PROSPECTIVE AND CHALLENGES OF SUSTAINABLE WATER RESOURCES FOR IRRIGATION IN KUWAIT

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ABSTRACT

Assessment of water resources, energy production and consumption, and food resources are essential for achieving and maintaining sustainability and development goals. The State of Kuwait is suffering from a shortage of renewable natural freshwater resources. It depends heavily on seawater desalination to meet the ever-increasing demand. Brackish groundwater, which is almost nonrenewable, is exploited for agricultural purposes after mixing with desalinated water. The reuse of treated wastewater (TWW), as a non-conventional water source is essential for current water circumstances. This work presents an overview of the available water resources in Kuwait and assesses the potential reuse of treated wastewater as a valuable water source for agriculture, the key technical, administrative, and legal challenges and opportunities of this resource are discussed within the context of environmental sustainability. Four interconnected recommendations are suggested to ensure the safe use of TWW. These include research and development, management of TWW reuse, public awareness of the associated risks and benefits, and the implementation of an executive framework for utilizing TWW in the future and existing urban development.

Keywords: Water resources management- Treated wastewater- Desalination- Smart farming- Brackish groundwater- Sustainability-Kuwait.

1 INTRODUCTION

The countries in the Middle East and North Africa (MENA) region are vulnerable to the adverse effects of population growth, global warming, climate change, COVID-19 impacts, and a decline in biodiversity. This vulnerability directly translates to high demand rates of water use for drinking and irrigation in a region that is already suffering from water scarcity (World Bank 2020). The food and agriculture industries were directly affected by the consequences of the COVID-19 pandemic and prolonged quarantine durations (ILO 2020). The national and international economic indices, such as budget deficits, government spending, employment, GDP growth, and poverty levels, have also been drastically impacted. Numerous studies have been conducted to investigate the COVID-19 pandemic's potential consequences on local, national, and international economic indices (UN-Habitat and WFP 2020).

The state of Kuwait is an arid country in the MENA region and is characterized by hot and dry summers and moderately cool winters, low annual precipitation (<115 mm), high annual ET rates (3,500 mm), and is under critical water stress (>10,000 persons per million cubic meter of water). Fresh groundwater is scarce and is restricted to lenses floating over brackish to brine water in the northern part of the country. This is due to the presence of the two large surface depressions of Raudhatain and Umm Al-Aish that allow significant amounts of rainfall and runoff water to infiltrate into the shallow lenses of fresh water. Most of the useable groundwater, extracted in the southwestern parts of the country, is brackish with an average total dissolved salts (TDS) of 3000–4500 ppm (Brebbia, 2018) Brackish water is blended with desalinated water for irrigation purposes.

The Municipal wastewater in Kuwait is generally treated at the tertiary level. Recently, reverse osmosis (RO) membranes have been introduced to renovate municipal wastewater to produce high-quality water. Therefore, treated wastewater is a very good additional resource for irrigation in Kuwait.

The main objective of this study is to assess the prospects and challenges of sustainable water resources for irrigation in the State of Kuwait. This is a chevied by (i) presenting an overview of the potentials of the available sources of water for irrigation in the country, and (ii) introducing a model for sustainable agriculture through non-conventional sources of water, smart farming schemes, and agriculture in controlled environments.

2 WATER RESOURCES IN KUWAIT

2.1 Desalination of Seawater

The state of Kuwait has nine water desalination plants that operate, on multiple effect distillation (MED), multi-stage flash (MSF) distillation, and reverse osmosis (RO) technologies (Jones et al. 2019).

Table 1 summarizes some information about the water desalination plants in Kuwait including the year of commission, desalination technology used, and net water production in the year 2019. However, the capacity of the desalination plants is experiencing stress from the gradual increase in water demand over time as presented in Figure 1. The net production of potable (desalinated) water is 409.7 million imperial gallons per day (MIGPD or MIG) (MEW, 2015). Moreover, the average daily demand remained steady at 410 MIGPD, with the maximum consumption in July 2019, at 445.3 MIGPD. This implies that there is always a net deficit between production and demand.

Table 1: Water desalination plants in Kuwait (Central Statistical Bureau, 2021)

Water Desalination Plants	Commission year	Desalination type	Total Net Production in 2019 (m^3/day)
Shuwaikh	1953	MSF-RO	20.3
North Shuaiba	1965	MSF	18.2
South Shuaiba	1971	MSF	35.9
East Doha	1978	MSF	37.0
West Doha	1983	MSF-RO	53.4
South Zour	1987	MSF-RO	103.8
North Zour	2016	MED	21.9
Sabiya	2006	MSF	96.2

MED, multiple effect distillation; MSF, multi-stage flash distillation; and RO reverse osmosis technologies.

