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Analysis on Reclamation and Reuse of Wastewater in Kuwait

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ABSTRACT

This study provides a general review of Kuwait current treatment and reuse practices of domestic wastewater and focuses on effluent types, quantities of treated and reused water, future plans, challenges, costs, and tariffs, as well as proposing recommendations for better utilization of treated effluent. The study shows that 1Mm^3/d is generated daily with annual per capita production of 154.6 m^3, which is increasing by 3.6% annually. 75% of all wastewater is treated to mostly RO quality, of which 58% is reused. The chemical and microbiological characteristics of tertiary treated effluent (TTE) and RO permeate (ROP) abide by both Kuwait Environmental public authority (KEPA) and WHO standards. 19% of all water consumed in the agricultural sector is recycled water. 270 K m^3 of TTE is used for landscape and fodder irrigation but not for edible produce. RO treated effluents of 318 K m^3/d are utilized for irrigation of crops and natural reserves. Comparisons to water standards indicate that TTE is a better option than ROP for crop irrigation, including vegetables and fruits consumed raw, as it contains essential nutrients that are necessary for plant growth. ROP is best for amities use, injecting depleted aquifers and creating subsurface water reservoirs to provide a strategic reserve for water security requirements. We also recommend that the national standards for treated reclaimed water uses in agriculture need to be adjusted to allow wider reuse of TTE and ROP without harming public health. In addition, more discriminating tests are further needed for WWTP inflow to ensure it adheres to chemical and biological standards to protect bioactivity in aeration tanks and the quality of the effluents.

Keywords: *Wastewater treatment, reuse, recycling, tariff, RO, Kuwait.*

1 INTRODUCTION

Located on the north west part the Arabian (Persian) gulf, Kuwait has an arid environment, characterized by irregular, sparse rainfall, and has the lowest index value for renewable water resources among countries worldwide (Roudi-Fahimi, Creel, & Souza, 2002). Mean annual per capita water renewable sources have already reached the so-called chronic water scarcity line (<500 m^3 per capita/y) (Cisneros, Jiménez, & Asano, 2008). Therefore, Kuwait relies mainly on expensive seawater desalination, followed by extraction of water from non-renewable groundwater resources to satisfy its demand for water (Al-Otaibi & Abdel-Jawad, 2007). Half of the oil production in Kuwait is consumed by co-generation to power desalination plants (Al-Shayji & Aleisa, 2018; Aleisa & Al-Shayji, 2018; Darwish, Al-Najem, & Lior, 2009; Fattouh & Mahadeva, 2014; World Bank, 2005a). Burning this fuel entails considerable ecological and health impacts due to emissions, including greenhouse gases(Al-Shayji & Aleisa, 2018; Aleisa & Al-Shayji, 2018). In addition, desalination brine of high salinity and high temperature is released and contains residual chlorine, heavy metals from corrosion, antiscalant, and antifoaming agents (Abdulraheem, 2010). Kuwait is considering wastewater reuse to reduce consumption of expensive desalinated water, and to reduce overtaxing of depleted aquifers (Aleisa & Al-Zubari, 2017). Reuse of treated wastewater is not only environmentally and financially sound, it is becoming indispensable for meeting the staggering water demand, particularly under conditions of alarming water scarcity (AL-Jarallah, 2013; Al-Shammari & Shahalam, 2006; Aleisa & Al-Shayji, 2018). Currently, the sanitary engineering division of the Ministry of Public Works (MPW) is pursuing a "Zero Release" project, which aims to reduce release of treated and untreated wastewater into the environment to zero and, hence, reuse all wastewater (Karam, 2010). In addition, the project aims to improve and expand the existing sanitation distribution network and plants (Aleisa & Al-Zubari, 2017).

This study provides a general review on current domestic wastewater treatment practices in Kuwait, focusing on wastewater treatment plants (WWTPs), effluent types, treated and reused water quantities, costs, tariffs, and expansion plans. This study also provides recommendations to improve wastewater treatment in Kuwait to alleviate the stress on scarce groundwater resources and provide a relatively less expensive alternative to the environmentally harmful desalination process.

2 WASTEWATER TREATMENT IN KUWAIT

Kuwait is ranked first among Arab countries and fifth globally in the coverage of sanitation services (Aleisa & Al-Zubari, 2017; Prescott-Allen, 2011). Approximately 90% of the total population has access to water and sanitation services (World Bank, 2005a). No fee is charged for wastewater collection in Kuwait. Inflow to the WWTPs is municipal wastewater, which is received from residential, governmental, and commercial buildings as well as surface water (Enezi, Hamoda, & Fawzi, 2004). Storm water infiltrations drain in a separate network from the wastewater network and is disposed untreated to the sea. Sanitation services in Kuwait are funded by an annual budget allocated by the government. The total wastewater generated is approximately 1Mm^3/d and 154.6 m^3/d/capita/y, which is estimated to be 70–80% of the freshwater consumption (Al-Shammari & Shahalam, 2006). The wastewater generation is annually increasing by about 3.6% (see Fig. 1). Approximately 75% of all wastewater is treated mostly to RO quality, of which 58% is reused. Most treated effluent is first stored in reservoirs at the Data Monitoring Center (DMC) with a combined capacity of 38 K m^3, to regulate and monitor the redistribution of treated effluent (A Abusam & Shahalam, 2013).

