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The future of wastewater treatment and reuse in Kingdom of Saudi Arabia

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ABSTRACT

The Kingdom of Saudi Arabia (KSA) is an arid country facing the challenge of renewable freshwater availability. KSA has an area of about 2.25 million km^2. KSA has no perennial rivers or permanent freshwater bodies. KSA has low rainfalls with high evaporation rates which makes it very dry country. After discovering oil, KSA has witnessed remarkable economic development and rapid increase in population with migration to the urban areas in the past four decades. KSA population increased from about 4 million in 1960 to about 32.5 million in 2018. These developments lead to more pressure due to increased demand on the scarce freshwater resources. In order to meet the growing water demands, the limited renewable freshwater resources have been heavily overexploited. Groundwater aquifers are the main natural renewable freshwater source in the country. The average per capita municipal daily water use in KSA has been increasing since 2009 when it hit 227 L/d and recorded a gradual increase to touch 270 L/d in 2016 which is the 3rd highest in the world. Faced with increasing water scarcity and gaps between water supply and demand, policymakers in KSA started to consider the treated wastewater as a major renewable water source and aim to achieve full utilization and reuse of treated wastewater by 2025. With a desalination capacity of about 2,500 million cubic meters per year which represents 30% of the world's desalination capacity, KSA is the largest seawater desalination producing country. However, desalinated water alone will not be able to supply enough freshwater to meet the increasing future water demand. However, with only 10% of the total municipal wastewater generated currently being reused, KSA is projected as the third largest reuse market after China and the USA, and reuse capacities are projected to increase by 800% by 2025. The projected growth and change in water portfolios offer tremendous opportunities to integrate novel approaches of water reclamation and reuse such as aquifer recharge and groundwater quality enhancement, district cooling and irrigation of reactional areas. Recent statistics in 2018 indicated that the volume of treated wastewater used to produce freshwater in KSA was approximately 390 million cubic meters per year. This statistic shows the revenue of the industry "sewerage" in Saudi Arabia from 2012 to 2017, with a forecast to 2024. It is projected that the revenue of sewerage in Saudi Arabia will amount to approximately 739.3 million U.S. Dollars by 2024. The KSA's treated wastewater utilization status up to date and the main key challenges facing KSA such as the substantial growth in wastewater services demand; low coverage of existing wastewater collection systems, treatment facilities, and reuse options; and the needed governmental capital investment in wastewater infrastructure development were analyzed. It has been recommended that there are initiatives that should be taken thus far to tackle these challenges towards successful achievement of KSA's efficient wastewater treatment and reuse.

Keywords: Public acceptance; Wastewater revenue; Water quality; Aquifer recharge; Water reclamation

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1. Introduction

Kingdom of Saudi Arabia (KSA) covers an area of about 2.25 million km^2 located in arid and hyper arid region has limited renewable freshwater resources with no perennial rivers or permanent freshwater bodies. KSA is considered as one of the driest areas due to low rainfall and high evaporation rates. After the discovery of oil reserves in early of 1950, KSA has witnessed remarkable economic development and rapid increase in its population in the past four decades. The population of KSA increased from less than 4 million in 1960 to more than 32.5 million in 2018. The population is expected to reach more than 56 million by 2050 [1]. In the 1980s, KSA started an ambitious agricultural development program to increase its food self-sufficiency ration and increase its agricultural production. Groundwater over abstraction from the non-renewable aquifer systems, resulted in substantial declines in groundwater levels and deterioration in groundwater quality [2]. Behaviors such as water supply-based policies, increasing population growth, and agricultural policies, urbanization, and rising living standards led to unsustainable scarce freshwater use [3]. KSA has limited non-renewable groundwater reserve with very limited recharge rates to renewable groundwater aquifer systems [4]. Despite the fact that renewable freshwater resources are very limited, the domestic sector in KSA consumes about 8.5 million cubic meters of water daily. While the global average renewable water resource per capita per year is 6,000 m^3, KSA has only 84.8 m^3/cap/y [5]. In spite of the water scarcity, Saudi Arabia has the third highest water consumption per capita at 250 l/cap/d. The country's water demand is expected to increase by 56% by 2035. Meanwhile, at the current rate of water withdrawal, ground water aquifers are expected to provide potable water only for the next 10–30 y. Recently, water sector in KSA is facing several challenges that threaten water, food, and energy security. Fuel subsidies and desalinated water production deplete the country energy resources along with consequent environmental cost, low water tariffs, and the increased leakage from water main transmission and distribution networks. These factors affect drinking water and wastewater production and treatment costs [6]. Sustainable development in KSA is facing the challenges of renewable freshwater resources scarcity and the ever-increasing water demand. With its present (2019) annual desalination capacity of nearly 2,500 million m^3 (about 30% of the world's desalination capacity), KSA is ranked as the first largest desalinated water producer. However, desalinated water alone will not be able to supply enough freshwater to meet the increasing future water demand. Only 10% of the total wastewater generated currently being reused. The projected growth and change in water portfolios offer tremendous opportunities to integrate novel approaches of water reclamation and reuse. Recent statistic in 2018 indicated that the volume of treated wastewater used to produce freshwater in KSA was approximately 390 million cubic meters per year. The statistic also indicated that the operating revenue from sewerage sector in KSA in 2018, was 629 million U.S. dollars. The main key challenges facing KSA wastewater sector are the substantial growth in wastewater services demand; low coverage of existing wastewater collection systems, treatment facilities, increasing the utilization and reuse ration and the needed governmental capital investment in wastewater infrastructure development.