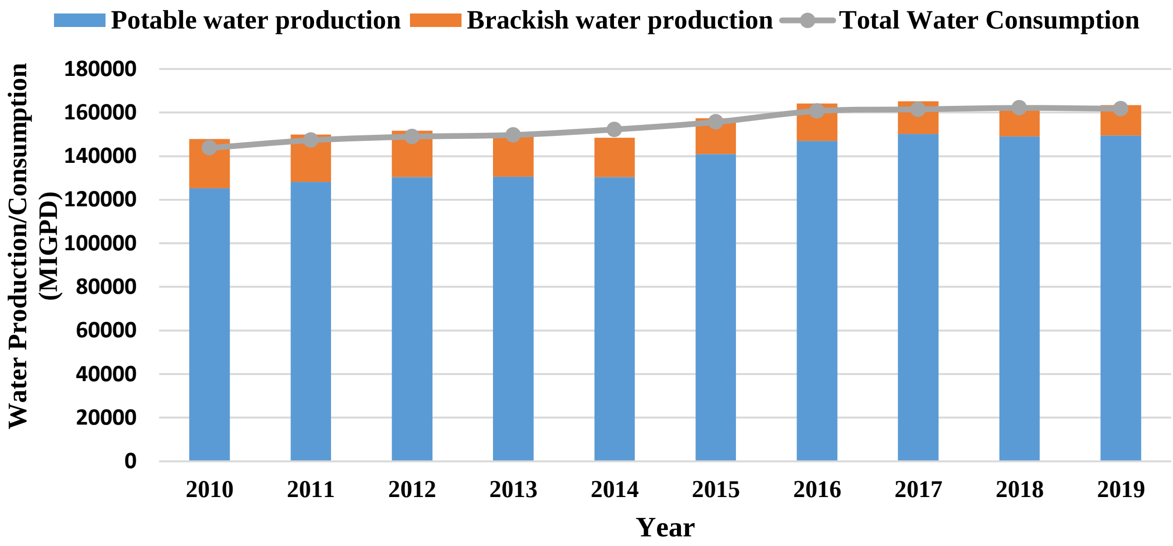

Figure 1. Development of installed desalination capacity, population and water consumption in Kuwait. (After Brebbia, 2018).

2.2 Brackish Groundwater

Figure 2 shows the water quality and iso-salinity (mg/L) of the Dammam Formation. Almost all of the groundwater in Kuwait is classified as brackish or brine. Brackish groundwater is mostly utilized for irrigation and landscaping, cattle raising, construction, non-potable usage in residences, and potable mixing with desalinated water at up to 10% of the total volume (Mukhopadhyay and Akber, 2018). The peak demand for brackish water peaked in 2006 at 36,234 MIGPD. The Ministry of Electricity and Water (MEW) made efforts to reduce the stress demand on brackish water by introducing treated wastewater as an alternative source for irrigation. The MEW production of brackish water reached 1047.4 MIG in 2019, with an average daily production of 32.9 MIGPD. The peak demand always occurs during the summer period. The peak daily use of brackish water in the summer of 2019 was 101 MIG with an annual average of 87 MIGPD (Central Statistical Bureau, 2021). Freshwater consumption in Kuwait has a strong seasonal variation, where peak demand occurs in the summer months. The shortage of desalinated water production is compensated with an increase in brackish water production during the demand months (Figure 3). The production of freshwater was 16% higher than the 2019 annual average (Central Statistical Bureau, 2021).

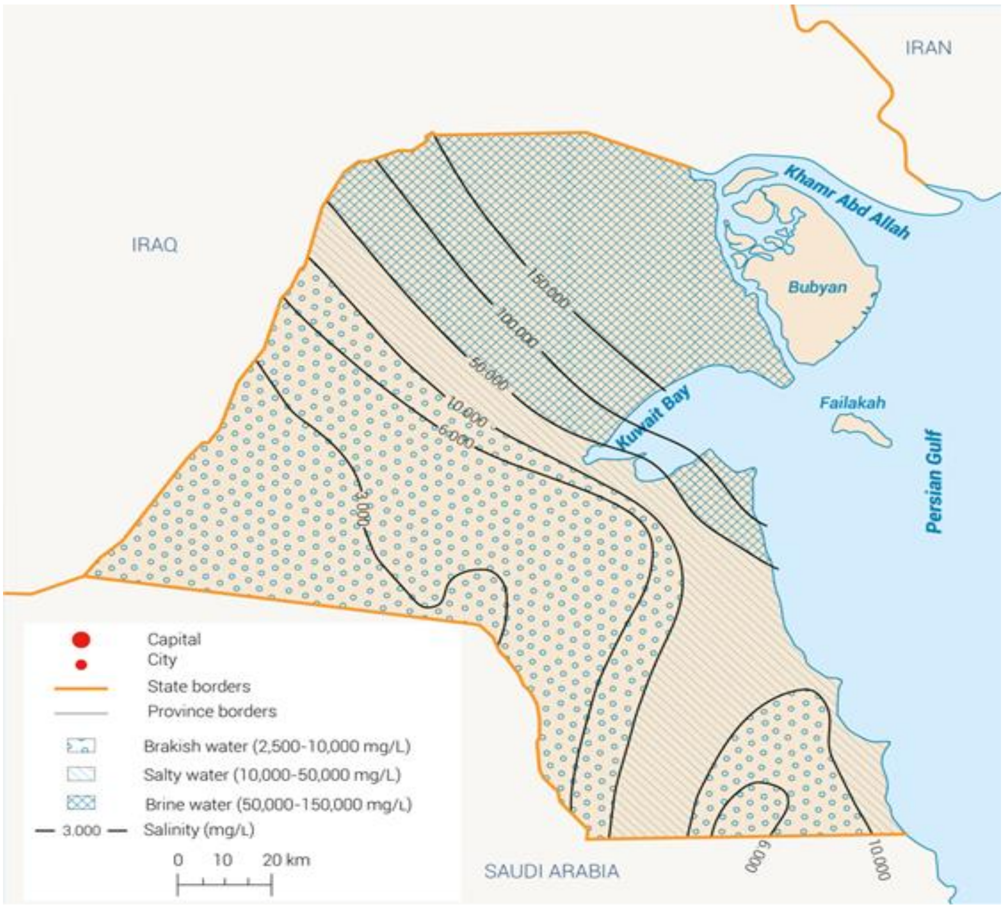

Figure. 2 Water quality and iso-salinity (mg/L) of the Dammam Formation.