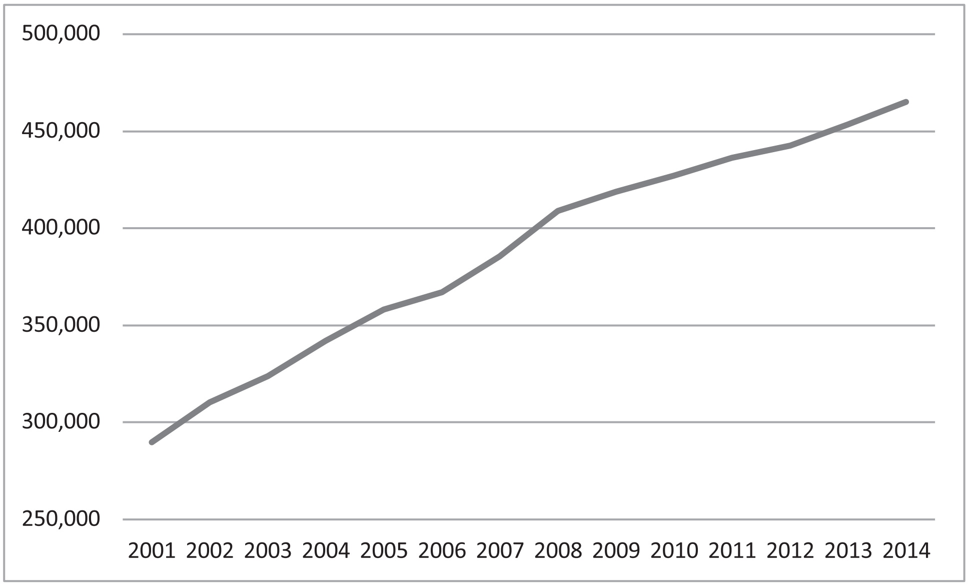

Fig. 1: Wastewater generated in Kuwait in million cubic meters per Year.

As shown in Fig. 2, 750 m^3 of each 1 K m^3 wastewater is treated to most RO quality. In addition, 518 m^3 of every 1 K m^3 of wastewater generated is reused. These values comprise the highest treatment and reuse rates among the Gulf Cooperation Council (GCC) (Aleisa & Al-Zubari, 2017). Thus, approximately 31% of the treated effluent is unutilized. Fig. 2 also shows that every 1.0 K m^3 of wastewater is produced by 9 individuals compared to 16 in the Kingdom of Saudi Arabia (KSA), which indicates a life style of overconsumption, especially with the fact that neither the agricultural nor industrial sectors in Kuwait are as developed as those of KSA.

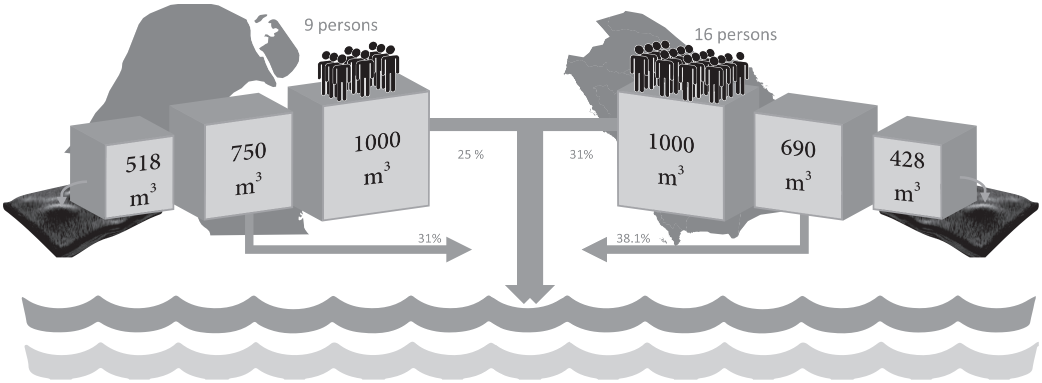

Fig. 2: Treatment and reuse of every 1 K m^3 of sewage water in Kuwait vs. that by the kingdom of saudi Arabia based on (Corcoran et al., 2010) and (Aleisa & Al-Zubari, 2017).

A total of 25% of untreated wastewater is discharged to the sea. A simulation study conducted by Aleisa et al. (2015) shows that the amounts of contaminants discharged into the sea will rise again if the MPW expansion projects to WWTPs did not commence on time. This wastewater contains a range of pathogens, including bacteria, parasites, and viruses and causes deoxygenated dead zones in the sea, accumulation of nitrous oxide, and emissions of methane, a powerful global warming gas (Corcoran et al., 2010). A study conducted by Al-Abdulghani et al. (2013) indicated high concentration phosphate and nitrogen especially in Sulaibikhat Bay (South-West sector of the bay) due to its exposure to anthropogenic activities such as reclamations, and sewage. These concentrations resulted in algae spread or eutrophication (Aljareeda, 2016), which absorbs dissolved oxygen and results in a severe reduction in water quality that kills fish and important microorganisms and reduces biodiversity. Samples collected at different depths from the GCC shores were analyzed using physical, chemical, and microbiological analytical techniques. The results indicate that contamination spreads via the north winds along the Arabian Gulf and plays an active role transferring pollutants to the marine ecosystems (Adnan, 2015; Alameeri, 2014).

