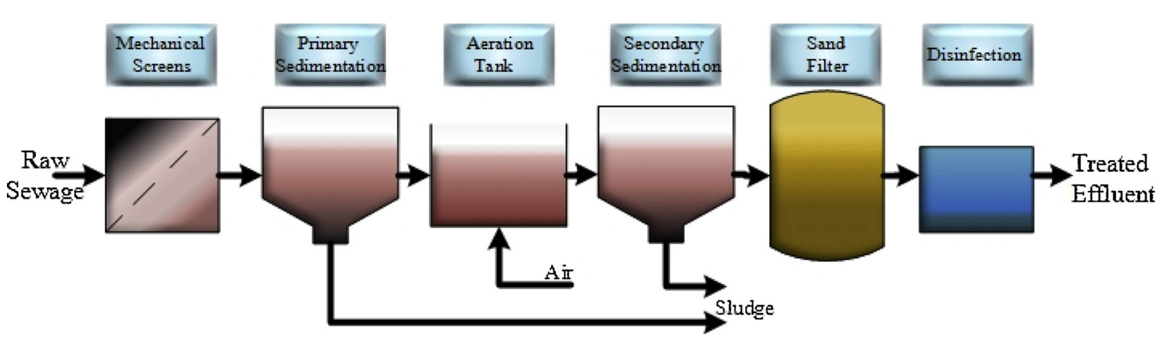

Fig. 1. General wastewater processing flow diagram in Saudi Arabia.

Table 4
Major wastewater plants in Saudi Arabia.

Ref.	Wastewater plant	technology	Design capacity (m^3/day)	Treatment type	Purpose
[9]	Manfouha-Riyadh	Tricking filter Activated sludge	North 200,000 South 200,000 East 200,000	Tertiary	Agriculture irrigation
[9]	Heet-Alkharj	Activated sludge	Phase I 100,000 Phase II 100,000 Phase III (Under Construction) 200,000	Tertiary	Irrigation Groundwater recharge
[2,9]	Al-Hayer-Riyadh	Activated sludge	Phase I 400,000	Tertiary	Irrigation Groundwater recharge
[2]	Refinery-Riyadh	Clarification & filtration	20,000	Tertiary	Agriculture Irrigation
[9]	Dammam	Activated sludge	215000	Tertiary	Landscape irrigation
[9]	Medinah	Media Filtration	460,000	Tertiary	Agricultur irrigation
[2,9]	Taif	Activated sludge	190,000	Tertiary /Secondary	Landscape irrigation
[2]	Makkah	Tricking filter/Activated sludge	Phase I 24000 Phase II 50,000	Tertiary	Irrigation Industrial
[2]	Qatif	Oxidation ditch	210,000	Tertiary	Landscape
[2]	Al-Khobar	Oxidation ditch	133,000	Tertiary	Landscape
[10]	Yanbu	Tertiary treatment	130,000	Tertiary	Industrial
[10]	Jubail	Tertiary treatment	115,000	Tertiary	Industrial
[2]	Jeddah	Tricking filter Tricking filter& filtration	Al-Khomra I 36,000	Secondary	Unknown
			Al-Khomra II 30,000		Landscape
			Plant A 32,000	Tertiary	Landscape
			Plant C 40,000		Landscape
[2]	Buraidah- I	Facultative	11,000	unknown	To sand dunes
Wastewater Plants Under Construction [11]					
Wastewater plant			**Design capacity (m^3/day)**	**Treatment type**	**Commercial Operation Date**
Jeddah Airport-II			500,000	Tertiary	2021
Madinah- III			375,000	Tertiary	2023
Dammam- West			350,000	Tertiary	2022
Taif- North			270,000	Tertiary	2022
Buraidah- II			150,000	Tertiary	2022
Riyadh- East			100,000	Tertiary	2023
Tabuk- 2			90,000	Tertiary	2023

