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Quality assessment of treated wastewater in Kuwait and possibility of reuse it to meet growing water demand

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ABSTRACT

Kuwait's water resources are insufficient and will become the limiting factor for sustainable development in the future. The need for water supplies in Kuwait is extremely high and expected to be growing due to increasing population growth. To face this challenge Kuwait has introduced a new element in water management system by considering and reusing treated wastewater. Currently, huge amounts of municipal wastewater are treated in four main treatment plants located at Regga, Jahra, Um Al-Haiman and Sulaibiya. In general overview on Kuwait's water resource, water demand and wastewater treatment plants (WWTPs) is presented. In addition, data of treated effluent quality was collected from three main sources; namely; available publications and records within Kuwait, and the results of a wastewater-monitoring program involving survey, collection and analysis of samples from selected wastewater streams. Data reveal that the treatment plants at Jahra, Regga and Um Al-Haiman provide wastewater treatment up to a tertiary level with sand filters following the conventional activated sludge process. All three plants produce excellent effluent quality at a tertiary level of treatment. The advanced WWTP at Sulaibiya treats wastewater beyond tertiary level with advanced facilities of ultrafiltraion and, reverse osmosis producing super quality of effluent with insignificant traces of pollutants. The COD and TSS removals are above 90% for all the plants. Sulaibiya in particular achieved almost 100% COD and TSS removal. The utilization of Sulaibiya plant effluent for recharging ground-aquifers is a viable option to store treated effluent for future need.

Keywords: Water demand; Advanced treatment; Wastewater reuse

1. Introduction

The development of sustainable water resources in Kuwait, an arid country with fast growing population, faces major challenges concerning future sources. Since mid 1950s Kuwait has sought to secure safe and renewable water resources that can be used for domestic, industrial and commercial purposes. At present, most of the potable water supplies in Kuwait are produced by multi-stage flashing (MSF) desalination plants. Water requirements for agricultural and other uses are met by brackish groundwater. A portion of tertiary treated wastewater is used for fodder

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irrigation [1]. However, there is an increasing concern about the production cost of desalination water and the depletion rate of groundwater [2]. In this context, effective and efficient reclamation and reuse of wastewater is considered as an important element of water resources development and management. It can provide a viable and sustained water supply for non-potable uses and reduce the need for cost-intensive desalination plants. This potential water resource provides an innovative and alternative option for non-potable utilization such as irrigation and landscaping [3]. Other alternatives include, water conservation, efficient management, and development of a new water resources. The quantities of wastewater are huge-about 60–70% of the daily freshwater consumption rate [4]. The average domestic water consumption in the year 2007 for a population of 3.3 million was 514 million m^3 [2].

Limitation on freshwater is likely to have a significant impact on economic and social development in Kuwait. In addition to the above concern, ecosystem deterioration caused by wastewater discharge to the Gulf Arabian water has become a major issue. This concern is resultant of the effluent quality produced in conventional wastewater treatment plants (WWTPs) in Kuwait. In these plants, the municipal wastewater effluent is usually treated to tertiary level. However, many of the pollutants found in wastewater are not completely removed or are partially removed by conventional treatment processes. These constituents are mainly consisting of both organic and inorganic compounds. The impact of these substances on environment and especially aquatic ecosystems are adverse in nature. For example the presence of phosphate and nitrate is often responsible for stimulating algae and undesirable aquatic growth in receiving water. Therefore, the environmental legislation has become more stringent in terms of allowable concentration of such substances in the effluent of WWTPs.

2. Water resources in Kuwait

Natural water resources in Kuwait are very limited and mainly consist of brackish groundwater. The non-conventional water resources include seawater desalination, and reclaimed wastewater. Most of the freshwater supplies in Kuwait are produced through five MSF desalination plants [2]. These plants were developed and used since 1950s. Brackish water is produced from ground water aquifer and utilized for blending with distilled water, for irrigation and landscaping. Treated wastewater is used in very limited quantities in fodder (animal feed) production and landscaping activities. Table 1 outlines the overall quantities and percent share of Kuwait's water supply resources for the year 2010 [2,3]. Distilled and groundwater dominate and share more than 80% of the available resources whereas renovated wastewater accounts for less than 20%.