3 WASTEWATER TREATMENT PLANTS IN KUWAIT

As shown in Table 1, currently, there are five WWTPs in Kuwait. These are Alriqqa, Um Alhayman, Sulaibiya, Kabd and Alkhiran (pilot plant). Aljahra WWTP that has been converted to a major pumping station feeding Kabd WWTP. WWTPs operate by the governmental sector except for Sulaibiya (Secretariat General of the Gulf Cooperation Council, 2015), some WWTPs have five years operation contracts by private companies. The WWTPs in Kuwait have raised treatment quality from secondary to tertiary since 1984 (Al Khizzy, 2009).

Table 1: Kuwait wastewater treatment plant capacities

	Aljahra	Alriqqa	Um Al Hay-man	Sulaibiya	Kabd	Alkhiran/ Wafra
Commenced	1982	1982	2001	2005	2012	2003
Initial Capacity m^3/d	65K	85K	27K	425K	180K	4K
Expanded/Max Capacity m^3/d	86K	180K	-	600K	270K	-
Current inflow m^3/d	220K	220K	20K	450K	180K	3.84K
Tertiary treated effluent m^3/d	-	166K	15.68K	-	180K	-
RO water treated m^3/d	-	-	-	320K	-	-

*Aljahra converted to a pumping station feeding Kabd WWTP.

3.1 Aljahra

Aljahra WWTP used to be the oldest WWTPs in the country. It used to treat wastewater to tertiary treatment using two main stages; secondary treatment using extended aeration, and tertiary treatment using granular media filtration with chlorination (Hamoda, Al-Ghusain, & Al-Mutairi, 2004). Because its design capacity could no longer accommodate the increasing demand, Aljahra WWTP has been decommissioned and converted it into a main pumping station (PS). Its inflow has been be redirected to a the WWTP in Kabd (Aleisa et al., 2015).

3.2 Alriqqa

Alriqqa WWTP uses the same purification steps of Aljahra WWTP (Hamoda et al., 2004) thus using conventional activated-sludge systems operated in extended aeration mode. Although capacity of Alriqqa WWTP is 180 K m^3/d, the plant is currently receiving over 220 K m^3/d. MPW plans to decommission Alriqqa WWTP and convert it into a DMC. Inflow will be redirected to the Um Alhayman WWTP after expansion. Effluent from Alriqqa WTTP is utilized for irrigating Ahmadi and Ardiya landscapes.

3.3 Um Alhayman

Um Alhayman receives wastewater from the district's main PS and from a sewage pit that receives wastewater via trucks from rural regions (Aleisa, 2008; Aleisa, Al-Ahmad, & Taha, 2011; Taha, 2008). More than 200 septic sewage tank truck loads, which accumulate to more than 6 K m^3/d of wastewater, are unloaded at Um Alhayman WWTP in addition to district sewage. Um Alhayman uses an oxidation ditch system for secondary treatment and uses sand filtration, UV and chlorination for tertiary treatment. Um Alhayman WWTP will be expanded to receive up to 700 K m^3/d by 2020 to replace Alriqqa WWTP (MPW, 2015). Um Alhayman effluent is utilized mainly for landscape irrigation.

3.4 Sulaibiya

The Sulaibiya WWTP and reclamation plant was commenced in 2005 as the largest facility in the world that applies reverse osmosis (RO) and ultrafiltration (UF) membrane water treatment (Hamoda, 2013; Hansen, 2015). The MPW awarded a 30-year concession contract to the developers to treat all sewage water generated from Kuwait City and Hawalli districts in return for a tariff to be paid by the government. This WWTP alone treats approximately 64% of the country's sewage (Aleisa, Al-Shayji, & Al-Jarallah, 2011). The Sulaibiya WWTP is divided into two sections: the biological treatment plant (BTP) and the reclamation plant (RP). Pre-screened effluent from the Ardiya PS first undergoes a backwash of the UF in the BTP. Then, the inlet distributes the resulting flow to nine aeration tanks that are about 8 m deep with a total volume of 208.9 K m^3. The mixed liquor then flows to an 8 m deep secondary clarifiers to be pumped next to the UF plant. The UF plant contains 8,700 UF membranes, each of which has 10 K transpiration tubes. UF purified effluent proceeds to the RO section, which contains 21 K membranes that filters the effluent through three successive stages. As a result, 85% of the inlet to UF/RO is purified, while the remaining is rejected as brine, and is dumped into the sea. Brine with high salinity and residual traces of chlorine and heavy metals (because of corrosion) is released along with anti-scalant and antifoaming agents. These residues combined reduce the amount of dissolved oxygen and lead to serious suffocation of costal organisms, which constitute the marine food chain. Additional technical specifications about Sulaibiya WWTP can be found in Hamoda (2013).