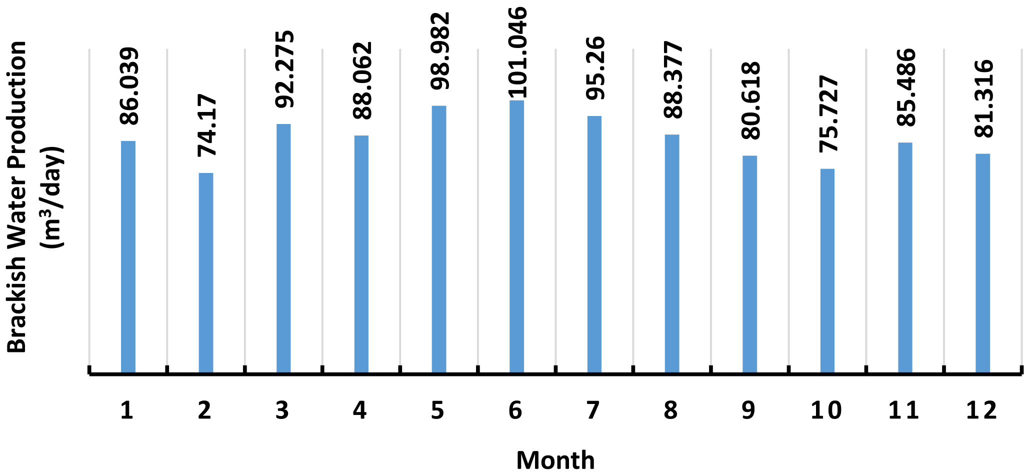

Figure. 3 Monthly brackish water production on the year of 2019 (Central Statistical Bureau, 2021).

2.3 Treated Wastewater

One of the alternative sources of water production is treated wastewater (TWW). In terms of sanitation coverage, Kuwait is the first Arab nation and fifth globally (Aleisa and Al-Zubari, 2017). Municipal wastewater and rainwater flow into waste-water treatment plants (WWTPs) from residences, the government, and commercial buildings (Al Enezi et al., 2004). Stormwater infiltrations are collected in a separate network from wastewater and released into the sea with no treatment. Kuwait's sanitation services are funded through an annual budget set by the government. Total wastewater generation is expected to reach 1 million cubic meters per day (154.6 cubic meters per capita per year), accounting for 70–80% of freshwater demand (Al-Shammari et al. 2013). Figure 4 shows that the annual increase of treated wastewater rises by 7.1%. About 75% of wastewater is treated to RO standards, with 58% being reused. The bulk of treated effluent is first stored in reservoirs at the Data Monitoring Center (DMC), which has a combined capacity of 38000 m^3. This allows for better management and monitoring of the redistribution of treated wastewater (Abusam and Shahalam, 2013).

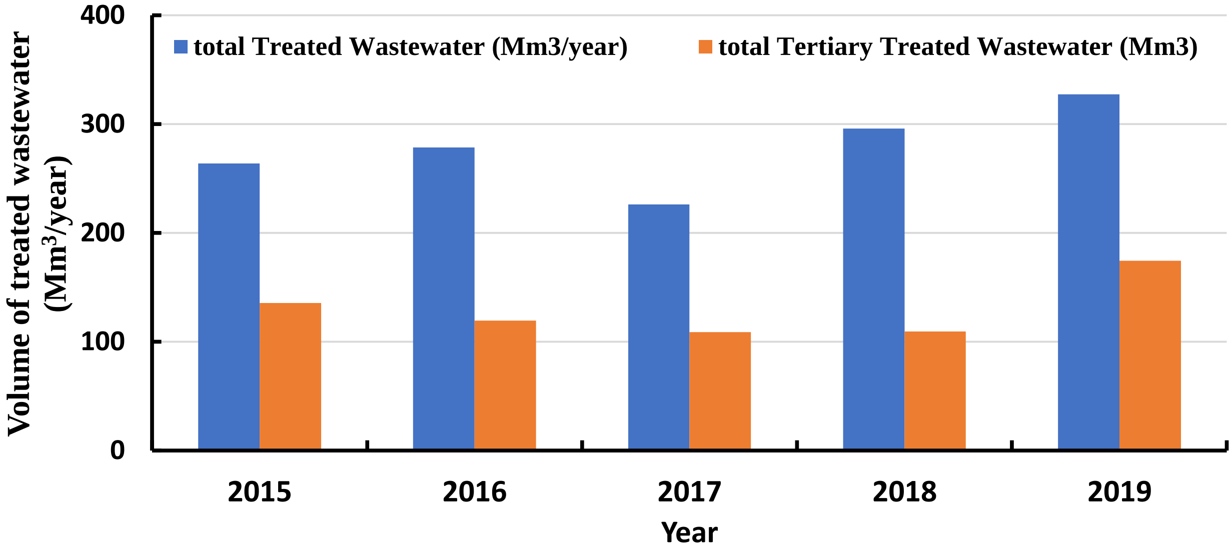

Figure. 4 Treated wastewater in Kuwait in million cubic meters per year (Mm^3) (Central Statistical Bureau, 2021).