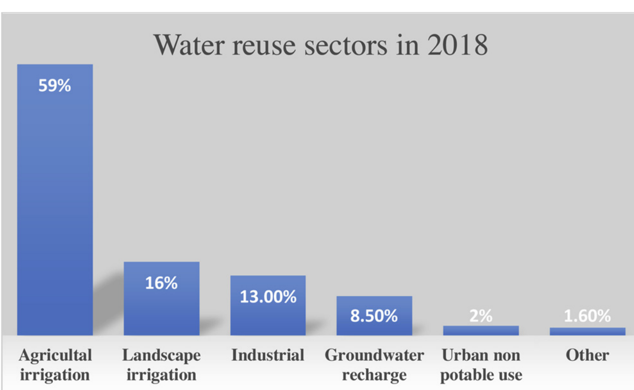

Fig. 3. Water reuse sectors in Saudi Arabia for 2018.

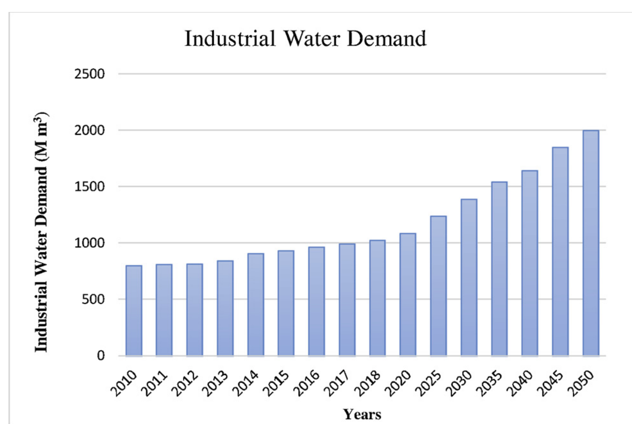

Fig. 4. Industrial water demand over a forty-year period.

treatment for the industrial influent is essential before discharge to the main wastewater line.

According to the ministry of Economy and Planning (MOEP), the industrial water demand is less than half of the domestic water demand. The industrial water demand has been increasing since 1980 to reach 56 million m^3. In addition, the treated water demands for industrial sector were 550, 710, 713 and 900 million m^3 in 2000, 2006, 2009 and 2014 respectively. The MOEP stated that the industrial water demand was grown by 2.2% per year between 2004- 2009 and about 5% per year between 2009 and 2014. MOEP also revealed that, the demand of industrial water is expected to exceed 1000 million m^3in 2020 [2].

The Fig. 4 indicates the increase of industrial water demand over a forty-year period from 2010 to 2050. The period between 2010 and 2018, the industrial water demand was improved annually by 3%. On the other hand, the industrial water demand in the future will go up by 5% per year due to the growth of industrial sector.

The water treatment cost differs by the type of technology, from US $ 0.34–0.75/m^3 for secondary treatment and US$ 1.19–2.03/m^3 for tertiary treatment. In addition, the total cost including treated water production and transportation of industrial water is estimated to be about $ 3.0. Therefore, treated water can be applied to cover the water demand industrial sector.

Industrial water management is a critical issue to minimize water use. Identifying water quality and water recycle is considered as a cost-effective method for the industrial site.

6. Renewable water sources

Drewes and Amy pointed out that only 2.2 km^3 of surface water is only available to use. Inland water bodies such as lakes, reservoirs and wadis represent about 0.7% of the country's total Moreover, shallow aquifers are limited to utilize due to the importance of water recharge to prevent resource depleting or water quality changes. Fossil water which, considered as non-renewable groundwater source is reserved in five main aquifers at depth of 150- 1500 m. In a study conducted by Drewes and Amy [14], it was reported that, 250 - 870 km^3 of non-renewable groundwater could be economically obtained from total groundwater resources available which are around 2185–2269 km^3. Both renewable and non-renewable groundwater is used primarily in the agricultural sector which is about 85% of total water withdrawal. The consumption rate of groundwater resources in 1990, 1992 and 1997 was 24.5, 28.6 and 15.4 billion m^3, respectively. Therefore, the productivity of groundwater will not survive for 50 years [14].