3.5 Kabd

Kabd WWTP has been constructed in an 800 m x 800 m area to handle an average daily flow of 180 K m^3/day and a peak flow of 270 K m^3/day. The plant receives the flow from Aljahra PS through 2 pipelines each which serve a wide area of state of Kuwait. The operation of the plant is completely computer controlled using the most modern state of art technology as Distributed Control System (DCS). Unlike the other WWTPs in Kuwait, Kabd biological treatment uses vertical activated sludge process to improve the denitrification rate, saves energy, enhance flexibility and system reliability of treatment. Some of TTE discharged to bird natural reserves, and land scape irrigation at Aljahra PS, highways and major malls.

3.6 Alkhiran (Wafra)

Alkhiran (Wafra) is a pilot WWTP that recycles wastewater from petrochemical operations reused in oil-related processes. The objective of this WWTP is to decrease pollution in the subsurface water aquifer as a result of re-injecting unclean water (Al-Salem, 2016). Alkhiran WWTP combines membrane-based technology to remove suspended, biological, and inorganic impurities from treated wastewater, so it can be used in this process (Al-Salem, 2016; Napier-Reid, 2000).

4 PROSPECTIVE WASTEWATER TREATMENT PLAN

Kuwait has embarked on major WWTP construction projects, including sewage collection, proper treatment, and increased treated wastewater reuse that will result in an 100% coverage of sanitary services coverage. The prospective projects will also relocate all WWTPs and major PSs out of residential areas for hygienic and recreational reasons. In addition, the prospective wastewater treatment projects aim to improve maintenance practices by abridging PSs. PSs will be reduced to five major stations instead of 60 minor ones. The total cost of the contracts involved is US $2,096,501,153 (Karam, 2015). The prospective WWTP projects have been divided into 16 stages, 8 of which have already been completed:

1. Sulaibiya WWTP capacity will be upgraded from 425 K m^3/d to 600 K m^3/d (Aleisa et al., 2015; Aleisa, Al-Refai, Al-Jadi, & Al-Naggar, 2012; Aleisa, Al-Shayji, et al., 2011; World Bank, 2005b) as it will receive wastewater from Alriggae and Mishrif PSs through Ardiya PS. The Sulaibiya WWTP will pump treated effluent into a DMC. The DMC will monitor and control distribution of the treated effluent to edible crops and natural reserves.

2. The Um Alhayman WWTP will be expanded from 20 K to 650 K m^3/d (Karam, 2015; Taha, 2008).

3. Future Egaela PS will be constructed instead of stations A14 and A15 (Aleisa et al., 2015). It will receive wastewater from Ahmadi and the Mubarak Al Kabeer districts and will have capacity of 360 K m^3/d (Karam, 2015).

4. Future PS at Alriggae will be constructed with a capacity of 800 K m^3/d to substitute for 29 existing PSs (Aleisa et al., 2015). Thus, it will cut on high operational and maintenance costs. Alriggae PS will serve both Kuwait City and Farwaniya districts (Aleisa et al., 2015).

5. The plan also includes replacing the dilapidated pumping and lifting stations and constructing new pipelines with greater depths to improve water flow, as well as exchange current manholes to accommodate future demand (Karam, 2015).

6. Ardiya PS will be expanded to receive around 600 K m^3/d, which will work as a pretreatment and PS receiving wastewater from Alriggae and Mishrif PSs (Aleisa et al., 2015).

5 EFFLUENT PROPERTIES

The effluent quality of both tertiary and RO treatment is regulated by KEPA standards, which are on several parameters more conservative than those of WHO. Nonetheless, this does not necessarily indicate an advantage as it may lead to lost opportunities in effective utilization of recycled wastewater. Fig. 3 depicts some chemical and microbiological characteristics of tertiary treated effluent (TTE) averaged over values obtained from Aljahra (former WWTP), Alriqqa, and Um Alhayman (Abusam & Shahalam, 2013; Al Khizzy, 2009; Hamoda et al., 2004). It provides the characteristics in order of magnitude (shown as a horizontal line mark) for acidity (pH), total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total dissolved solids (TDS), chlorides, ammonia, nitrites, copper, zinc lead, cadmium, phosphates, sulfates, total coliform (T. coli), and fecal coliform (F. coli). The location of the dashes with respect to each column depicts the position of the effluent with respect to KEPA standard limits for contaminant levels for irrigation to landscape and fodder (FAO; WHO, 2006). The values and ranges are rescaled to a percentile scale for better visualization of results and goodness with respect to KEPA. The normalization is calculated using Eq. 1, where is the parameter value of effluent to be normalized; and indicate a score range from 0% to 100%, respectively; and indicate minimum and maximum allowable limits for each parameter separately as for KEPA (FAO; WHO, 2006) .