2. Overview of the water resources in the Kingdom

With a semi-arid environment, KSA is exposed to temperature variability, low annual rainfall, no natural perennial water bodies such as rivers or freshwater lakes, and non-renewable groundwater aquifer systems with limited reserves [7]. KSA has an annual rainfall less than 100 mm with very high evaporation rates of about 2200 mm, which limits its surface water resources and supplies. Due to limited surface water, KSA relied on groundwater over abstraction which led to aquifers water levels decline and groundwater quality deterioration. Despite the increase of desalinated water, the percentages by different sources (i.e., surface water (11%), groundwater (73%); desalination (11%), and wastewater treatment (5%)) [8]. Water resources in KSA are classified into two main groups: conventional resources including surface water and renewable and non-renewable groundwater, and non-conventional resources including desalinated and treated wastewater. Various water resources with their share in KSA are shown in Table 1. The daily per capita average water consumption in KSA is considered high and ranges from 270 to more than 500 L/cap/d in some of the KSA cities as shown in Fig. 1, the government target is to minimize the per capita daily water use to less than 150 L by 2030. In the 5-years plan (2015–2019) KSA water sector financial requirements are more than USA$65 billion as shown in Fig. 2. In 2018 both renewable and non-renewable groundwater contribute by about 38% and surface water with about 3%, while the remaining is from desalination which is about 59%. The government target is to reduce the contribution of surface and groundwater to only 10% and 90% will be from desalination. Fig. 3 shows the targeted mix in water supply in KSA by 2030 [9]. Treated wastewater provides about 5% of the total water supply. Treated wastewater quality analysis results indicated that it is safe to be reused for industrial processes, district cooling, groundwater aquifer recharge, and for agricultural irrigation. The total annual treated wastewater produced in KSA in 2019 was 850 million m^3 (MCM). Out of them 375 MCM were reused and about 185 MCM were used in agriculture irrigation [10]. The use of recycled wastewater lessens the dependence and reduces the pressures on the limited freshwater resources. It also reduces the amount of treated and non-treated effluent into the environment. These effluents deposit organic and inorganic nutrients (e.g., nitrogen and phosphate) into water systems, which can cause eutrophication and algal blooms and severely degrade existing bodies of water [11]. Table 2 shows the summary of some major wastewater treatment plants in KSA.

3. Wastewater reuse options

KSA will increase the reuse of treated wastewater in future from 2.0 BCM in 2018 to more than 5.0 BCM by 2050 as shown in Fig. 4. Treated wastewater reuse is in practice

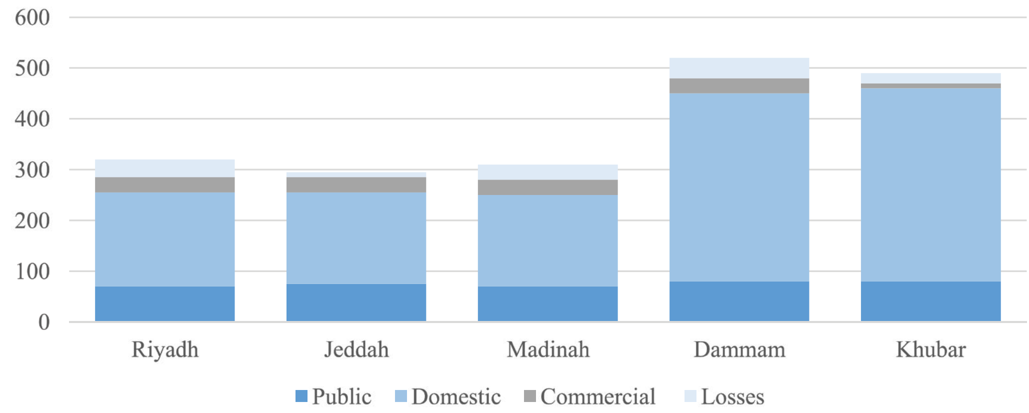

Fig. 1. Daily per capita average water consumption in the domestic sector (L/cap/d).

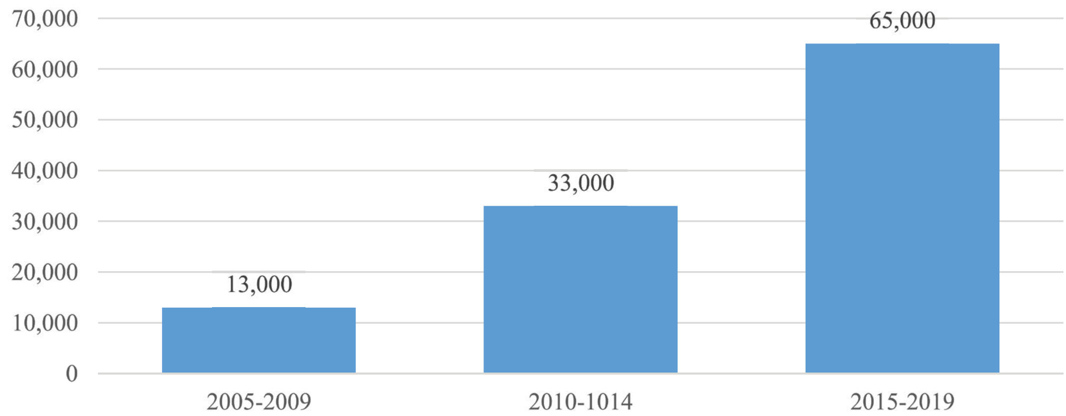

Fig. 2. Financial requirements of the water sector (million US$).

Table 1
Water resources in Kingdom of Saudi Arabia [9]

Water sources	Volumes (million m^3/y)-2019
Conventional water resources	
Groundwater (non-renewable)	2,060
Groundwater (renewable)	2,300
Surface water	100
Non-conventional water resources	
Desalinated water	2,200
Treated wastewater	2,044
Total water resources	8,704

in many countries specially in arid region which experienced renewable freshwater shortage. In KSA treated wastewater can be used for agricultural and landscaping irrigation, wetlands, industrial purposes, aquifer recharge and district cooling. KSA already using treated wastewater at present in agriculture irrigation and industrial purposes. However, a major fraction of wastewater remains unused and discharged to the environment.