Additionally, climate change which is strongly related with the increase of temperature (Global Warming), has a negative effect on water resources and soil moisture in Saudi Arabia. Chowdhury and Al-Zahrani [15] reported that, the average predicted increase in temperature between 2011-2050 will be in the range of 1.8-4.1°C. consequently, the amount of water lost from surface water and dam reservoirs during the evaporation process will increase. For instance, the water surface of dam reservoir in the southwestern region is declining by 5 m per year [16]. Moreover, ground water recharge could be reduced by 91.4 million m^3 per year due to the raise in temperature by 5°C. On the other hand, the agricultural water demand will increase by around 10% in the summer and 18% in winter [15–17]. Water quality indicators such as: salinity, pH, dissolved oxygen and microorganisms will be affected due to climate change therefore water treatment costs could be raised.

6.1. Rainfall and surface water

Rainfall, surface water and shallow groundwater, which limited, represent the main resources of natural renewable water. Currently, the natural renewable resources are approximately three times lower than the water demand and expected to increase by 56% in 2035. For most regions, rainfall is not reliable water source because it is irregular and temporary. The weather condition in Saudi Arabia is dry most of the time. The southwest region has the highest amount of rainfall rate, followed by the western region. For example, it varies from 50 mm in most of the country to 500 mm per year in the Assir region. Saudi Geographical Survey (SGS) reported that, the average annual rainfall is approximately 100 mm [18]. In contrast, the evaporation rate per year across the country varies from 2700 up to 4200 mm [14].

Currently, there are 508 dams operating in 13 regions with total capacity of 2.25 billion m^3 [19]where Table 5 displays the major dams in Saudi Arabia. Those dams can be classified based on purposes to: Ground water recharge, Water supply, Irrigation and Flood control. MEWA indicated that, the total numbers of Ground water recharge, Water supply, Irrigation and Flood control dams are 344, 63, 2 and 99 respectively.

Fig. 5 shows the increase in population and water consumption in the Kingdom of Saudi Arabia, between 2007 to 2050. It is noteworthy that, 70% of the total population is concentrated in six major cities which are Riyadh, Jeddah, Dammam, Makkah, Taif, and Madinah. Table 6 demonstrates the total drinking water Quantity distributed in 2016 through the country. The population rose by nearly 30% between 2007 and 2018: from 25.2 to just under 33.5 million. Likewise, the drinking water consumption in 2018, around 3360 million m^3, was almost 70% higher than it was in 2007. Although the water consumption between 2007 and 2018 was large, it is expected to increase sharply in the following thirty years, rising from about 3600 million m^3 in 2020 to more than 7600 million m^3 in 2050.

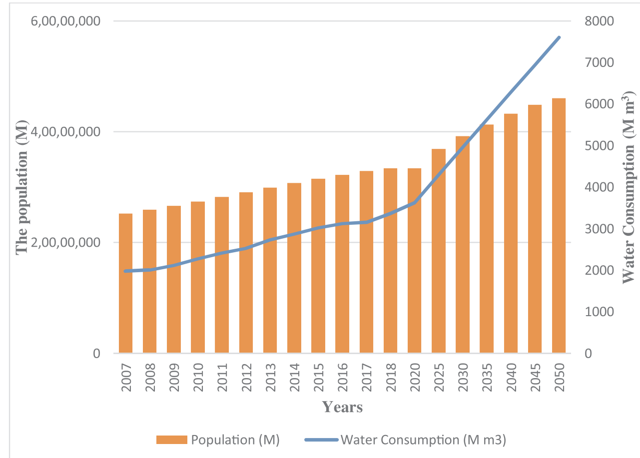

Fig. 5. The population and water consumption in the Kingdom of Saudi Arabia between 2007 to 2050.

Table 6
Total drinking water Quantity distributed in 2016 [20].

