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Water Resources Crisis in Saudi Arabia, Challenges and Possible Management Options: An Analytic Review

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***Abstract*—**The Kingdom of Saudi Arabia (KSA) is heading towards a severe and rapidly expanding water crisis, which can have negative impacts on the country's environment and economy. Of the total water consumption in KSA, the agricultural sector accounts for nearly 87% of the total water use and, therefore, any attempt that overlooks this sector will not help in improving the sustainability of the country's water resources. KSA Vision 2030 gives priority of water use in the agriculture sector for the regions that have natural renewable water resources. It means that there is little concern for making reuse of municipal wastewater for irrigation purposes in any region in general and in water-scarce regions in particular. The use of treated wastewater is very limited in Saudi Arabia, but it has very considerable potential for future expansion due its numerous beneficial uses. This study reviews the current situation of water resources in Saudi Arabia, providing more highlights on agriculture and wastewater reuse. The reviewed study is proposing some corrective measures for development and better management of water resources in the Kingdom. Suggestions also include consideration of treated water as an alternative source for irrigation in some regions of the country. The study concluded that a sustainable solution for the water crisis in KSA requires implementation of multiple measures in an integrated manner. The integrated solution plan should focus on two main directions: first, improving the current management practices of the existing water resources; second, developing new water supplies from both conventional and non-conventional sources.

***Keywords*—**Saudi Arabia, water resources, water crisis, treated wastewater.

I. Introduction

WATER is essential for humankind and other creatures to survive; without water, no life can exist. The KSA is among several other countries in the Middle East Region that suffers from a serious water scarcity, climatic changes, and population growth, which have affected the sustainability of water resources and caused the degradation of several renewable and nonrenewable resources. Currently, most of the consumed water is usually extracted from deep groundwater aquifers [1]. The average annual rainfalls is about 59 mm and during the summer season the temperatures could reach 55 °C; this characterizes the country's climate as having very harsh climatic conditions. Saudi Arabia has no lakes or rivers, and more than 90% of its total area is covered with desert. Based on the UNESCO Water Scarcity Index, Saudi Arabia falls under the condition of extreme water shortage [2].

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With a current growth rate of about 2.3%, Saudi Arabia's population is expected to reach 42 million by 2040 [3]. This will further intensify pressure on the existing water resources, which are already limited and scarce.

Experts have warned that Saudi Arabia could run out of water within a few decades if effective measures are not taken to limit the use of deep groundwater aquifers in the agriculture sector. Some 88% of Saudi water resources go to agriculture, while the sector contributes only to 3% of GDP [4]. In this study, an attempt has been made to compile the available information from different sources including articles that are published in peer-reviewed journals, with the main goal to portray the current state of water resources management in the KSA and also to describe the potential opportunities for sustainable water use in the country.

A. Water Withdrawal and Use in Saudi Arabia

The total water withdrawal is estimated at 23.67 km^3 in the year 2006, which shows a 40% increase as compared to that of 1992. In 2014, the total internal renewable water was estimated to be 2.4 BCM/year (Table I) [5]. About 1 billion cubic meter of runoff is annually collected by dams. The water shared between the different sectors is clearly shown in Fig. 1.

TABLE I
WATER WITHDRAWAL IN SAUDI ARABIA [5]

Total Renewable Water Resources (billion m^3/year)	2.4	Year (2014)
Total Dams Capacity (billion m^3/year)	1.0004	Year (2014)
Total Water Withdrawal (billion m^3/year)	23.67	Year (2006)
Agriculture Water Withdrawal (billion m^3/year)	20.83	Year (2006)

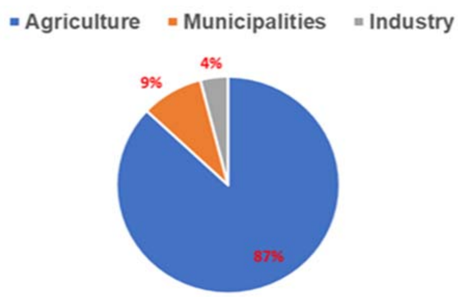

Fig. 1 Water withdrawal by sector in Saudi Arabia, 2010 [6]

Water withdrawal is mostly obtained from groundwater at 90.3%, surface water at 4.6%, desalinated water at 4.4% and treated wastewater at 0.7% (see Fig. 2) [4]. Most water withdrawn comes from deep aquifers, and if extraction continues at the current alarming rate, these aquifers expected to be depleted within the next 25 years. The total renewable water resources form only 10% of the total water withdrawn, which is an unsustainable practice [4].