3. Population growth and water demand

Demand for water supplies is growing rapidly due to rapid population growth, urbanization and socio-economic development. Kuwait's population has doubled in the past 30 years and is predicted to double in the next 30 years. Although fresh water is scarce in Kuwait, water consumption per capita is very high and this explains the huge demand for fresh water in the future. During 1977, the average consumption of freshwater per capita reached about 50 m^3/year. This number increased over the following years, and continued to grow at a very high rate. In 2009, the Per capita consumption has reached more than 200 m^3. This large quantitative growth in consumption per capita could not be sustained without corresponding growth in the distillation production capacity, in order to sustain the water needs of the rapid population growth. Fig. 1 shows the growth rates and annual changes in the total water production and consumption (distilled and brackish) over the past 17 years in Kuwait [2].

Detailed records of population and total water production in Kuwait appear in Table 2.

Fig. 2 shows past and projected population and water demand trends up to year 2030.

From the records, the changes of both population and water demand can be distinctly conceived and therefore, statistical relationships can be developed by fitting regression line in the trends. These relationships can be used to estimate projected population and water demand in the coming years. Table 3 presents these relationships with correlation coefficient of the fitted line.

Potable, brackish and total water uses in 2009 were 537, 175 and 713 million m^3/y, respectively. Comparing with year 2020, the potable and total water uses in

Table 1
Overall quantities and percentage of Kuwait's water supply resources for the year 2009

Water resources	Million m^3/year	Share (%)
Desalination	518	62.3
Groundwater	171	17.8
Reused wastewater	164	19.8

Source: Refs. [2,3].

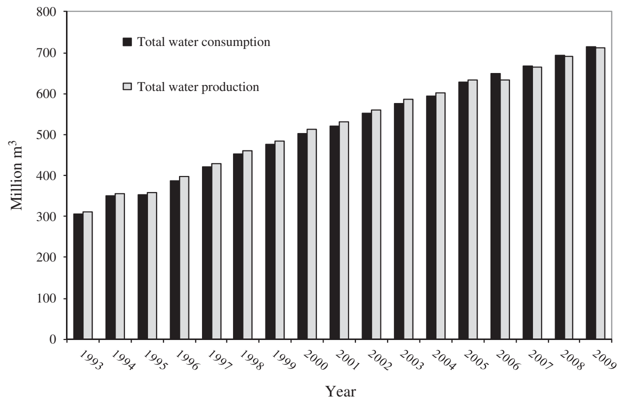

Fig. 1. Annual changes in the total production and consumption water.

Table 2
Population and water production records for years from 1993 to 2009

Year	Population (million)	Brackish water production (million m^3)	Distilled water production (million m^3)	Total water production (million m^3)
1993	1.53	99.88	210.98	311
1994	1.65	113.55	242.23	356
1995	1.72	98.55	260.79	359
1996	1.78	107.64	288.95	397
1997	1.83	117.36	311.44	429
1998	2.06	126.92	332.84	460
1999	2.14	125.78	358.21	484
2000	2.23	138.59	374.84	513
2001	2.30	145.38	385.57	531
2002	2.42	148.75	412.18	561
2003	2.54	154.91	430.89	586
2004	2.75	158.89	443.09	602
2005	2.99	163.87	469.32	633
2006	3.18	164.63	469.80	634
2007	3.40	156.40	507.60	664
2008	3.50	171.43	518.84	690
2009	3.68	175.57	537.11	713

year 2020 are expected to increase by 43 and 41%, respectively. By year 2035, potable and total water need would be about twice that of 2009. Brackish water has lower quality than that of potable water, particularly, with respect to dissolved solids. In case the supply of this type of water is not available, its equivalent quantity needs to be replenished from alternative sources. It is a part of the total need of the country in non-agricultural sectors.

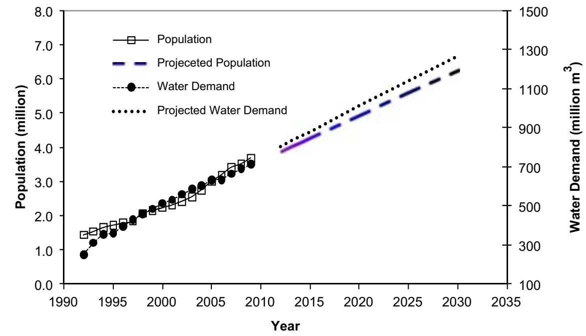

Fig. 2. Past trends and projected growth in Kuwait's population and water demand.