Region	Percentage of ground water	Percentage of desalinated water	Total percentage of distributed water
Riyadh	41%	28%	33%
Makkah	1%	36%	23%
Madinah	2%	8%	6%
Qassim	10%	0%	4%
East Province	25%	19%	21%
Asir	1%	5%	3%
Tabuk	5%	1%	2%
Hail	5%	0%	2%
Jazan	1%	3%	2%

6.2. Desalination

Desalination is considered to be a strategic solution for the water shortage in the Kingdom. General process for desalination in Saudi Arabia is shown in Fig. 6. In addition, the desalination technologies and capacity that are utilized in GCC are presented in Fig. 7.

Table 5
Major dams in Saudi Arabia [2,19].

Name of dam	Completed	Dam height (m)	Reservoir capacity (million m^3)	purpose
King Fahd	1998	103	325	Ground water recharge
Wadi Abha	1974	33	213	Water supply
Wadi Jazan	1970	35	51	Irrigation
Wadi najran	1980	73	86	Flood control
Qaa hathutha-Madinah	2001	7	40	Ground water recharge
Wadi Alaquiqu- Baha	1988	31	22.5	Water supply
Tarba- Tayif	1984	15	21.8	Water supply
Arda- Tayif	1984	24	21	Water supply
Tarabah- Tayif	1981	21	20	unknown
Fareah- Madinah	1982	13.5	20	Flood control
Wadi Alfaraah- Madinah	1982	13.5	20	Flood control

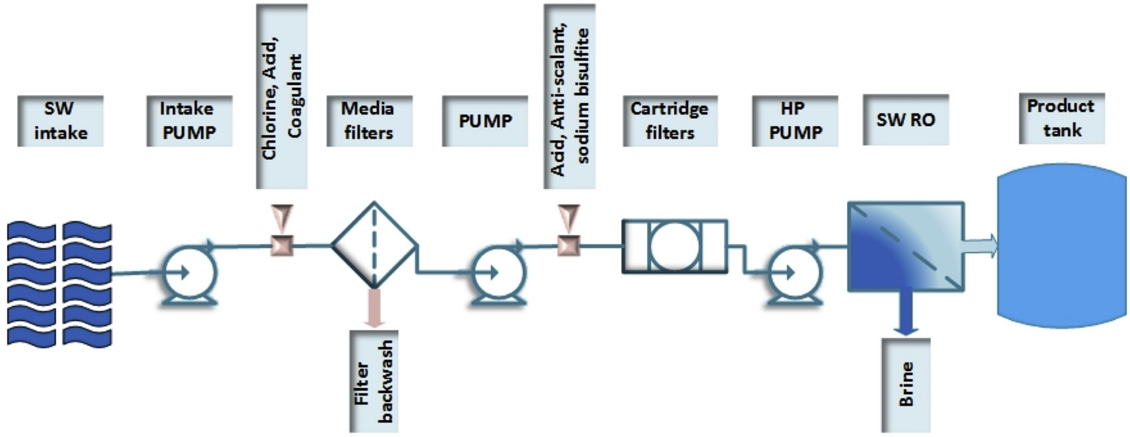

Fig. 6. General process for desalination in Saudi Arabia.

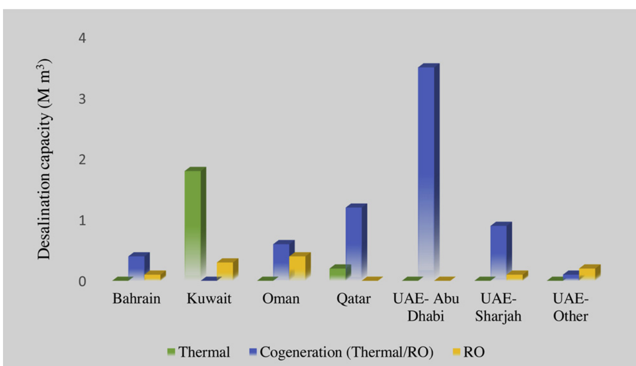

Fig. 7. Installed desalination capacity by type for GCC in 2017 [22].