2.3.1 Wastewater plants in Kuwait

Table 2 presents a total of six operating WWTPs in Kuwait. These are Alriqqa, Um Alhayman, Al-Wafra, Kabd, Sulaibiya, and Alkhiran (pilot plant). Aljahra WWTP has been converted to a major pumping station feeding Kabd WWTP. The WWTPs in Kuwait have raised treatment quality from secondary to tertiary since 1984 (Abu Al-Rous and Obaid 2021). Aljahra, being the country's oldest, is utilized to treat wastewater from secondary to tertiary treatment in two stages: secondary aeration and tertiary granular media filtration with chlorination (Hamoda et al., 2004, Hamoda 2013). It was decommissioned and turned into the main pumping station since its design capacity could no longer meet the expanding demand. The inflow has been rerouted to the Kabd WWTP (Aleisa et al., 2015). Figure 5 demonstrate the amount of treated wastewater for each treatment plant for the period of 2015-2019.

Table 2: Capacities of Kuwait's wastewater treatment plants (Central Statistical Bureau, 2021).

Treatment plants	Operating Year	Design Capacity (1000 m^3/day)	Average Daily Flow (1000 m^3/day)	Tertiary treated effluent (1000 m^3/day)
Al-Riqqa	1982	180	235	166
Um Al-Hayman	2001	27	2400	15.68
Al-Wafra	2002	6	560	--
Al-Khairan	2009	5.600	2230	--
Kabd	2011	270	150	180
Al- Sulaybiya*	2004	600	450	--

- RO treated water of 32000 m^3/day

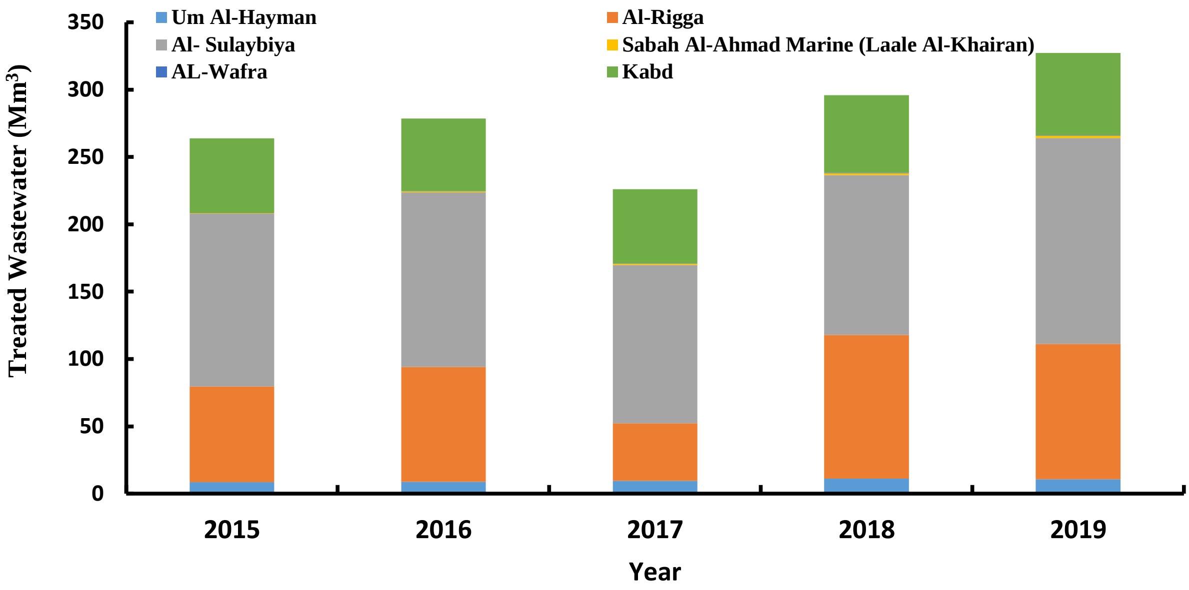

Figure 5 Annual amounts of treated wastewater for the period 2015-2019 (Central Statistical Bureau, 2021).

2.2.2 Reuse of treated wastewater

Even if the quality of the treated wastewater (TWW) exceeds that for potable use, the decision-makers in Kuwait decided to prohibit all amenity uses and limit agricultural usage to safe crops (Pescod, 1992). Recycled water accounts for 19% of all water utilized in the agriculture sector. The TWW is utilized for landscape irrigation and fodder cultivation on a daily basis, but not for edible crops (Aleisa and Al-Zubari, 2017). The TWW is sprayed on golf courses, community gardens, and amenities of the airports, governmental headquarters, and landscapes along major highways, the landscape of Kuwait University's new campus in Shedadiya, natural reserves, and the landscapes and fountains of Kuwait's major malls. The United Company for Agricultural Produce, which produces 70% of Kuwait's cow feed, also uses tertiary processed wastewater to irrigate animal feed, such as alfalfa (Aleisa, 2019).