Table 3
Relationships for projection of population and water production

	Fitted linear line	Correlation coefficient
Population	$Y = 0.1306X - 259.46$	$R^2 = 0.98$
Potable water production	$Y = 20.233X - 40{,}103$	$R^2 = 0.99$
Total water production	$Y = 25.57X - 50{,}644$	$R^2 = 0.99$

Note: X = number of years.

Table 4
Information about main WWTPs in Kuwait

WWTP	Construction year	Treatment level	Design capacity (m^3/day)	Present[a] inflow (m^3/day)
Jahra	1982	Tertiary	70,000	81,131
Regga	1982	Tertiary	180,000	146,182
Um Al-Haiman	2001	Advanced	27,000	11,325
Sulaibiya	2005	Advanced	375,000	419,190
Total			652,000	657,828

[a]Average of inflows for 2004–2009. Source: Ref. [3].

4. Wastewater in Kuwait

In Kuwait, the amount of wastewater produced varies with the season and this amount is expected to increase as more residential areas are connected to the sewage system [5]. Presently, four sewage treatment plants at Regga, Jahra, Um Al-Haiman and Sulaibiya are used to treat municipal wastewater [3]. The collected wastewater receives primary, secondary and tertiary treatment. In the primary level, physical separation processes such as screening, sedimentation

Table 5
Comparison of secondary effluents of Kuwait WWTPs

Plant	pH	Cond. (μS/cm)	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	TN (mg/l)	TP (mg/l)
Regga	7.08	1,212	13.74	32.49	6.95	10.4	29.0
Jahra	7.79	1,825	24	45	25	29.49	N.A.
Um Al-Haiman	6.8	1,107	6.2	23.43	7.50	9.30	35.40

Source: Ref. [3].

and grit removal are used to remove large objects and settable solids. In the secondary treatment, biological treatment processes are utilized in which microorganisms convert non-settable and dissolved organic pollutants to settable solids. Sedimentation process typically follows allowing these settable solids to settle out. In the tertiary treatment, the secondary effluent is usually disinfected using chlorine and is also filtered to eliminate residual suspended solids.

Sulaibiya wastewater plant utilize ultrafiltraion (UF) and reverse osmosis (RO) membrane technology to polish tertiary effluent.

Table 4 presents information about the location, construction year, design capacity, average inflow, and the highest level of treatment that can be achieved at the main WWTPs in Kuwait. Average inflows in the years 2004–2009 in all operating plants is about 658,000 m^3/d, while the total capacity of these plants is 652,000 m^3/d.

5. Quality of treated wastewater in existing plants

WWTPs in Kuwait, in general, do not have primary settlers as wastewater is usually pumped directly after a preliminary treatment stage (screening and grit removal) to a secondary treatment stage (biological treatment in an activated sludge system). Hence, the quality of effluent from secondary and tertiary at Regga and Jahra plants are summarized with respect to major pollution parameters. Table 5 contains average (2004–2009) quality of secondary effluent from Regga, Jahra and Um Al-Haiman. It appears that, at secondary level, the effluent from Jahra plant which operates at above design capacity is worse in comparison with the effluent resulting from the other two plants.

Summary of tertiary effluent (final effluent) quality in terms of major non-metal parameters for three plants; namely Jahra, Regga and Um Al-Haiman appear in Table 6. Effluent quality represents the normal quality expected at a tertiary level of treatment [6]. However, it is evident that the tertiary effluent from the Jahra plant constituted pollutants at higher content values than those observed in the other two plants. The signs indicate probable effect of overloading by flow which is almost at its design capacity.