The wastewater is treated in about 70 sewage treatment plants across the country [12]. Following treatments, a fraction of treated wastewater is recycled for reuse, while the remaining treated wastewater is discharged into the water bodies or into empty Wadies. MEWA (2018) reported that approximately 610 MCM/y wastewater was treated in KSA. The Food and Agriculture Organization (FAO) showed that approximately 547.5 MCM wastewater was treated in 2002 [13,14]. The Ministry of Economy and Planning (MOEP) reported that approximately 730 MCM of wastewater was treated in 2008 [15]. The plant specific treated wastewater volume, treatment types and disposal methods for some major sewage treatment plants are summarized in Table 2. The data show that the annual wastewater treatment capacity of these major plants is approximately 601.8 MCM/y, while these plants treat approximately 567.1 MCM/y. The current and forecasted sewage network covers about 50% of the total wastewater generated. 95%–100% coverage would be required by 2030. KSA has 5.6 million m^3/d of wastewater treatment capacity as of 2018 with 3.2 million m^3/d under construction with 0.4 million m^3/d planned for decommissioning. Additional 8.4 million m^3/d of capacity will be required by 2023 to achieve the treatment target. Fig. 5 shows cumulative sewage treatment capacity planned to reach commercial operational date (COD) between 2021 and 2030 [16].

In 2018 agricultural 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. 6. The historical data on treated wastewater reuse indicate increasing trends. In next few years, it is likely that treated wastewater reuse may be increased significantly and treated wastewater will become a potential source for water supplies (preferably, for agriculture). Significant fraction of the remaining wastewater is likely to be discharged into the environmental system without treatment or with minimal treatment. Consequently, there is a risk of contamination of groundwater system. By reducing discharges of wastewater, environmental risks can be reduced. On the other hand, reuse of treated wastewater is subjected to satisfaction of certain regulatory criteria. If the regulatory criteria are not satisfied, use of treated wastewater might impose health hazards [17,18].

To minimize these effects, wastewaters are needed to be adequately treated prior to reuse. In case of secondary treatment, treated wastewater typically have 30–100 MPN (most probable number) fecal coliform per 100 mL, while the tertiary treatment produces effluent of 1–7 MPN fecal coliform per 100 mL [19]. The microbiological regulations for reusing treated wastewater in agriculture indicate that tertiary treatment is required for reusing treated wastewater in agriculture in Saudi Arabia. KSA has established numerous centralized and decentralized wastewater treatment plants. The system involves the collection of wastewater from individual homes, home clusters, isolated communities, industries, and institutional facilities [20,21]. Recently, a new sewage treatment plant producing a tertiary treated effluent with an average

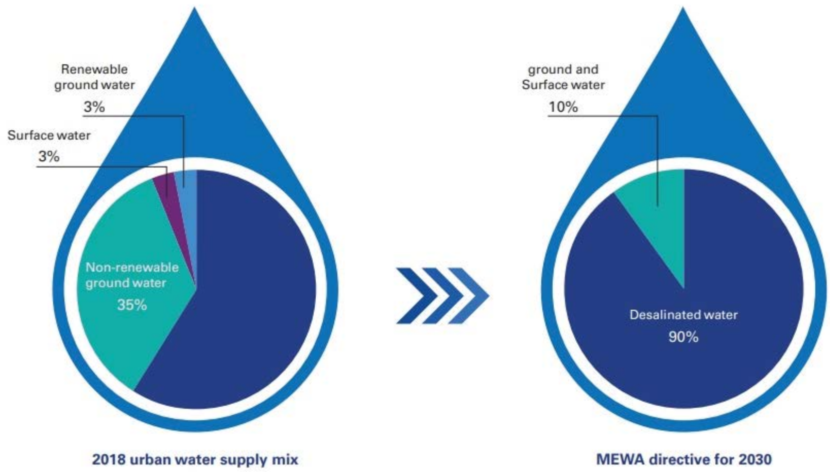

Fig. 3. Targeted change in water supply mix in KSA by 2030.

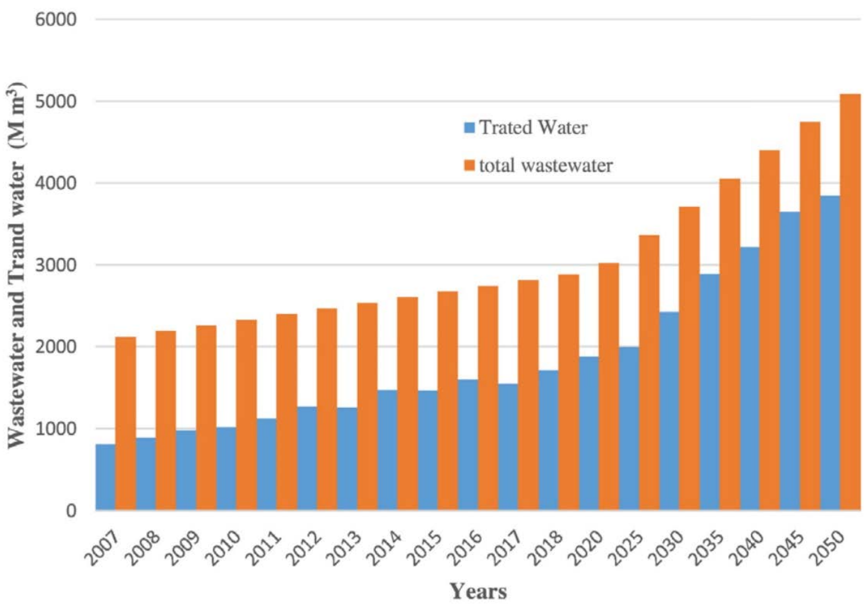

Fig. 4. Changes in the wastewater effluent and treated water to 2050 [12].