The DMC pumps treated effluent from Alsulaibiya WWTP to the agriculture farms. A total of 200,000 m^3/day is pumped to Abdally and Wafra farms, while the rest is either dumped into the sea or directed to a constructed lake of Umm Al Rimam (Aleisa, 2019). Research standards revealed that TWW is an excellent alternative source for agricultural irrigation to RO, including raw vegetables and fruits (Aleisa, 2019; Al-Khamsi, 2013). Artificially recharged subsurface reservoirs are not only safe, but they also have the potential to improve the quality of hosted water by providing natural protection against pollution and vandalism, as well as maintaining water at a consistent temperature (Al-Otaibi and Abdel-Jawad, 2007).

It is effective in terms of land usage since it can handle large capacities underground while only requiring a small amount of surface. The storage necessary to provide Kuwait with a stable strategic reserve should be equal to 28.7% of the average annual use, or 111 Mm^3 (Al-Otaibi and Abdel-Jawad, 2007). Ground level and manufactured surface reservoir capacity, on the other hand, is just 9.3 Mm^3, which is only 7% of the needed storage level capacity for water security.

2.2.3 Treated water properties

The Kuwait Environmental Protection Agency (KEPA) set the regulations that control the effluent quality of both tertiary and RO treatment, which are more conservative on numerous criteria than WHO guidelines. Figure 6 shows some chemical and microbiological features of tertiary wastewater

(TWW) based on data collected in Alriqqa and Um Alhayman (Abusam and Shahalam, 2013; Abusam and Al-Haddad, 2016; Aleisa, 2019).

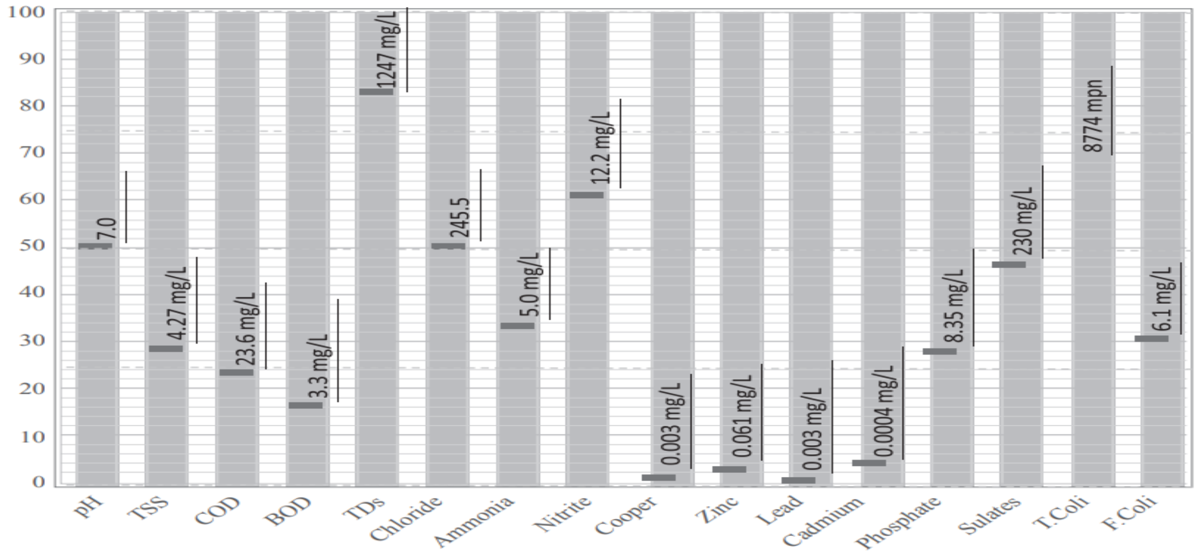

Figure. 6 TWW chemical and biological parameters normalized over Kuwait treatment plants comparable to KEPA standards (after Aleisa, 2019).

The position of the dashes in relation to each column represents the effluent's concentration limits of major elements as per KEPA standards for irrigating landscape and fodder (OECD and FAO, 2021). For a better representation of the limits and goodness with regard to KEPA, the values, and ranges are rescaled to a percentile scale.

2.3 Cost of treated effluent versus desalinated water

Aleisa et. al (2019) conducted a brief cost estimation of treated effluent wastewater against desalinated water. According to the findings, the government pays 2.7 Kuwait Dinars (KD) (US $8.10) for 1 MIG (4,545 m^3) of desalinated water, whereas the tariff is 0.8 KD (US $2.40) for the same volume. The government pays 0.55 KD (US $1.65) and 0.85 KD (US $2.55) for every 1,000 imperial gallons of TWW and RO permeate, respectively (Aleisa, et al., 2011). TWW and RO permeate have tariffs of US $0.36 and US $0.549 per 1,000 imperial gallons, respectively. The substantial discrepancy between the cost and tariff per 1,000 imperial gallons, as illustrated in Figure 7, is attributed to the government's subsidy of water and electricity.

Desalinated water is three times the price of RO-permeate and five times the price of treated wastewater (TTW). This cost-benefit analysis indicates that tertiary-TWW has great potential for agricultural use and reduction of stress of brackish groundwater. The TWW is used for irrigation worldwide.