6. Effluent quality and plant performance

Table 7 presents the average quality of the tertiary or advanced effluents of the four municipal plants in Kuwait. It is apparent that the advanced effluent of the Sulaibiya plant contains only traces of organic and inorganic pollutants. In the Sulaibiya plant, membrane filers (UF and RO) are used to further treat the tertiary effluent which has already undergone secondary biological treatment. It is evident from Table 10 that the effluent quality of the other three conventional plants (Jahra, Regga and Um Al-Haiman) is very good for such a conventional plants. As can be seen, COD is less than 25 mg/l, TSS is less than 10, TN is less than 10 mg/l and TP is less than 10 mg/l. This indicates that the three plant are performing very well. In fact, inspection of the whole collected records indicated that none of the plants had exceeded the proposed effluent standard for COD (100 mg/l) [7]. Removal of the carbonaceous matter is well expected from activated sludge systems in such a warm climate. Records

Table 6
Comparison of tertiary effluents (2004–2009) of Kuwait WWTPs

Plant	pH	Cond. (μS/cm)	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	Coli form (CFU)
Regga	6.89	NA	3.65	13.12	1.98	22.3
Jahra	7.54	1,786	5	23	15	7.93
Um Al-Haiman	6.8	1,124	3.5	13.6	3.2	NA

Source: Ref. [3].

Table 7
Average quality of tertiary effluents of the treatment plants

Plant	COD mg/l	BOD mg/l	TSS mg/l	TN mg/l	TP mg/l
Jahra	45	25	5	24	7
Regga	21	6.95	9	10.5	29
Sulaibiya	0.094	0.043	0.004	0.668	0.102
Um Al-Haiman	23	7.5	4	4	7

of these plants, as summarized in Table 6, also show that these plants seem to be very efficient in removing TN and TP from wastewater.

As can be seen from Table 7 and Figs. 3–6, COD and TSS removal reached above 90% in all the plants. The Sulaibiya plant, in particular, achieved almost 100% removal of both COD and TSS. Table 7 also shows that TP removal rates differ from one plant to another. At the Jahra plant TP removal rates were 75.2–79.7%; 100% at the Sulaibiya plant; and, 91–100% at Um Al-Haiman plant. This table indicates clearly that the Sulaibiya plant has achieved the highest TP removal rate. Sualibiya plant consists of a modern oxidation ditch system designed with anaerobic, anoxic and oxic compartments that enhance biological removal of both nitrogen and phosphorus. That is to say, it is a nutrient removing plant. Furthermore, it is the world's largest wastewater membrane plant. In addition to the biological removals of the nutrients, advanced membrane filtration (UF and RO) also remove nutrient trace concentrations. On the other hand, none of the other three plants is designed for enhanced phosphorus removal. In such conventional plants, which do not have primary settler either, total phosphorus removal is expected to be about 20% [8].

The TN removal efficiencies of the four plants range from 71.9 to 100% (Table 8). Such high removal rate is actually expected only for Sulaibiya and Um Al-Haiman plants. They are oxidation ditch plants. The anoxic and oxic compartments of an oxidation ditch system enables biological nitrogen treatment through the processes of nitrification (conversion of ammonia into nitrate) and denitrification (conversion of nitrate into nitrogen). On the other hand, Regga and Jahra plants have only oxic tanks (aeration tanks) and are not equipped with anoxic tanks. Thus, they are not designed for enhanced nitrogen removals. Only nitrification processes are expected to take place in the aeration tanks of Regga and Jahra plants. Nitrification processes only convert ammonia to nitrates but do not remove nitrogen from wastewater. Thus, in conventional plants such as the Regga and Jahra

Table 8
Overall removal efficiency of municipal plants in Kuwait

Year	Jahra				Regga			Sulaibiya				Um Al-Haiman			
	COD %	TSS%	TN %	TP %	COD %	TSS %	TN %	COD %	TSS %	TN %	TP %	COD %	TSS%	TN %	TP %
2005	90	97	72	80	97	99	100	100	100	98	100	97	98	100	100
2006	95	97	95	84	93	96	98	100	100	98	100	97	99	72	96
2007	95	97	93	81	89	98	100	100	100	98	100	97	98	82	91
2008	94	97	86	78	86	94	99	100	100	98	100	96	97	87	93
Min	90	97	72	78	86	94	98	100	100	98	100	96	97	72	91
Max	95	99	95	80	99	99	100	100	100	98	100	98	99	100	100

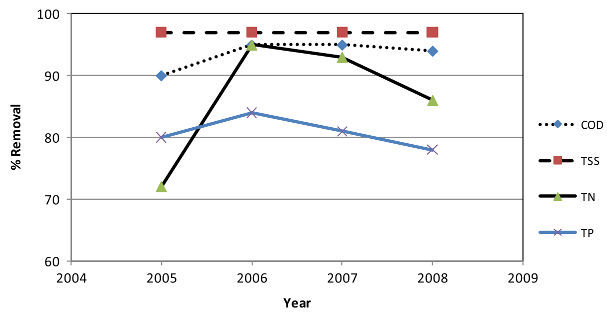

Fig. 3. Removal efficiency at the Jahra WWTP.