Table 2
Summary of some major wastewater treatment plants in KSA

No.	City	Plant name	Design (m^3/d)	Treatment scheme	Actual (m^3/d)	Disposal
1	Buraidah	Buraidah	11,000	Facultative + maturation ponds	13,000	To sand dunes
2	Unaizah	Unaizah	7,080	Aerated lagoons	9,900	To Wadi
3	Al-Kharj	Al-Kharj	21,000	Aerated lagoons + sand filters	21,600	To Wadi
4	Qatif	Sanabis	8,340	2 stage facultative	22,195	Gulf
5	Qatif	Gesh	8,990	2 stage facultative	15,930	Gulf
6	Qatif	Awamia	9,260	2 stage facultative	13,430	Gulf
7	Qatif	Qatif	210,000	Oxidation ditch	35,000	Gulf + L.I.
8	Al-Hasa	Oyoon	6,310	2 stage facultative	17,100	To Lagoon
9	Al-Hasa	Emran	13,320	2 stage facultative	22,100	To Lagoon
10	Al-Hasa	Hufuf-Mubarraz	29,500	2 stage facultative	136,780	To Lagoon
11	Khafji	Khafji	25,000	2 stage facultative	5,190	Gulf
12	Jeddah	Al-Khomra	36,000	Trickling filters (stone)	66,000	Red Sea
13	Jeddah	Plant C	40,000	Package contact stabilization	63,000	L.I. + Lagoon
14	Jeddah	Plant A	32,000	Package contact stabilization	55,000	L.I. + Red Sea
15	Jeddah	Bani Malik	8,000	Package contact stabilization	6,500	L.I. mostly
16	Jeddah	Al-Jamia	8,000	Package contact stabilization	7,000	Red Sea + L.I.
17	Jeddah	Tertiary (Al-Khomra)	30,000	Trickling filters + ozonation + clarification + sand filtration + reverse osmosis	20,000	Red Sea L.I.
18	Jeddah	Al Iskan	3,000	Activated sludge	3,500	
19	Makkah	Old plant	24,000	Trickling filters (stone)	65,000	Wadi + A.I.
20	Makkah	New	50,000	Plug flow activated sludge + nitrification–denitrification	—	
21	Riyadh	Al Hayer Old Plant (South)	200,000	Trickling filters (plastic) + polishing lagoons, anaerobic sludge digestion	200,000	Wadi + A.I. + Refinery
22	Riyadh	Al Hayer New Plant (North)	200,000	Activated sludge + nitrification–denitrification + filtration	200,000	Wadi + A.I. + Refinery
23	Riyadh	Refinery	20,000	Clarification + filtration + reverse osmosis + ion exchange	13,500	
24	Riyadh	KSU Plant	8,000	Settling, trickling filters	8,000	L.S. + Cooling power plant
25	Riyadh	Diplomatic Quarter	9,300	Screening, activated sludge	9,500	L.I.
26	Dammam	Dammam	208,000	Oxidation ditch	140,000	Gulf + L.I.
27	Al-Khobar	Al-Khobar	133,000	Oxidation ditch	100,000	Gulf
28	Madinah	New	120,000	Conventional activated sludge	100,000	Wadi + L.I. + A.I.
29	Safwa	Safwa	7,570	Completely mixed	8,600	Gulf
30	Khamis Mushait	Al-Dhoba	7,500	Oxidation ditch	10,000	Wadi + L.I. + A.I.
31	Abha	Abha	9,000	Extended aeration	11,500	Wadi
32	Taif	Taif	67,000	Activated sludge + nitrification–denitrification + filtration + activated carbon filtration	34,000	L.I. + A.I.
33	Jubail	Jubail Industrial City	12,500	Tertiary treatment	38,630	A.I.
34	Saihat	Saihat		Secondary aerobic biological	15,717	
35	Aramco facilities	Saudi Aramco (total 9 at different locations)	66,000	Variable	66,000	A.I. + Sea

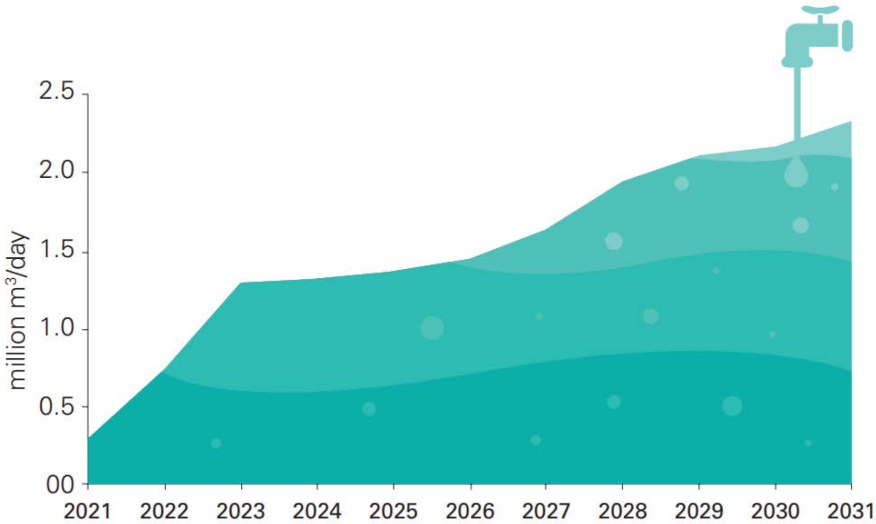

Fig. 5. Cumulative sewage treatment capacity planned to reach commercial operational date between 2021 and 2030 (KPMG, 2021).

capacity of 400,000 m^3/d and the maximum capacity of 640,000 m^3/d was built. The estimated total available supply of treated sewage effluent from the six largest cities exceeds 4.8 million m^3/d [22]. In 2012, all population in KSA was served with water supply and sanitation in all cities [23,24] with an invest of about US$23 billion including sewage collection and treatment infrastructure [25]. Looking forward, the country has aggressive long-term goals of increasing water reuse to more than 65% by 2020 and more than 90% by 2040, all by transforming more of its existing and planned wastewater treatment assets into source water suppliers across all sectors [26].