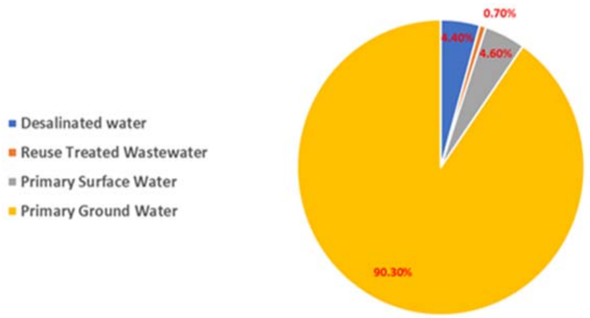

Fig. 2 Water withdrawal from different sources in Saudi Arabia [4]

II. Desalination

Saudi Arabia is among the top countries in the world in the production of desalinated water, with 30 desalination plants on the country's east and west coasts producing 1.3 billion cubic meters of desalinated water in 2015. At present, nearly 70% of the nation's water comes from desalination, but there are plans to make the nation completely water independent (i.e. independent from fossil groundwater) within the next few decades [7]. Desalination is one of the most important solutions to water scarcity in Saudi Arabia; however, it puts more pressure on energy security. According to the 2013 World Bank report, the country is burning 1.5 million barrels of crude oil equivalent every day to produce desalinated water and generate electricity [8]. Moreover, desalination has a significant environmental impact, including damage to marine environments that is caused by the release of brine and other chemicals into the sea as well as air pollution due to high emissions of CO_2 and other harmful gases. Desalination is cheaper per cubic meter in larger plants as compared to small plants. Thus it is more efficient to build a large plant to supply a city than to build a local desalination plant for a town. As well, desalination will not be a viable solution to supply water to cities located at large distances from the coastal area due to the transportation cost. The total production and transmission cost of desalinated water has increased from about 0.87 US\$/m^3 in 2006 to about 1.09 US\$/m^3 in 2010 with an average annual rate of 4.6% [9].

III. Treated Wastewater

Nowadays, wastewater reuse is in practice in several countries throughout the world. In several parts of the world, there is a growing awareness of the important wastewater reuse, and hence, many countries have already started to introduce wastewater reuse in the future water resources planning. Currently, treated wastewater is extensively used in agriculture in arid parts of USA, Australia, and in some countries in the Middle East. Wastewater is a rapidly and globally expanding area of infrastructure development that enables the sustainable re-use of scarce water resources for non-potable purposes in industry, agriculture, and greening. Particularly in the agricultural sector, which is the largest and most inefficient consumer of water, the use of treated water for irrigation may also provide a means of reducing withdrawn rates of freshwater. In Saudi Arabia, the total annual volume of wastewater produced reached about 2 billion cubic meters in 2012, but only 62.1% is actually collected. Out of the collected wastewater, only 70% is treated (treatment performed to a secondary and tertiary level as shown in Table II).

TABLE II
WASTEWATER UTILITY DATA IN SAUDI ARABIA [10]

No. of People Connected to Sewage Network	16,287,874	2010
% of People Connected to Sewage Network	58	2010
No. of Wastewater Connections	1,172,078	2014
Volume of Wastewater Produced (m^3/year)	2,024,000,000	2012
Wastewater Collected (%)	62.1	2012
Wastewater Treated to Secondary Level (%)	51.8	2010
Wastewater Treated to Tertiary Level (%)	18.1	2010

In KSA, only a small fraction of the treated wastewater is used in agriculture and industry, with much of it remaining unused (see Table II). Most of the treated municipal wastewater, totaling over 2.2 million cubic meter per a day, is discharged to waste either to tidal waters in coastal areas or into nearby Wadis at interior locations [11]. Saudi Arabia only using 8% of the total wastewater produced in 2010, which seems to be unreasonable given the growing escalation of the water crisis. Currently, the country has an ambitious plan to reuse all treated wastewater effluents and have already made considerable progress towards this end. Well-planned water reuse integrated in a global water management scheme is economically sound and results in significant water savings [12]. Some researchers described water recycling and brackish water desalination as incurring very similar costs [13]. Energy is the determining factor in the economics of different water sources, with the specific energy consumption for surface, brackish or wastewater being 0.4-1.0 kWh/m^3, versus that of seawater at 3-3.4 kWh/m^3 [14]. Therefore, energy reduction could have a significant effect on carbon dioxide emission, and positive impact on the environment. In Saudi Arabia, more focus should also be given to the agriculture sector in order to optimize the economic efficiency and sustainability of using treated wastewater in agriculture practices [15].