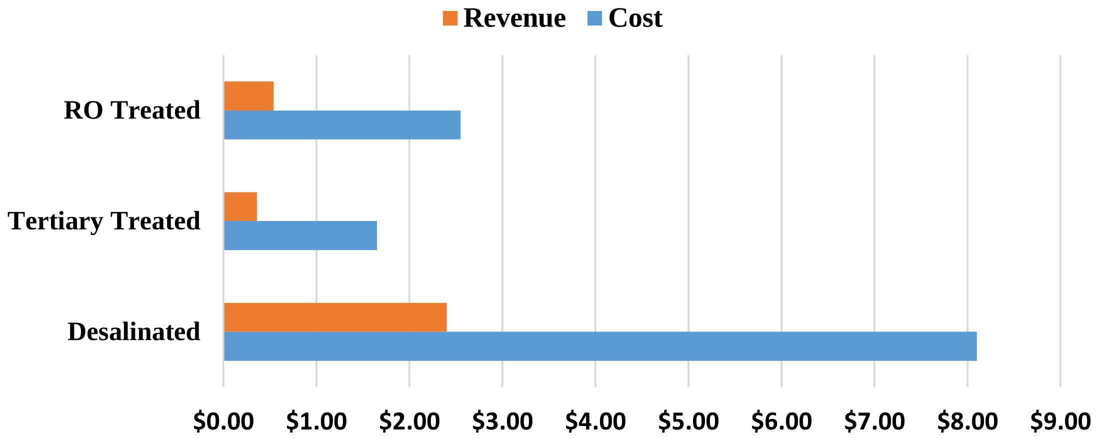

Figure. 7 Kuwaiti costs and revenues per 1,000 TWW imperial gallons (4,545 m^3) of RO-TWW, tertiary-TWW, and RO desalinated. (After Aleisa, 2019)

3 SUSTAINABLE WATER RESOURCES FOR AGRICULTURE IN KUWAIT

Irrigated land, despite its tiny size, contributes significantly to the agricultural output. Although irrigation increases land production dramatically, poor management of this resource results in soil degradation and increases its salinity. TDS of the treated urban wastewater is about (1,300–2,450 mg/L) is another source of water suitable for agricultural usage. Fresh groundwater (600–1,000 mg/L) which is the only natural water resource that may be utilized for agriculture without being treated. However, fresh groundwater is limited and accounts for only 0.4% of groundwater reserves. Brackish water in the amount of 100 million cubic meters (Mm^3) is abstracted annually from various wells around the country.

Brackish groundwater is utilized in landscaping, agriculture, and the oil industry, among other uses. However, this resource is expected to be severely depleted in the next 50 years if current usage rates are maintained. The Sulaibiya Wastewater Treatment and Reclamation Plant, which processes roughly 60% of Kuwait's total residential wastewater through RO technology were inaugurated in March 2005 to address the growing need for irrigation water in Kuwait. During the 30-year concession period, the plant processed up to 375,000 cubic meters of raw household wastewater per day and would eventually grow its capacity to 600,000 cubic meters per day.

When fully operational, the plant is expected to supply 26% of Kuwait's total water consumption, lowering the yearly demand from non-potable sources from 142 to 26 Mm^3. The government of Kuwait greatly subsidizes the cost of water production. The Ministry of Electricity and Water (MEW) spends KD 3.855 (US$14.26) to produce 1,000 imperial gallons (IG) (4,545 m^3) of water, but the user pays just KD 0.8 (US$2.96). Farmers receive treated wastewater from the Sulaibya facility for KD 0.200 (US$0.74) per 1000 IG. The Sulaibya facility treats wastewater using ultrafiltration (UF) and RO, which adds an extra KD 0.500 (US$1.85) to the total cost per 1000 IG.

3.1 Solar Desalination

Several projects have been implemented to test the capabilities of solar power to produce significant amounts of desalinated water for agriculture. The first large experimental project of this type was undertaken in 1992 in Tenerife, often known as the 'Garden of the Gods,' but it has been abandoned since then due to the deterioration of the groundwater quality (Paton and Davies, 1996).

The findings of this pilot experiment confirmed the concept and indicated its applicability in other dry areas. Since the Tenerife greenhouse, two more research centers on 'Seawater Greenhouse Development' have been constructed as part of the same project to test the technology in more harsh climates, enhance water production rates, explore agricultural yields, and improve temperature management. The second Seawater Greenhouse was built in 2000 at Al-Aryam Island in Abu Dhabi, United Arab Emirates. Crop output has been exceptional in terms of both quality and quantity. In conjunction with Sultan Qaboos University, the third system and collaborative research facility were built in 2004 in Muscat, Oman (Davies & Paton, 2005). The findings of this pilot plant operation clearly showed that the amount of desalinated seawater generated by the greenhouse was significantly less than the design values, owing to leaks and a lack of low-temperature cooling water. The remedy is to lower the condenser's temperature and make it even colder. Deep saltwater (lower temperatures) might be used as an option to increase the condenser's performance.