3.1. Wastewater reuse in irrigation

Water reuse and recycling are also viewed as a positive step toward climate change adaptation and mitigation. A project for irrigating an area of about 9,000 ha of date palms and forage crops near Riyadh was irrigated using about 146 MCM of treated wastewater in 2012. In cities such as Dhahran, Jeddah, Jubail, Riyadh, and Taif treated wastewater was reused for irrigating landscaping, road verges, and green areas in municipal parks [27]. The use of recycled wastewater in agriculture helped to save energy and reduces the cost of freshwater pumping, providing irrigation and reducing the water footprint of food production. It also can provide adequate nutrients and fertilizer for crops so that mining for mineral fertilizers can be decreased. For example, it has been demonstrated that reusing treated municipal wastewater for agricultural irrigation in Saudi Arabia provided adequate nutrients, lowered costs for irrigation and fertilization, and increased yield and profit for wheat and alfalfa. A large amount of treated wastewater was discharged to Hanifa Valley, which is located in eastern Riyadh and extends beyond the city into the surrounding rural areas. The vision for Hanifa Valley is to use treated wastewater to transform this urbanized valley into a ribbon of naturalized parkland to promote the area as a safe, green, and healthy environment. Moreover, this will connect the area with residential development, farming, recreation, cultural activities, and tourism [28]. In order to address the water deficit, Saudi Arabia has started an increased utilization of water recycling. The city of Riyadh has been very successful in using nearly 50% of its treated wastewater (about 120 million m^3). Treated wastewater is currently being used at various industrial and commercial enterprises of the city, which has the potential to expand in the future due to the high cost of desalinated water which is about USD0.8/m^3 [29]. The expected growth in wastewater collection and treatment services will produce more treated wastewater (i.e., about 2.5 km^3/y in 2035). The priority is expected to shift from the ongoing major agricultural use to industrial use, with higher anticipated revenue. Use of treated wastewater is projected to be greatest in the Riyadh, Makkah, Medina, and Eastern Province regions, which are home to the KSA's six largest cities [19].

3.2. Wastewater reuse in aquifer recharge

Depletion of water supplies for potable and irrigation use is a major problem in the rural Wadi valleys of KSA. Using managed aquifer recharge tool using treated wastewater conveyed can help to solve these challenges. In many cases, there are no local sources of water supply of any quality in the Wadi valleys. In Al-Kharj area, treated wastewater is transmitted through an open canal with a length of 40 km, where the water is stored in a pond and then filtrated through the sandy soil to recharge groundwater aquifer system. Economic analysis shows that the cost for supplying desalinated water is about USA$ 2–5/m^3 plus transmission and distribution cost. However, the cost of aquifer recharge with treated wastewater is USA$ 0.25–0.50/m^3 plus transmission and distribution cost. Several studies illustrated that, the cost of water treatment in Saudi Arabia varies with 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. The wastewater reuse, indirect for potable use and direct use for irrigation,

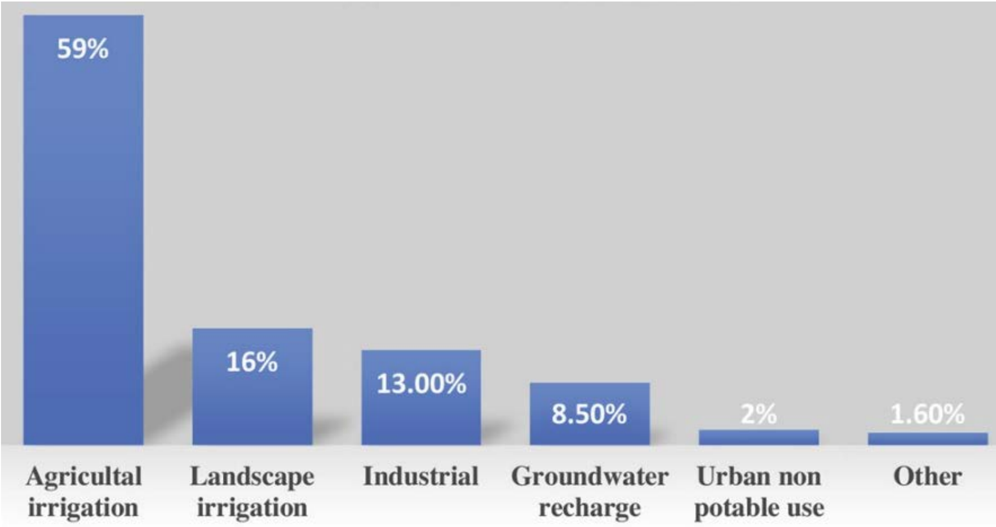

Fig. 6. Wastewater reuse in Saudi Arabia for 2018.

can have a zero-treatment cost because it is discharged to waste in many locations. In fact, the economic loss caused by the wastewater discharge to the marine environment can be greater than the overall amortized cost to construct an aquifer recharge system, including conveyance pipelines and the operational costs of reuse in the rural environment. The aquifer recharge and associated reuse system can solve the rural water supply problem in the Wadi valleys and reduce the economic losses caused by marine pollution, particularly coral reef destruction [30].