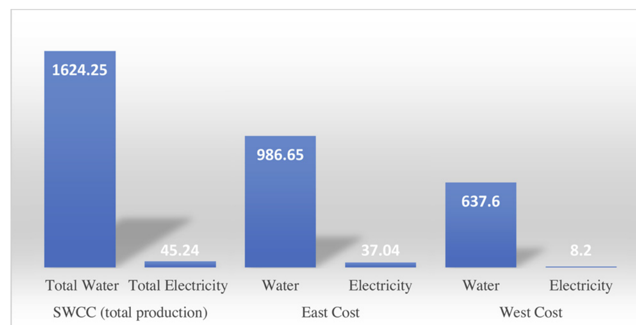

Fig. 8. Total Desalinated Water Export (million m^3) and Electric Power Export (million M.W.h) by SWCC in 2016 [24].

Table 7
Annual desalination production and consumption for GCC in 2017 [22].

Country	Production (Million m3)	Consumption (Million m3)
Bahrain	174.9	174.4
Kuwait	562.1	533.2
Oman	228.6	222
Qatar	495	595
UAE- Abu Dhabi	1170.5	1154
UAE- Dubai	404.1	358.6
UAE- Sharjah	115.3	90.5
UAE- Other	66.5	90.5
Total	5486.6	4717.9

Saline Water Conversion Corporation (SWCC) is considered the largest producer for the desalinated water. Thirty desalination plants were created and managed by SWCC with a total of 5.2 million m^3/day of desalted water production in 2018. Moreover, thirty five pump stations and 286 water reservoirs with total capacity of 16.8 million m^3 are constructed too. SWCC built 7700 km of pipes which varying in diameters from 200 to 2000 mm to transport the desalinated water to the inland cities such as Riyadh [21]. Annual desalinated water (production) and consumption for GCC in 2017 are illustrated in Table 7.

To date, SWCC annual report indicated that the average cost of desalinated water for long-term is about 0.8 US$/m^3. For moderate water consumption, the water tariff that included the sewage cost represents about 50% of the water production cost. The total Electric Power Export and Desalinated Water Export in 2016 for Saudi Arabia are presented in Fig. 8.

In fact, desalination industry faces two main challenges. The first one is the crude oil dependence for energy. Ouda [23] reported that, 1.5 million barrel/day which is around 12% of the crude oil production used to power the desalination plants. A considerable number of desalination plants exceeded their lifetime and need major maintenance to improve the production efficiency. Therefore, developing desalination plants via private sector participation is essential. Major desalination plants have been developed by private sectors such as Shuaibah 3, Shuqaiq Phase II and Marafiq. Additionally, the decision of privatize SWCC has been taken and approved since 2018. The efficiency (efficient) improvement of the desalination industry and the reduction of the governmental budget cost for water are the main targets of privatization.

7. Conclusion

Water resources and availability in Saudi Arabia have been explored. Analytical and forecasting study for the fresh water consumption, wastewater problem and industrial water demand were also presented. Exponential Smoothing and Linear Regression methods are used to estimate the future water demands. The major findings can be summarised as follows:

- The drinking water consumption in 2018 was almost 70% higher than it was in 2007 and expected to increase sharply in the following thirty years due to the growth of population.
- The total municipal wastewater went up steadily between 2007 and 2018, from about 2125 to 2884 million m^3 and expected to increase between 2025 and 2050 to reach 5090 million m^3.
- The growth of treated water is estimated to be annually about 4% between 2025 and 2050, while the total effluent of wastewater is still higher by average of 28% in the same period.
- In the last ten years, the industrial water demand was improved annually by 3% and expected to increase to 5% due to the growth of industrial sector.

- Insufficient economic and water management studies for wastewater treatment.
- No health or environmental studies investigated the potential influence of using the water reused in future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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