Thermodynamic and economic efficiencies of solar desalination systems for various greenhouse related parameters on the desalination process were determined in this final research (Mattheus et al. 2000). According to simulation tests, the greenhouse's size had the biggest overall impact on water production and energy consumption. Low power consumption and excellent efficiency went hand in hand. A 200 m wide by 50 m deep shallow greenhouse produced 125 m^3 of fresh water per day. When compared to the worst-case scenario with the same total area (50 m wide by 200 m deep), which produced 58 m^3 per day, this was more than a factor of two. Low power consumption and excellent efficiency went in hand. The narrow deep structure used 5.02 kWh/m^3, while the broad shallow greenhouse used 1.16 kWh/m^3. Total freshwater production was also determined for three other variations (temperate, tropical, and oasis) (Mahmoudi et al., 2010). The model predicts that the Seawater Greenhouse will run smoothly throughout the year, with significant differences in performance across the different configurations.

3.2 Controlled-Environment Agriculture (CEA) and smart farming

Controlled-environment agriculture (CEA) allows optimized and tailored growth conditions that result in high and quality consistent produce even in regions of hot and dry environments. They allow the growth of a vast range of agricultural products that usually cannot be grown in such harsh environments. However, the CEA technologies have many obstacles, including technical, economic, and/or environmental challenges. This might be exacerbated by characteristics peculiar to specific contexts, such as Kuwait's interconnected water-energy production system (Albrecht et al. 2018). The CEA technologies, however, have the potential to produce fresh food in nations with environmental constraints as well as local and regional food security problems, thanks to clever design, inventive development, and a supportive legislative framework. Advanced CEA technologies used in a temperature-controlled indoor environment had yields of major vegetable crops cultivated in a desert region by 11 times or more (Abdullah et al., 2021). The potential productivity of indoor farming may be increased even more by vertical agriculture.

The CEA environments can be constructed within the vicinity of metropolitan areas to provide easy access to fresh food with minimum transportation costs. The construction of around 15 km^2 of indoor farms might remove the need to import six key food crops altogether (tomato, potato, green pepper, carrot, lettuce, and cabbage). Vertical farming systems would require less than 0.1 km^2 to obtain the same results (Abdullah et al., 2021). In the Gulf Cooperation Council (GCC) region, indoor and vertical agriculture is a relatively new idea, with no large government initiatives yet. The GCC countries have a unique opportunity for successful implementation of the CEA systems, because of the relatively cheap energy (GCC 2017).

4 KEY CHALLENGES AND OPPORTUNITIES

4.1 Water Challenges in Kuwait

Growing water scarcity and the significant financial, economic, and environmental costs associated with addressing sectoral water demands are Kuwait's key water challenges. Due to factors like population expansion and urbanization, rising food demands, the effects of climate change, unsustainable consumption, water losses, inadequate water reuse, and the ongoing degradation and depletion of groundwater supplies, these problems are predicted to get worse (Aljamal et al. 2020). It is predicted that the freshwater demand could range between 722 MCM/ year and 3,036 MCM/ year by 2025 (Aleisa, 2019). It is getting increasingly difficult to meet the rising water needs brought on by rapid urbanization and population expansion as well as high per capita consumption rates. More sea/brackish desalination facilities must be built in order to meet these demands (Aljamal et al. 2020).

4.1.1 Dependency on Desalination

Kuwait has established a policy of providing municipal water from seawater desalination because of the scarcity of freshwater. This has led to a large share of drinking water (85%) being supplied by seawater desalination plants. By 2024, the installed capacity of desalination plants is anticipated to reach 3.85 MCM/year, according to the Ministry of Electricity and Water (MEW 2015). This implies an expansion of desalination plants and an increase in oil and gas for operation. Currently, 55% of local consumption of energy is linked to desalination plants. The environmental cost will also increase due to more production of rejected (brine) water, and an increase in the levels of air pollution due to the burning of oil and gas.

4.1.2 Inefficient Water Use and Water Networks Leakage

Due to high demand, Kuwait has a high per-person water consumption rate (447 L/capita/d). Because of the widespread usage of subsidies, using economic incentives is challenging. The current tariff has little effect on water use or cost reductions. The distribution system in Kuwait, on the other hand, suffers from a large non-revenue water loss rate (water losses as a result of leakage) (Mukhopadhyay and Akber 2018; Aljamal et al. 2020).(Mukhopadhyay and Akber 2018)

4.1.3 Exploitation of Groundwater Aquifers

There is an overreliance on brackish groundwater for domestic use, as well as for use in agriculture and landscaping. (Akber and Mukhopadhyay 2021)

4.1.4 Limited Reuse of the Wastewater Treatment

The reuse potential of the generated wastewater is not fully developed. The lack of explicit wastewater collection and treatment tariffs causes the effluent to be recovered at a very minimal cost. Such cost-recovery ratios increase the financial weight of the wastewater sector on the budget and make the sector dependent on government funding (Aljamal et al. 2020). Consequently, it deprives the water sector of an enforcement mechanism for water conservation.

4.1.5 Institutions and Legislations

Due to the fragmented nature of the water sector's administrative structures, sub-sectoral water management strategies predominate and prevent the sector from being managed as a whole. There is informal and insufficient coordination of planning between the water industry and other connected industries, especially agriculture and energy (Aljamal et al. 2020).