3.3. Environmental and recreational uses

Treated wastewater can be used for many non-potable purposes such as decorative water features (fountains), dust control, and fire protection. Irrigation of landscapes, parks, amenity plantations, road verges, maintenance of natural hydrological regimes and golf courses can also be a potential use. It also, can be used to create manmade wetlands, enhance existing natural wetlands, and sustain or augment stream flows. At present about 40% of treated wastewater is used in some Arab countries for environmental and Recreational uses such as UAE, Kuwait and Qatar [31].

3.4. Industrial

Treated wastewater reuse in industrial sector is another potential option. Industrial facilities can use treated wastewater for cooling system make-up water, boiler-feed water, process water, and general wash down uses. It can also be used for road maintenance, and concrete production in the construction projects. Industrial reuse proposes depend on the effluent quality and in some cases, it may require additional treatment.

3.5. District cooling

At present a huge amount of fresh water – mainly desalination – is used for district cooling in KSA. District cooling for residential areas could be an economic option and another application for treated wastewater use in the region where desalinated water is used. The used desalination water in district cooling is costly and the economic factor could play an important role for increasing the tertiary treated wastewater in cooling in the future in KSA.

4. Challenges facing wastewater reuse

The reuse of wastewater for different purposes depends on the degree of its treatment (primary, secondary and tertiary). The tertiary level treated wastewater is free from all health hazards and can be used to irrigate all crops. The secondary level treated wastewater is suitable for nursery flowers and palm trees, cotton, vegetables but should not be used for cattle rearing with milk or meat. The primary level treated wastewater can only be used for timber trees after taking strict precautionary measures such as isolated farms, and preventing direct contact of workers with the water. There are many barriers facing the treated wastewater reuse including technological, institutional, environmental, economic and social (public acceptance) barriers. Additionally, it is important to develop an economically viable model for the concerned stakeholders, to ensure the widespread sustained adoption of this strategy. Table 3 summarizes risks to be considered when selecting reuse applications [32]. Detailed surveys of the local situation will be required to be able to assess actual risks and constraints, and to select the most appropriate technology and applicable risk prevention measures. In the next step, these risks will be compared with the benefits linked with the specific application of wastewater reuse. Many factors decide on viability of reuse projects because such projects require the establishment or adjustment of existing infrastructure, change in water use habits, etc. In order to decide on viability of reuse projects, a more detailed evaluation of applications should cover suitability of soils and crops, environmental and health risks need for additional infrastructure and public acceptance of reuse.

Table 3
Categories of wastewater reuse and potential constraints

Agriculture and landscape irrigation	
Crop irrigation	Surface- and groundwater pollution, if not properly managed
Commercial nurseries	Marketability of crops and public acceptance
Park/school yards	Effect of water quality, particularly salts, on soils, grasses and crops
Freeways (median strips) courses, cemeteries greenbelts, and residential areas	Public health concerns related to pathogens (bacteria, viruses Golf and parasites)
Industrial recycling and reuse	
Cooling boiler feed	Constituents in reclaimed wastewater cause scaling, corrosion, biological growth and fouling
Pathogens in cooling water	Public health concerns, particularly aerosol transmission of process water
Groundwater recharge	
Groundwater replenishment and salt water intrusion control	Organic chemicals in reclaimed wastewater and their toxicological effects
Subsidence control	Total dissolved solids, nitrates and pathogens in reclaimed water
Recreational/environmental uses	
Lakes and ponds	Health concerns from bacteria and viruses
Marsh enhancement and stream flow augmentation	Eutrophication due to nitrogen and phosphorus in receiving water
Fisheries	Toxicity to aquatic life
Non-potable urban uses	
Fire protection	Public health concerns on pathogens transmitted by aerosols
Air conditioning and toilet flushing	Effects of water quality on scaling, corrosion, biological growth toilet and fouling
Potable uses	
Blending in water supply	Constituents in reclaimed water, especially trace organic reservoirs chemicals and their toxicological effects
Pipe-to-pipe water supply	Aesthetics and public acceptance
	Health concerns about pathogen transmission, particularly viruses

Treated wastewater reuse brings a number of challenges regarding which contaminants must be removed and to what extent the quality of the treated wastewater should be for each case, considering local environmental conditions, economic factors, scientific knowledge, awareness campaign, legislations, and regulations requirements. Treated wastewater reuse requires proper planned strategies that incorporate multiple factors and measures to minimize technical, public health and environmental and ecological risks. This means that combinations of source control, treatment processes, flow schemes, users' conditions, and other engineering and scientific factors should be the basis for treated wastewater reuse scenarios [32]. Many factors still prevent the increase in reusing treated wastewater including economic, environmental, technical, social, regulatory, institutional and political constraints. Social and public acceptance for reusing of treated wastewater is an important factor. Awareness and education programs are needed also to improve the public acceptance and attitude towards wastewater reuse. Policies, strategies, monitoring and regulatory framework are needed for better wastewater treatment and management in the Arab region to protect human health and environment.

4.1. Economics of wastewater treatment and reuse

The cost of water reuse is influenced by various factors such as treatment level, intended reuse options, location of treatment, wastewater collection and transportation. According to Qadir et al. [33], the average cost of recycling water is approximately USA$1.79/m^3. However, compared to desalination, wastewater reuse has the advantage of cost. Fryer [34] demonstrates that the relative marginal cost of seawater desalination is higher than water recycling and amounts to up to USA$2,000 per acre-foot. The water recycling represented a general fluctuation pattern between approximately USA$300 and USA$1,000 per acre-foot. Even so, water recycling appears cheaper than desalination.