$$a+\frac{(x-A)(b-a)}{(B-A)} \tag{1}$$

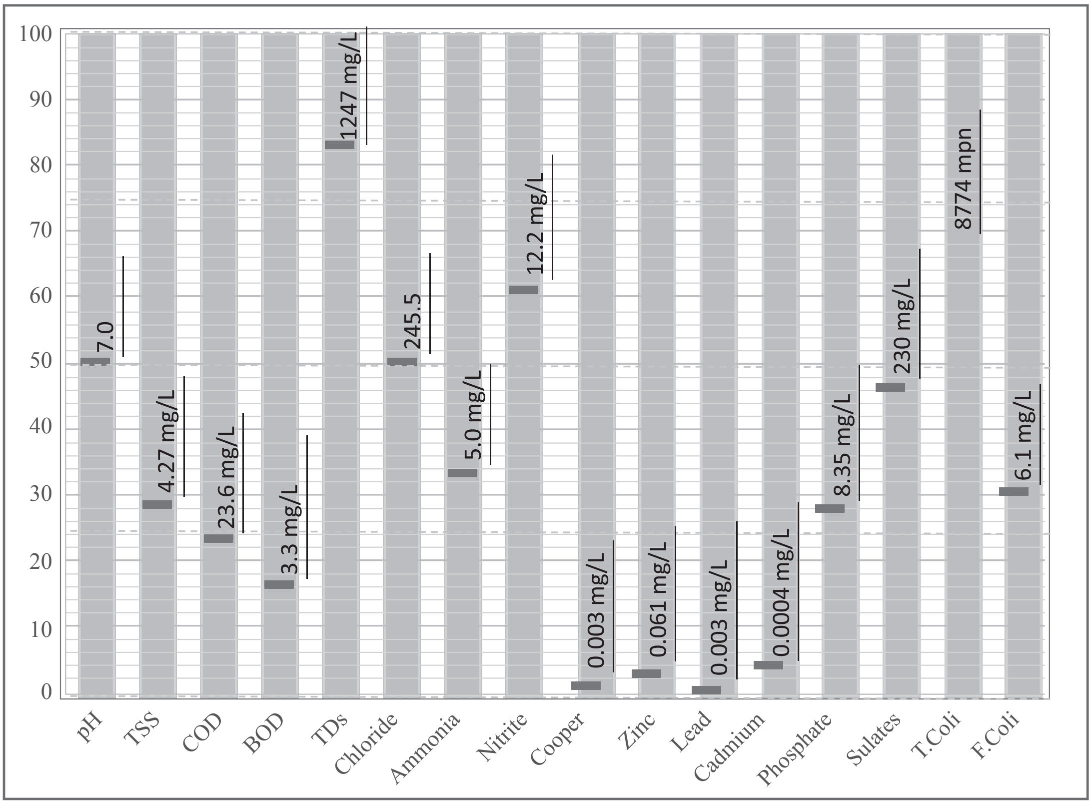

Fig. 3: Normalized chemical and biological Parameters of TTE Average over treatment plants in Kuwait compared to KEPA standards (Abusam & Shahalam, 2013; Al Khizzy, 2009; Hamoda et al., 2004)

The normalized results show that TTE adheres to Kuwait environmental protection authority (KEPA) standards. In addition, WHO recommends that only treated wastewater with a total most probable number (MPN) of less than 100 colonies per 100 ml in 80% of the samples examined can be utilized for irrigation. In Kuwait, TTE adheres to this count (Kuwait News, 2015). No outbreaks of infectious disease have occurred since 1976 when utilization of treated water took place (FAO). However, on some incidences effluent quality of Aljahra former WWTP and Alriqqa plants show some rise in some parameter specifically chlorides and TDS, which renders it suitable only for restricted irrigation use (Malallah & Daifullah, 2008). This is due to overloading those WWTPs (Aleisa & Al-Zubari, 2017). As indicated earlier, Aljahra WWTP has been decommissioned and transformed into a PS feeding Kabd, while Alriqqa will be converted into a DMC. Al-Shammsari et al. (2013) show that the effluent also adheres to WHO (2006) remaining parameters for landscape irrigation. In addition, illegal connections to the main sewers from industrial services and slaughterhouses (Ghobrial 1993, Secretariat General of the Gulf Cooperation Council 2015) carry toxic elements to WWTP. Traces of heavy metals, such as cadmium, chromium, copper, mercury, nickel, lead, and zinc, have been detected in sewage arriving at WWTPs (Enezi et al. 2004). These metals interfere with the microbiological activity in the WWTP and degrade treatment efficiency and quality.

On the other hand, RO treated permeate (ROP) not only exceeds the standards for irrigation of KEPA (KEPA,

2001) and MEW but also satisfies those for potable water quality of both WHO (2012) and KEPA (Hamoda, 2013) , including taste, color, turbidity, and odor requirements. Records indicate that ROP of Sulaibiya WWTP remained within potable use standards (Hamoda, 2013) during the past ten years with no cases of violations (Abusam & Al-Haddad, 2016; Hamoda, 2013). ROP properties obtained from Sulaibiya WWTP are provided in Table 2 and Table 3.