4.2 Key Challenges and Opportunities of Reclaimed Water for Irrigation

The key challenge of reusing TWW is to sustain suitable water quality for the irrigation of targeted crops. Ensuring appropriate quality is the responsibility of the service provider. With the anticipated population increase in Kuwait, there is a need to increase the capacity of the infrastructure for wastewater treatment to attain the required level of treatment for safe reuse. In addition, farmers must comply with the specific regulations for TWW reuse, especially those related to irrigation methods and the cultivation of permissible crops.

Due to water scarcity, Kuwait's farmers endure using TWW as a source of irrigation water. Desalinated seawater and reclaimed wastewater can be mixed with brackish groundwater. Exceeding TWW quality limits would cause serious health problems to the public if used for irrigating edible crops. Farmers awareness of health impact and safety practices for the reuse of TWW for irrigation is a must for public safety.

Awareness campaigns for the public on the benefits of TWW reuse and its relatively low health impact should also be organized by the related governmental sectors. Public acceptance of water reuse depends on the type of reused water and treatment levels. Acceptance level is expected to be low when it comes to using TWW for irrigating fresh produce than for fiber and wood trees. Educational campaigns are excellent for raising awareness of the benefits of TWW reuse and the development of positive perceptions and acceptance of the public. The additional social challenge of public acceptance should be addressed carefully for TWW-reuse projects. Farm-level management includes three major categories: (1) crop selection and diversification, (2) irrigation management, and (3) soil-based practices such as tillage and fertilization. The management challenge of reusing TWW in a developing country can be attributed to unplanned activities and undefined responsibilities.

In Kuwait, the existing TWW-reuse laws and codes will minimize this challenge. However, there is a need to have applicable executive programs for implementing the TWW-reuse policies. Addressing health and environmental risks is important to be able to successfully implement TWW reuse in agriculture. Continuous monitoring of the environmental impacts of reusing TWW on soils and groundwater is vital. There are significant opportunities for maximizing the benefits of TWW reuse in Kuwait. The increasing population and decreasing water resources will create a growing demand for TWW to reduce the gap between supply and demand. It may be possible to expand the current reuse of the recycled TWW (1.3×10^6 m^3) twofold. The total annual collected wastewater in Kuwait exceeds 5×10^6 m^3, while current national programs target only 2.4×10^6 m^3 for using TWW in afforestation and greenbelts.

There is also an opportunity to improve the infrastructure of the treatment plants that are now treating less than 75% of the collected wastewater. This improvement is supported by recent developments in wastewater treatment technology. TWW is a reliable unconventional water source and should be considered as a resource when cities plan new expansions, especially new urban developments near desert areas in the country. Interdisciplinary research by combining biophysical aspects with social, economic, and policy aspects is very much essential in order to reduce health risks associated with wastewater reuse.

CONCLUSIONS

This study assesses the benefits and challenges of using sustainable water resources for irrigation in the State of Kuwait. This is done by giving a broad overview of the nation's potential irrigation water resources and by creating a sustainable agriculture model using non-traditional water sources, innovative agricultural methods, and controlled-environment agriculture. Municipal wastewater in Kuwait is generally treated at the tertiary level. Recently, reverse osmosis (RO) membranes have been introduced to renovate municipal wastewater to produce high-quality water. The treated wastewater is, therefore, treated wastewater is a very good additional resource for irrigation in the country. Hence, desalination technologies are used to produce freshwater for domestic purposes. Research and development, management of TWW reuse, public knowledge of the related risks and advantages, and the adoption of an administrative framework for using TWW in existing and future urban development are all crucial considerations for sustainable water resources.

RECOMMENDATIONS

The followings are our recommendations for sustainable water resources in Kuwait for irrigation and the safe use of TWW;

- To increase the quality of the produced TWW, scientific research is required to create wastewater treatment methods that are both inexpensive and efficient. Additionally, it is necessary to investigate how small-scale treatment systems or units might be used on a field scale.
- Application of new technologies such as geographic information systems, remote sensing, and modeling in the research of the TWW reuse. Those technologies provide interactive maps and user interfaces that can help stakeholders and policymakers to choose the best implementation of the TWW.
- The management of TWW reuse should adhere to all applicable laws and rules. In order to ensure (i) the quality of TWW for irrigation, (ii) the cultivation of the permitted crops, and (iii) farmers comply with regulations and guidelines for safe TWW reuse, it would be necessary to establish a formal inspection committee made up of representatives from governmental and non-governmental organizations.
- There is an urgent need to have well-defined governmental programs for implementing the TWW-reuse policies especially in the desert expansion of the existing cities or in the planning for new cities.
- Creating effective public awareness programs and campaigns to raise awareness of the nation's current water shortage, conservation techniques, the advantages and disadvantages of TWW reuse in agriculture, and governance initiatives to control TWW use to protect public health and preserve water resources. These programs can be successful if the general people, who frequently utilize TWW for irrigation, are made aware of them through media, extension services, partnerships with water usage stakeholders, and governmental and non-governmental organizations.
- Performance of socio-economic analysis studies to analyze the public acceptance of the TWW reuse in agriculture.
- Analysis of the current and future availability of TWW for long-term use for agriculture in terms of amounts generated and expected treatment quality in Kuwait.
- Assessment of the impacts of the long-term use of TWW on the environment, human health, and agricultural lands of new proposed cities in Kuwait, i.e., urban agriculture.

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No potential conflict of interest was reported by the authors.

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