4.2. Engagement of private sector

To support the future success of public private partnerships in wastewater treatment and reuse in KSA three-pronged approach should be considered:

- Financial sustainability
- Guaranteed revenue streams
- Infrastructural sustainability

Currently, the Kingdom of Saudi Arabia's National Water Company (NWC) is developing a clear business plan for privatization of wastewater treatment and reuse infrastructure through the special purpose vehicle (SPV) model, which is relatively new to Saudi Arabia. SPVs offer great potential in isolating and managing potential financial risk, allowing access to new revenue streams and wider markets, enabling the encashment of assets and contracts via transfer to the SPVs, and increasing opportunity to embrace global best practice [16]. NWC holds firm to the belief that a market-led approach, with suitable protections that reflect NWC's goals and objectives, will allow the market to maximize reuse and optimize arrangements for the benefit of all. Nevertheless, the process is still ongoing to quantify and structure the precise arrangements to ensure effective cost recovery, while staying true to NWC's principles of improving KSA's macroeconomic environment, promoting sustainable development, and promoting citizens' welfare.

4.3. Social acceptance

Treated wastewater reuse is increasingly important for sustainable water resource management, especially in water-stressed countries located in the world's arid regions that rely on groundwater and desalination process for meeting their water demands. Data were collected from 624 households in the Dammam Metropolitan Area, Saudi Arabia using a structured questionnaire and analyzed using descriptive and inferential statistics. The results from logistic regression indicates that the likelihood of a household to accept reusing treated mixed wastewater is influenced by gender with odds ratio (OR) of 2.71–2.18, residential location (OR = 1.32–1.03), age (OR = 1.22–0.18) and educational level (OR = 1.33–0.98), with a tendency for more acceptance of treated grey wastewater than mixed wastewater [35]. These findings showcase the difficulty that the country could face concerning the public acceptance of treated wastewater for non-domestic uses to augment current freshwater sources even among the educated class. This study is significant because sustainably meeting the country's rising water demands requires the stringent implementation of strategic wastewater reuse policy, including bold steps towards wastewater streams segregation, and intensive public awareness campaigns to change negative perceptions on treated sewage effluent. This study concludes that a substantial reduction in the country's reliance on costly desalinated water and fast depleting non-renewable groundwater requires complete reuse and recycling of treated wastewater for wider non-conventional purposes. For most uses, reclaimed water tends to have lower social acceptance than desalination. There are various reasons why people do not trust reclaimed water. First, most people do not understand the difference between treated and untreated water [36]. Secondly, they are often concerned about the type of wastewater, treatment levels and the availability of information. There are particular concerns with the wastewater produced by the petroleum industry, brought to the surface when drilling oil. This kind of wastewater is difficult to treat due to the high content of oil [37]. Therefore, though reclaimed water undergoes a very thorough treatment process which makes it entirely safe to drink, the public are reluctant to drink treated sewage. However, it is not impossible that people will accept drinking such treated sewage. For example, Singapore has successfully used reclaimed water, a product named NEWater, to supply drinking water [38]. This reflects that treated wastewater could become widely accepted through public education.

4.4. Environmental impacts

There are some environmental disadvantages of desalination. Since Saudi Arabia is rich in oil and gas, clean energy such as solar energy tends to be used less than fossil energy. The overuse of fossil energy may cause serious environmental pollution. For instance, oil might generate large quantities of carbon dioxide, which is the main factor leading to global warming. Furthermore, the gas emissions from oil could undermine the ozone layer and cause acid rain (ibid.). In addition to environmental pollution caused by fossil energy, brine discharge is another serious problem. After desalination, the brines generally have a higher concentration of salt, nearly twice that of natural seawater [39]. The brines are generally discharged back to the same place where the seawater comes from. This might lead to increased concentration of salt in the sea, which is a potential threat to aquatics. In contrast with the desalination, wastewater reuse is regarded as an eco-friendly way to supply fresh water. Recycling water can maximize the use of rainfall and other current water resources so that the limited underground water resources can be conserved. In the meantime, decreased energy consumption could reduce the pollution caused by the use of fossil energy. Therefore, recycled water is a sustainable and eco-friendly method to supply good quality fresh water.

4.5. Technical challenges for wastewater reuse

When considering wastewater reuse for irrigation, an evaluation of the advantages, disadvantages and possible risks has to be made very carefully. Advantages include improvement of the economic efficiency of investments in wastewater disposal, irrigation water, and conservation of freshwater resources and use of wastewater nutrients (e.g., phosphate and nitrogen). Wastewater is normally produced continuously throughout the year, whereas irrigation is mostly limited to the growing season. Most of the recent experiments in Saudi Arabia shown that the use of treated wastewater as a supplemental irrigation source not only increased crops production, water use efficiencies but also served as a source of plant nutrients and reduce fertilizers use [40]. Many different irrigation methods are used by farmers to irrigate crops with treated wastewater. They range from watering individual plants from a can of water, flooding irrigation, to highly automated irrigation methods by a center pivot system. The success of the irrigation with wastewater is safe when the national regulations for each country regarding its treatment and use are strictly followed and the irrigation method and technology selected carefully. After irrigation, the wastewater returned to the environment usually will be with higher quality than the wastewater produced by the treatment plants