Table 2: RO Permeate quality for Sulaibiya WWTP Averaged over July 2016 to January 2017

Test	*Min*	*Max*	*Average*	*KEPA*
Ammonia Nitrogen (mgN/l)	0	0.46	0.088	1.5
Biochemical Oxygen Demand (5 Days) (mg/l)	0	0.55	0.053	20
Grease & Oil (mg/l)	0	0.06	0.006	5
Hardness (mgCaCO3/l)	1.46	4.12	3.58	500
Nitrate Nitrogen (mgN/l)	0.41	1.16	0.820	3
pH	6.13	7.4	6.82	6.5-8.5
Sulphides (mg/l)	0	0.001	0.00	.05
Total Dissolved Solids (mg/l)	27.9	55	37.97	600
Total Organic Carbon (mg/l)	0.1	18	0.272	
Total Phosphate (mgPO4/l)	0	0.73	0.178	
Total Suspended Solids (mg/l)	0	0.2	0.009	15
Volatile Suspended Solids (mg/l)	0	0.1	0.004	
Total Coliform (CFU/100ml)	0	0	0.0	200µg/l

Table 3: Trace metals for RO Permeate for Sulaibiya WWTP

Test	*Unit*	*Results*	*KEPA*
Cadmium	µg/l	0.00	0.003 mg/l
Cobalt	µg/l	0.00	0.2 mg/l
Chromium	µg/l	0.721	0.05 mg/l
Copper	µg/l	0.00	2 mg/l
Nickel	µg/l	0.752	0.2 mg/l
Lead	µg/l	0.00	0.01 mg/l
Zinc	µg/l	2.576	3 mg/l
Aluminium	mg/l	0.038	0.2 mg/l
Total iron	mg/l	0.035	0.3 mg/l
Manganese	mg/l	0.002	0.1 mg/l
Sodium	mg/l	12.786	200 mg/l

6 EFFLUENT REUSE

In Kuwait, the decision was taken to exclude all amenity uses for the treated effluent and to restrict agricultural use to safe crops (FAO) even if quality exceeded that for potable use. Nineteen percent of all water consumed in the agricultural sector is recycled water. 270 K m3 of TTE is used daily for landscape irrigation and to produce fodder but not edible production (Aleisa & Al-Zubari, 2017). TTE is pumped onto golf courses, community gardens (Sabah Al Salem, Aumaria and Rabia), airports, governmental headquarters, and landscapes on major highways (Karam, 2015), the landscape of the new campus of Kuwait University in Shedadiya area, the natural reserves, and landscapes and fountains of major malls in Kuwait . The United Company for Agricultural Produce, which supplies 70% of cattle feed consumed in Kuwait, also utilizes tertiary treated wastewater (TTE) for irrigating livestock feed (Johar & Al-Alawi, 2008), such as alfalfa (Karam, 2015).

A pilot study for using TTE in extinguishing fires in Amghara area has yielded excellent results in speed of controlling the fire and avoiding flashovers. Nowadays, the local fire service directorate is arranging with the sanitary sector of Ministry of Public Works (MPW) to provide fire vehicles and equipment with treated wastewater. In addition, a joint project between the MPW and the Kuwait Oil Company (KOC) aims to utilize treated wastewater to be injected in oil wells during extraction instead of using natural gas to increase production by boosting depleted pressure in oil reservoir formations. Future use of TTE is directed towards industrial activities as a coolant. Most of the TTE used in these projects originate from Alriqqa and Aljahra WWTPs (Al Khizzy, 2009).

On the other hand, ROP from Alsulaibiya WWTP is pumped to crop farms through the DMC (Karam, 2015). A total of 200 K m^3/d are pumped to Abdally and to Wafra farms (Kuwait News, 2015), while the remaining is either sent to a manmade lake (Umm Al Rimam) or is discharged to the sea. This is due to the lack of supporting infrastructure for redistribution in the meantime. Besides, farm owners in areas supplied by ROP complain about the slow pumping rate, particularly during summer. This is because the location of the Sulaibiya WWTP is not convenient to supply water to relatively distant farms as this was not the intention for the plant during the design stage. The location of Sulaibiya WWTP was deliberately chosen due to the abundance of brackish aquifers in the area, where the original plan was to use the ROP for brackish aquifers' reinjection. However, due to public opposition, the MPW backed away from this objective and redirected the treated effluent to crop irrigation.