Despite that wastewater reuse could have a very important role alleviating the water crisis in KSA, there are also some challenges and constrains that prevent its full utilization. These can be listed as the higher costs of the system, low demand and level of public acceptance. KSA still lacks an established distribution network to supply treated wastewater to end users; trucks are the primary method of distribution [16]. In addition, the country still lacks proper regulations for the use of treated wastewater in the agriculture sector. Analysis of the treated municipal wastewater of Jeddah city, collected at different geographic locations, showed that the concentrations of the element's nitrogen, phosphorus and carbon as well as the trace elements lead and cadmium are below the limits fixed for the use of these waters for agricultural irrigation [17].

Wastewater can be both a resource and a problem. Wastewater and its nutrient content can be used extensively for irrigation and other ecosystem services. Its reuse can deliver positive benefits to the society. However, wastewater reuse also exacts negative externality effects on humans and ecological systems, which need to be assess.

IV. Agriculture Water Use

Agriculture is the largest consumer of water with about 87% of freshwater used for irrigation; of this water, 90% is extracted from deep groundwater aquifers (see Fig. 3). The agriculture sector only contributes 3% to GDP (see Fig. 4).

The growing demand for freshwater in municipal and industrial sectors is expected to bring more competition between these sectors and the agriculture sector which will ultimately lead to a reduction of the agriculture sector's share. Therefore, the limited availability of water for agriculture, especially in arid regions, will expand water extraction from deep nonrenewable groundwater which will have long-lasting impacts on the environment and water security. Consequently, the challenges to ensure future food security with less available water will continue to be the main obstacle and serious problems facing irrigated agriculture in the future.

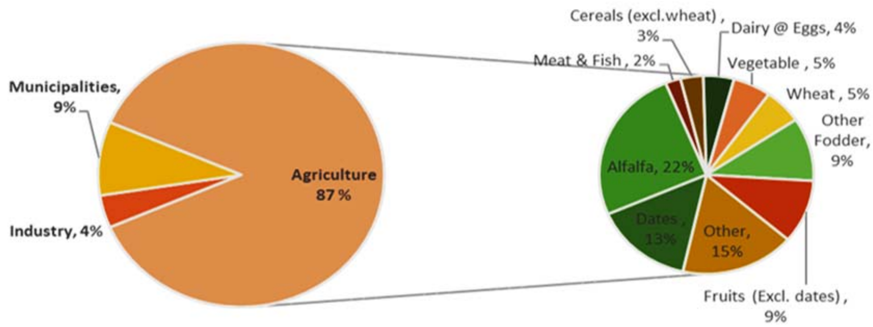

Fig. 3 Water Use in Saudi Arabia, 2010 [18]

Fig. 4 Sectoral GDP and water withdrawal [19]

The total arable land in Saudi Arabia is estimated at about 3,647,000 ha, which forms about 1.63% of the total area of the country (see Table III). As per the last statistics, total arable land equipped for irrigation in Saudi Arabia is 1,730,767 ha. Out of the total area equipped for irrigation, only 69% is actually irrigated (see Table IV). Throughout the country, the major source of irrigation water is almost exclusively fossil groundwater; this is clearly shown in Table V.

TABLE III
Arable Land in Saudi Arabia [5]

Arable Land Area (ha)	3,647,000	2014
Percentage of Cultivated Land (%)	1.63	2014

Modern irrigation systems, either drip or sprinkler irrigation, covers about 67.6% of the total irrigated area, while the remaining 34.4% of the irrigated area is an under surface irrigation system, referred to as traditional irrigation (see Fig. 5). It is clear from Table IV that the largest irrigated areas are located in the regions of Riyadh, Qassim, Jazan and Hail. The number of artesian wells extracting water from the deep groundwater aquifer is highest in Riyadh with 21,301, followed by the Eastern region, Qassim, Madinah and Hail, which is a serious indicator of the growing depletion of non-renewable groundwater resources in these regions. More than 95% of irrigation area in regions like Al Jouf, Tabuk, Eastern and Qassim are still using the deep non-renewable groundwater aquifer as the main water source. Almost all of the agricultural production areas are dependent on groundwater pumping for irrigation, which is challenging and costly [20].