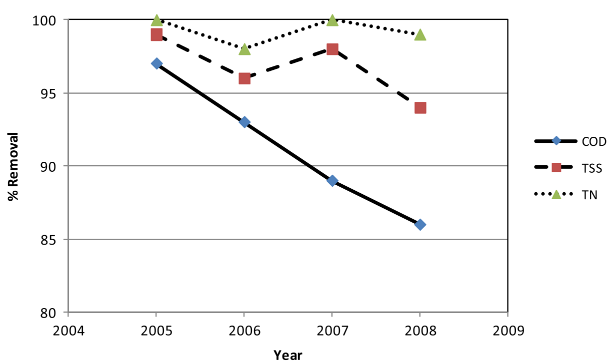

Fig. 4. Removal efficiency at the Regga WWTP.

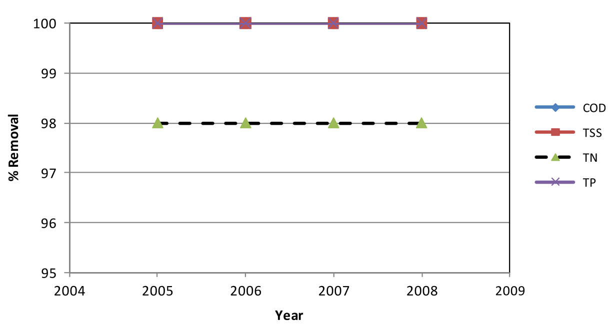

Fig. 5. Removal efficiency at the Sulaibiya WWTP.

plants, TN removal is expected to be in the range of 50–60% [8]. Therefore, records of nitrogen concentrations for Jahra and Regga plants need to be clarified. If these records are confirmed, then the secondary clarifiers of these plants probably acted as anoxic compartments. In turn, this may explains the frequent sludge bulking problems at these plants encountered in the last years.

7. Evaluation of wastewater effluent quality for reuse

Four main treatment plants (Jahra, Regga, Um Al-Haiman and Sulaibiya) treat more than 650,000 m^3/d of urban wastewater in Kuwait. Among

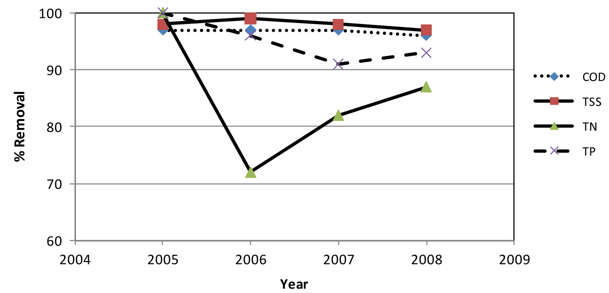

Fig. 6. Removal efficiency at the Um Al-Haiman WWTP.

them Regga, Jahra and Um Al-Haiman provide treatment up to a tertiary level producing good quality effluent of 196,000 m^3/d. The effluent quality is more than adequate for restricted irrigation. Sulaibiya plant is relatively new and applies most modern treatment processes beyond tertiary level and produces refined wastewater effluent with insignificant traces of pollutants. Treated effluent from the plant reaches about 340,000 m^3/d and it is suitable for various types of reuse except probably pools or other facilities where prolonged contact with human body and chances of body-intake exist.

8. Treated wastewater effluent (TWE) for reuse

8.1. TWE for irrigation uses

8.1.1. Present status

The prime goal of the National Greenery Master Plan for Kuwait from 1995 to 2025 was to utilize 100% of treated wastewater effluent (TWE) mainly in restricted agricultural irrigation (e.g. fodder crops irrigation), greenery landscaping (grass, plants, trees and bushes) and in the development of forestation areas [9,10].