Although the local regulations prohibit it, research shows that TTE is a better option than RO for crop irrigation, including vegetables and fruits consumed raw (Al-Khamsi, 2013; Al-Shammiri, Al-Saffar, Bohamad, & Ahmed, 2005; Alhumoud, Behbehani, & Abdullah, 2003). This is because treated TTE contains essential salts as potassium, iron, magnesium, copper, boron, etc., as well as nutrients, such as nitrogen and phosphate that are necessary for plant growth. This saves cost of organic and inorganic fertilizers and chemical compounds that are typically added to maximize crop yield. Hence, the national standards for treated reclaimed water uses in agriculture need to be adjusted to allow wider reuse of TTE without harming public health. ROP, on the other hand, is more beneficial when used for injecting depleted aquifers (Al-Shammari et al., 2013), to replenish them and provide a strategic reserve for water security requirements (Al-Otaibi & Abdel-Jawad, 2007), and to avoid seawater intrusion to aquifers. Concerns for contaminating aquifers by treated wastewater to RO quality are improbable especially with the fact that records reveal that all effluent of Sulaibiya WWTP remained within potable use standards (Hamoda, 2013) during the past ten years with no cases of violations so far (Abusam & Al-Haddad, 2016; Hamoda, 2013). Storing water underground is far more efficient than storing water in surface reservoirs (Sticklor, 2014). Subsurface reservoirs created using artificial recharge techniques not only are safe, they also could improve the quality of hosted water while constituting natural protection against pollution and vandalism as well as keeping water at uniform temperature (Al-Otaibi & Abdel-Jawad, 2007). In addition, Underground water storage (a.k.a. managed aquifer recharge) is cost effective, as it only comprises 10% of the cost of typical manmade water reservoirs with no post treatment required for withdrawal. Storing water underground minimizes evaporation, which is a major cause of water loss in surface reservoirs in arid and semi-arid climates (Sticklor, 2014). It is efficient in terms of land-use as it can handle huge capacities underground with minimum surface requirements (Al-Otaibi & Abdel-Jawad, 2007). The required storage to supply reliable strategic reserve for Kuwait should comprise 28.7% of the average annual consumption, which is equivalent to111 Mm³ (Al-Otaibi & Abdel-Jawad, 2007). However, the capacity of ground level and manmade surface reservoirs capacity is only 9.3Mm³, which constitutes 7% of the required storage level capacity for water security.

7 COST OF TREATED EFFLUENT VERSUS DESALINATED WATER

The cost for 1 K imperial gallons (4,545 m^3) of desalinated water in Kuwait is 2.7 Kuwait Dinars (KD) (US $8.10) to the government, whereas the tariff is 0.8 KD (US $2.40) for the same volume (Al-Humoud & Al-Ghusain, 2003). TTE and ROP production costs the government 0.55 KD (US $1.65) and 0.85 KD (US $2.55) per 1 K imperial gallons, respectively (Aleisa, Al-Shayji, et al., 2011). The tariff to consumers is US $0.36 and US $0.549 per 1 K imperial gallons for TTE and ROP, respectively (Al Khizzy, 2009; Karam, 2010). As shown in Fig. 4, the large difference between the cost and tariff per 1 K imperial gallons is due to government subsidies for water and electricity. Desalinated water costs three times more than ROP and five times more than TTE.