TABLE IV
Arable Land in Saudi Arabia

Region	Traditional irrigation		Modern irrigation		Total	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Riyad	43010	15	243275	85	286286	24
Makkah	43924	98	1032	2	44957	4
Madinah	26618	93	2020	7	28638	2
Quassim	15541	7	208712	93	224253	19
Eastern	16 081	15	92 987	85	109 067	9
Asir	22232	99	296	1	22527	2
Tabuk	5 113	11	42057	89	47169	4
Hail	12368	10	116139	90	128507	11
Northern	18	14	114	86	133	0
Jazan	177375	99	1995	11	79370	15
Najran	8811	69	4008	31	12819	1
Baha	2658	98	55	2	2713	0
Al Jouf	11688	11	93224	89	104912	9
Total	385438	32	805913	68	1191351	100

TABLE V
PERCENTAGE OF AREA USING ARTESIAN WELLS AS A SOURCE FOR IRRIGATION

Region	Total area (ha)	Percentage of total area (%)	No. of artesian wells	Percentage of area using artesian wells as an irrigation source (%)
Riyadh	286286	24	21,301	92
Makkah	44957	4	8,427	28
Madinah	28638	2	12,150	92
Qassim	224253	19	12,565	96
Eastern	109 067	9	16,735	97
Asir	22527	2	9,669	34
Tabuk	47169	4	4,178	97
Hail	128507	11	10,144	92
Northern	133	0	191	93
Jazan	79370	15	6,172	49
Najran	12819	1	4,618	79
Baha	2713	0	2,920	35
Al Jouf	104912	9	5,337	99
Total	1191351	100	114,407	-

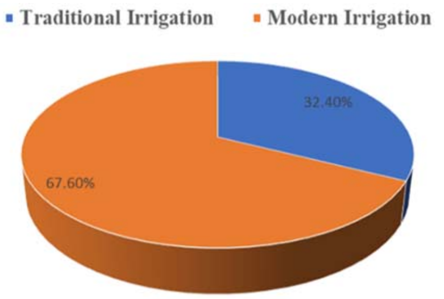

Fig. 5 Modern and Traditional Irrigation in Saudi Arabia

Traditional irrigation is still more commonly practiced in regions such as Jazan and Asir, and accounts for about 99% of all irrigated areas. Traditional irrigation is also practiced in other areas like Al Baha, Makkah and Al Madinah. The reasons that traditional irrigation is still more common in such regions might be attributed to the higher runoff production as compared to other regions in the Kingdom, and hence, flood irrigation is still in practice. The flood-irrigation method is associated with the central plains where fertile lands spread alongside the Wadis. In the Asir region, irrigation using dams is practiced at a low level. The greater share of water resources is consumed by irrigated agriculture, which accounts for more than 70% of all global water consumption. Policy reform in the agriculture sector is becoming more crucial worldwide, especially in arid and semi-arid regions. In Saudi Arabia, due attention should be given to implement top-down regulations and decentralized reforms of irrigation management. Sustainable agriculture and food could not be achieved in KSA if progressive depletion of the principle deep groundwater aquifer continues at its current alarming rate. The limited water resources should be utilized more wisely and the current practices of using the scarce water in an inefficient and irrational way should be addressed. Despite that, Saudi Arabia's agriculture sector is the largest consumer of water, while it still suffers from low productivity and poor water use efficiency. Many researchers have indicated that bad water management in the agriculture sector worldwide is the main reasons for wasting irrigation water [21]-[23]. Good water management necessitates effective coordination and integration of the water management in the agriculture sector, with the overall water management, this action is very crucial, especially in countries facing a growing water crisis such as Saudi Arabia.

In the wake of a World Bank report on global water scarcity released in February 2016, various Saudi government officials and water experts warned that the Kingdom could run out of water entirely by 2029 if it did not radically reform its agricultural practices and address high water consumption patterns across the country [24]. Therefore, Saudi Arabia is facing a catastrophe if agricultural practices do not change. The remaining groundwater needs to be preserved. The solution for the water scarcity in KSA cannot be solved by implementing one solution at a time. The most sustainable solution will be to implement several solutions at a time in an integrated manner.

The integrated solution should go in two main directions: the first, better management of the existing water resources; and second, developing new resources either conventional or nonconventional.

The first solution could include improving current irrigation efficiency, which is nearly 47% to at least 65%. This option could save 3.71 billion m^3/year (see Table VI). This amount of water is greater than the total annual amount used to meet the municipal water demand throughout the country. Increasing irrigation efficiency could be achieve by improving agricultural and irrigation practices and by using new irrigation water saving technologies and low water requirement crops. Water use-efficiency in various sectors can be enhanced and improved [25].