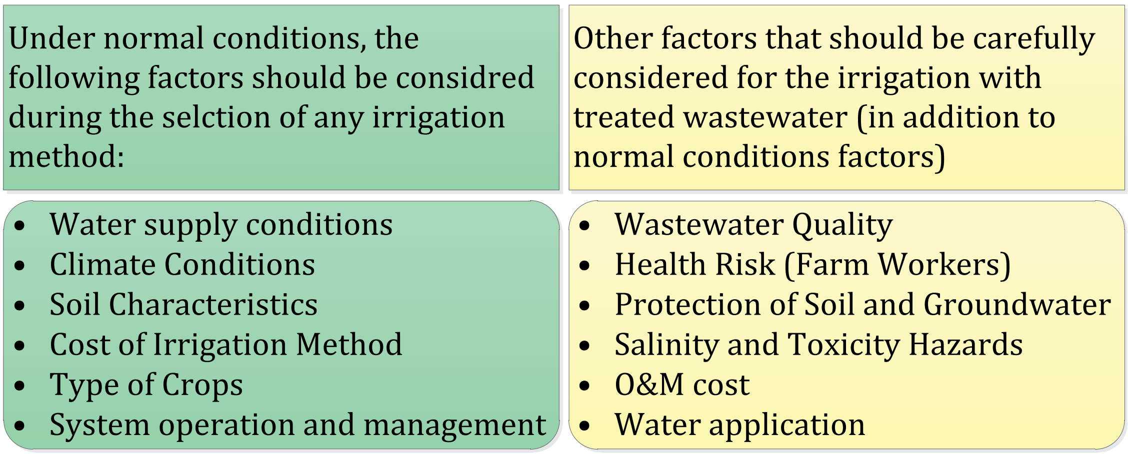

Fig. 7. Selection criteria for irrigation method with treated wastewater.

due to the additional treatment provided by the soil layers through the natural occurring of physical, biological and chemical process. Also, reuse of wastewater for irrigation is considered as an economic and environmental solution for wastewater discharge/disposal option. The selection of the most suitable irrigation methods with treated wastewater, many criteria should be considered as shown in Fig. 7.

4.6. Legal and institutional challenges

The treated wastewater reuse historically can be traced back to the 1970s in KSA. In 1978, the Council of Leading Islamic Scholars of KSA issued a fatwa (Islamic declaration) that encouraged the use of treated wastewater, and this fatwa paved the road to extensive use of treated wastewater in KSA: Impure wastewater can be considered pure water and similar to the original pure water, if its treatment using advanced technical procedures is capable of removing its impurities with regard to taste, color and smell, as witnessed by honest, specialized and knowledgeable experts. Then it can be used to remove body impurities and for purifying, even for drinking. If there are negative impacts from its direct use on the human health, then it is better to avoid its use, not because it is impure but to avoid harming human beings. The Council of Leading Islamic Scholars prefers to avoid using it for drinking (as much as possible) to protect human health. This fatwa alleviated any religious concerns that the public or officials might have concerning the use of treated wastewater. In KSA, the first regulation on wastewater treatment and reuse was published in May 2000, entitled 'Treated Sanitary Wastewater and Its Reuse Regulations', thus requiring secondary or tertiary wastewater treatment levels. Later on, in 2006, MWE published two booklets entitled 'Design Guidelines for Wastewater Treatment Plants in Saudi Arabia' and 'Using Treated Water for Irrigation: Controls, Conditions, Offences and Penalties'. These initiatives held an important role in the establishment of safe wastewater treatment and reuse practices standards. The 2006 standards for treated wastewater use specify the minimum treated wastewater quality requirements for restricted and unrestricted use.

5. Conclusions and recommendations

KSA treated wastewater reuse initiative provides large volumes of treated wastewater to customers for uses including agricultural, industrial, commercial, and district cooling uses among other non-potable purposes and has created an environmentally friendly and financially sustainable long-term market for treated sewage effluent. TSE benefits include: (i) addressing the water shortage challenges in KSA and conserving scarce water resources, (ii) developing new infrastructure and operating it efficiently and (iii) providing environmental benefits such as net carbon reductions, by indirectly contributing to lesser capital requirements for power and water generation.

KSA is progressing towards achieving its wastewater collection and treatment system coverage objectives and treated wastewater utilization goal. The ongoing initiatives are noteworthy and have had good success to date, but many more initiatives are still urgently required. The government's financial ability to support the wastewater vision is in doubt in view of the recent drop in crude oil prices, the heavily subsidized water tariff, and free wastewater services to the domestic sector. Therefore, the water and wastewater tariffs need adjustments that reflect the economic value of the service to secure the long-term sustainability of the system. A wastewater tariff system should be introduced to the domestic sector to complement the recently introduced tariff system for the governmental, commercial and industrial sectors. Moreover, the tariff system should provide financial sustainability for the wastewater system, and encourage water conservation given the country's social, cultural and political conditions. However, such water and wastewater tariff adjustments, if realized, might face strong public opposition given the low public awareness of the country's water shortage. Accordingly, there is a need for a proactive, long-term and well-designed public and institutional awareness campaign to promote water and wastewater tariff adjustments and treated wastewater use among various sectors of the society. Strong consideration should also be given to combining the recharge of alluvial aquifers by tertiary-treated wastewater with the development of downstream well production fields.

This will produce water supplies through the natural processes of the aquifer to use in industrial and urban supplies, and secure strategic reserves for emergency uses [30]. Therefore, new guidelines should be introduced into the treated wastewater guidelines for groundwater aquifer recharge and industrial uses. Further study is recommended to identify the optimum treatment technology for wastewater in the country and to evaluate and mitigate the potential impacts of treated wastewater contaminants on human health. The measures of the Saudi government for the development and implementation of the wastewater sector and the introduction of private-sector participation were an effective step in improving wastewater provision. However, a strong public-sector counterpart is required for the successful participation of the private sector. Therefore, further attention should be given to strengthening public-sector capabilities for the long-term sustainability of private-sector participation. Moreover, the public sector needs comprehensive human capacity building, regulation, institutional reform, and the development of a comprehensive treated wastewater database. All these measures will optimize the value of treated wastewater use and private-sector participation in wastewater provision.

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