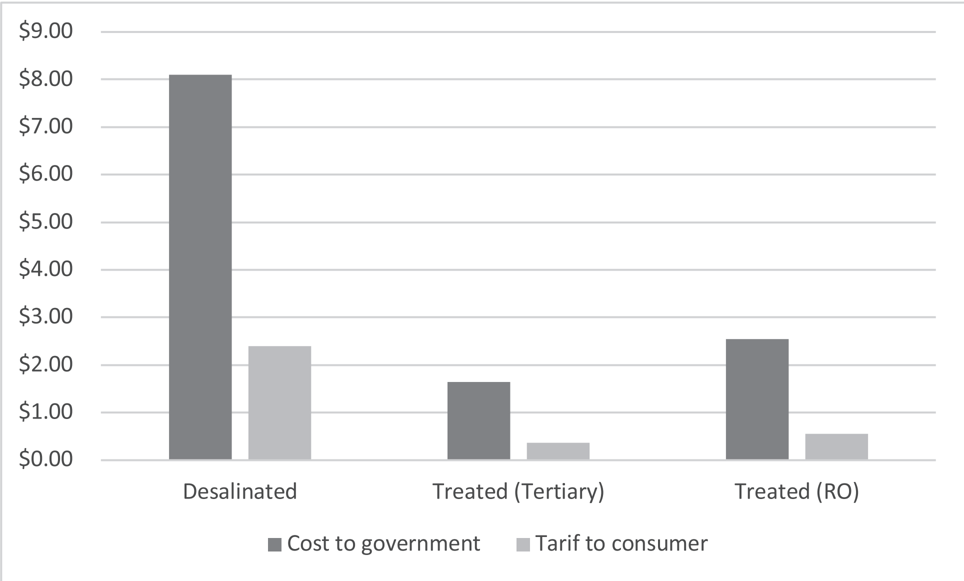

Fig. 4: Costs and revenues per 1 K imperial gallons (4,545 m^3) in Kuwait

8 RECOMMENDATIONS

Given the scarcity of natural water resources in Kuwait and increasing demands, treated wastewater is a vital nonconventional water resource to reduce dependence on expensive and environmentally unfavorable water desalination, as well as to alleviate stress on the overtaxed brackish-water aquifers. The five WWTP are being upgraded to satisfy demand and growth while aiming to achieve the country's strategic goal of "zero" wastewater released untreated and unutilized. In Kuwait, out of every 1 K m^3 of wastewater generated 750 m^3 is treated mostly to RO quality and 518 m^3 is reused. Thus, approximately 31% treated effluent is unutilized, and 25% of sewage is discharged untreated, this percentage however is decreasing quickly. The regulations exclude all amenity uses for the treated effluent and to restrict agricultural use to safe crops even if its quality exceeded that for potable use. Hence, TTE is utilized for landscaping and fodder irrigations, whereas ROP is utilized for irrigation of crops and natural reserves. Nonetheless, this has led to lost opportunities in effective utilization of recycled wastewater. Research shows that TTE is a better option than ROP for crop irrigation, including vegetables and fruits consumed raw. This is because treated TTE contains essential salts and nutrients that are necessary for plant growth. This saves cost of organic and inorganic fertilizers and chemical compounds that are typically added to maximize crop yield. ROP water quality, on the other hand, is best for amities use and injecting depleted aquifers to provide a strategic reserve for water security requirements. Concerns for contaminating aquifers by treated wastewater to RO quality are improbable especially with the fact that records reveal that all effluent of Sulaibiya WWTP remained within potable use standards since its commencement in 2005. Creating subsurface reservoirs using ROP artificial recharge techniques not only are safe and cost effective, they also could improve the quality of hosted water while constituting natural protection against pollution and vandalism as well as keeping water at uniform temperature. This indicates that the national standards for treated reclaimed water uses in agriculture need to be adjusted to allow wider reuse of TTE without harming public health while using ROP for amenities, and aquifer recharge. More discriminating tests are further needed for WWTP inflow to ensure it adheres to chemical and biological standards to protect bioactivity in aeration tanks and the quality of the effluents.

Besides the above, we also recommend the following:

1. Obtaining political and social support to reinforce the necessity of the reuse of treated water in the presence of a legal and regulatory framework with specific responsibilities in terms of planning, financing of investments, implementation, operation and maintenance and monitoring of sewage plants.

2. Disseminating awareness to increase the public acceptance of reusing reclaimed water. Educational curricula must be further enriched regarding the adverse implications of water consumption on the environment and public health.

3. Diversification of the utilization of TTE and including industrial uses, such as cooling, concrete mixing (Al Ghusain, 2003), and other applications.

4. Utilization of sludge produced as a byproduct from all WWTPs. Only a small proportion of the sludge is fed back to the aeration tanks, to support bioactivity; the rest is send to drying sun beds, then disposed. Future MPW projects, particularly for Kabd, include utilizing sludge to generate electricity (Al Diqbassi, 2010) or as manure for non-edible crops. Although no projects yest have been conducted in this regard, more studies are needed to test the feasibility of utilizing sludge for energy production.

5. Improving the infrastructural projects for redistributing treated effluent and adopting artificial recharge techniques for subsurface reservoirs.

6. Encouraging privatization of WWTPs by facilitating loans, loan guarantees, credits, tax exemptions, and other financial incentives.

7. Banning illegal connections to the main sewers from industrial services and slaughterhouses as they carry trace elements and organic pollutants that interfere with the microbiological activity of WWTPs and degrade treatment efficiency and quality.

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دراسة حول ممارسات إعادة استخدام مياة الصرف الصحي في الكويت

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الخـلاصة

تقدم هذه الدراسة استعراضاً شاملاً لمعالجة المياه وممارسات اعادة استخدامها في الكويت مع استعراض أنواعها والخطط والتحديات المستقبلية والتكاليف والرسوم المفروضة، وكذلك تقدم الدراسة توصيات لتحسين الاستفادة منها بأنواعها. ويبلغ الانتاج الكلي من مياه الصرف الصحي مليون متر مكعب يوميا، ما يعادل 154.6 متر مكعب للفرد في السنة وتتزايد هذه الكميات بمعدل 3.6 ٪ سنويا. يتم معالجة ما يقارب 75 ٪ منها ويتم اعادة استخدام 58 ٪ معظمها الى المرحلة الرباعية. وتختضع الخصائص الكيميائية والميكروبيولوجية للمياه المعالجة ثلاثياً ورباعياً لمعايير الهيئة العامة للبيئة الكويتية ومعايير منظمة الصحة العالمية. 19 ٪ من المياه المستهلكة في القطاع الزراعي هي من المياه المعاد تدويرها. 800 ألف متر مكعب يوميا يستخدم لري المسطحات الخضراء وإنتاج العلف والمحاصيل غير الصالحة للأكل. يتم استخدام مياه الصرف المعالجة رباعيا والتي تبلغ 400 ألف متر مكعب في يوم لري المحاصيل والمحميات الطبيعية. وتبين المقارنات مع معايير المياه أن المياه المعالجة ثلاثيا هي أفضل من الرباعية لري المحاصيل، بما في ذلك الخضار والفواكه، لاحتوائها على العناصر الغذائية الضرورية لنمو المحاصيل، في حين تعتبر المياه المعالجة رباعياً أفضل للاستخدام البلدي، ولإعادة حقن طبقات المياه الجوفية المستنزفة ولعمل خزانات مياه جوفية لتوفير احتياطي استراتيجي لمتطلبات الأمن المائي. وعليه نوصي بضرورة تعديل المعايير الوطنية لاستخدامات المياه المعالجة للسماح بإعادة استخدام أوسع نطاقا للمياه المعالجة ثلاثيا ورباعياً دون الإضرار بالصحة العامة. وبالإضافة إلى الحاجة إلى مزيد من الاختبارات التمييزية للتدفقات الواردة لمحطات معالجة مياه الصرف الصحي لضمان التزامها بالمعايير الكيميائية والبيولوجية لحماية النشاط الحيوي في خزانات التهوية وجودة مخرجاتها.

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