TABLE VI
EXPECTED EFFECT OF INCREASING IRRIGATION EFFICIENCY ON AGRICULTURE WATER CONSUMPTION

Total water withdrawal (billion m^3/year)	23.67
Total amount of water currently used in the agriculture sector (billion m^3/year)	20.59
Water consumption at 47% irrigation efficiency (billion m^3/year)	9.67
Total amount of water wasted (billion m^3/year)	10.91
Water Consumption at 65% irrigation efficiency (billion m^3/year)	13.38
Total amount of water expected to be saved when rising irrigation efficiency from 47% to 65% (billion m^3/year)	3.71

Since water in Saudi Arabia is very scarce, the cropping pattern should be chosen in such a way that gives priority to cash crops that have higher economic return and less water consumption. Table VII shows that the maximum return per unit of water is obtained from vegetables, followed by dates, and finally, wheat. Therefore, the return per unit of water obtained from vegetables is more worthy than wheat and dates.

To achieve food security and save water resources, water demand management should be considered, and future plans and policies should give more attention toward increasing the production of vegetables, fruits and other high value cash crops to make use of 'Virtual Water' by importing cereals for human and animals uses [26].

TABLE VII
CASH RETURN PER UNIT OF WATER FOR SOME MAJOR CROPS IN SAUDI ARABIA [27]

Crop	Rate of Water Consumption (m^3/ha/year)	Average Productivity (tons/ha)	Producer Prices (SR/ton)	Return on Water (SR/1000 m^3 of water)
Wheat	8000	4.88	1000	610
Vegetable (Tomatoes, Onion, Potatoes)	15000	20.5	1500	2050
Dates	26500	6.25	6100	1466

Non-Conventional Sources of Irrigation

Water-scarce countries like Saudi Arabia, will have to rely more on the use of non-conventional water resources to alleviate water scarcity. Under most circumstances, treated wastewater can be a better alternative source than some fresh water sources, if strict regulations are implemented and proper management are provided. As well, it is a constant water source, and nitrogen and phosphorus in the wastewater may result in higher yields than freshwater irrigation, without additional fertilizer application [28].

In Saudi Arabia, a great deal remains to be accomplished towards better optimization of the use of the available treated wastewater in such a way that it can actually help in alleviating the adverse impact of the water crisis in the country.

This study suggested that treated wastewater should be introduced as an additional source for irrigation in regions that are facing overexploitation of groundwater resources. Introducing treated wastewater in these regions could decreases the demand for freshwater in agriculture. This suggestion clearly illustrated in Table VIII.

TABLE VIII
REGIONS WHERE TREATED WASTEWATER SHOULD BE CONSIDERED AS ADDITIONAL SOURCES FOR IRRIGATION

Region	% of area using artesian wells as an irrigation source	Suggested solution to control the over exploitation of Deep Ground Water Aquifers
Riyad	92	Treated waste water should be considered as an additional source for irrigation
Madinah	92	Treated waste water should be considered as an additional source for irrigation
Qassim	96	Treated waste water should be considered as an additional source for irrigation
Eastern	97	Treated waste water should be considered as an additional source for irrigation
Tabuk	97	Treated waste water should be considered as an additional source for irrigation
Hail	92	Treated waste water should be considered as an additional source for irrigation
Northern	93	Treated waste water should be considered as an additional source for irrigation
Najran	79	Treated waste water should be considered as an additional source for irrigation
Jouf	99	Treated waste water should be considered as an additional source for irrigation

V. CONCLUSIONS AND RECOMMENDATIONS

This study places emphasis on the urgency of adopting conservation and water-demand management initiatives, as well as developing conventional and non-conventional water resources in Saudi Arabia to achieve an acceptable balance between water needs and availability. The study suggests that in order to reach sustainable agricultural in the KSA, a holistic approach is urgently needed. The integrated approach needs a wide range of short- and long-term actions; the first part of the integrated solution includes effective management of the existing non-renewable resource to preserve the deep aquifer in sensitive areas and limiting their use only to supply drinking water, while prohibiting their use for agriculture purposes. Great water reduction in agricultural water consumption could be achieved by increasing irrigation efficiency only from 47% to 65%, which would save over 3 billion m^3/year. This can be realized by improving agricultural and irrigation practices and using new irrigation water saving technologies and cultivating low-water requirement crops.

The second part of the integrated solution includes developing new water resources from both conventional and non-conventional sources. The use of treated wastewater should be viewed as a means of increasing water availability. Therefore, treated wastewater must be considered as an integral component of irrigated agriculture in the critical regions of the KSA where the deep groundwater aquifer has reached an alarming low-level due to over exploitation. Encouraging rain fed agriculture and more efficient water harvesting techniques are highly recommended in the southwestern part of the country on the abandoned terraces of the Al Sarawat Mountains and along the coasts of the Red Sea, which benefit from annual runoff water born in the neighboring and relatively humid mountains.

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