In Kuwait, TWE is conveyed from the main WWTPs located at Jahra, Riqqa, Sulaibiya, and Um-Al-Haiman to reuse places through distribution networks or tanker truck deliveries. There are two distribution networks for TWE in Kuwait: Ministry of Public Works (MPW) distribution network and Public Authority for Agricultural Affairs and Fish Resources (PAAF) distribution network. Both MPW and PAAF distribution networks consist of pump stations, gravity mains, and pressure mains. MPW distribution network links Jahra, Riqqa and Sulaibiya WWTPs to the storage reservoirs at the Data Monitoring Center (DMC) in Sulaibiya area. From DMC, TWE is distributed further to the main farming areas. At the present time, TWE which is chlorinated further at DMC is pumped to farming areas in Sulaibiya, Abdally and

Table 9
Amounts of wastewater inflow and outflow and recovery percent in 2011 for the main WWTPs

Plant	Inflow (m^3/d)	Outflow (m^3/d)	Recovery (m^3/d)
Jahra	68,146	67,600	99.20%
Riqqa	220,108	218,303	99.18%
Sulaibiya	425,497	340,715	80.07%
Umm-Al-Haiman	20,611	20,450	99.22%
Total	734,362	647,068	88.11%

Source: Ref. [12].

Table 10
Agriculture and landscape demands for TWE in 2011

Location	Quantity used in 2011 (m^3/d)
On-site irrigation at treatment plants	
Ardiya plant	480
Jahra plant	2,290
Riqqa plant	1,099
DMC ground	600
Agricultural farms irrigation	
Sulaibiya farm	233,491
Abdally farms	100,849
Wafra farms	81,220
Landscape irrigation	
Riqqa header tank	31,811
Riqqa greenery areas	188,107
Total amounts of TWE used in agriculture and landscaping	639,947

Source: Ref. [12].

Wafra areas. PAAF distribution network conveys TWE from Riqqa plant to greenery areas. On the other hand, tanker truck deliveries are used only to transport TWE from Jahra TWWP, Um-Al-Haiman WWTP and Riqqa header tank to remote greenery areas such as Fintas area.

8.1.2. Present demands

Table 9 shows that the total TWE available for reuse in 2011 was about 647,000 m^3/d. As expected, it also shows that the recovery rate was about 99% for all the conventional plants at Jahra, Riqqa and Um-Al-Haiman. The low recovery rate reported for the advanced plant located in Sulaibiya area can be attributed to the huge amounts of TWE used to dilute the brine stream before its discharge to the sea.

Agricultural and greenery demands in 2011 are given in Tables 10 and 11. As can be seen from these tables, TWE utilized in agriculture and landscape irrigations in 2011 represented about 98% of the available TWE for reuse. This, in fact, represents a significant increase in TWE utilization rate in comparison to that in 2000. In 2000, TWE utilization rate was only 13% [11].

8.1.3. Future demands

Tables 11 and 12 present the future projected TWE demands for landscape irrigation, agricultural irrigation, and recreation and tourism. Future demands were estimated mainly on the basis of future plans reported in the Greenery Master Plan [9,10], except the TWE future demands for Sulaibiya farms which was a direct projection of the historical demands. Further, it is assumed that recreational and tourism demands will grow and expected to reach 23,600 m^3/d in 2020. As shown in Table 13, total TWE future demands is expected to be exceeded by more than a third of the generated TWE. However, excess TWE may be injected in the ground to replenish the depleting groundwater and to be kept as a reserve for high demand periods.

9. Quality standards for water reuse in Kuwait

There are two numerical sets of standards for the quality of municipally treated wastewater in Kuwait.

Table 11
Projected TWE demands for agriculture and landscape

Year	Landscaping (m^3/d)	Farming areas			Total (m^3/d)
		Abdally (m^3/d)	Sulaibiya (m^3/d)	Wafra (m^3/d)	
2020	300,000	145,000	200,00	133,000	778,000

Table 12
Projected total TWE demands

Year	Landscaping (m^3/d)	Agriculture (m^3/d)	Recreation and tourism (m^3/d)	Total (m^3/d)
2020	300,000	478,000	23,600	801,600

Table 13
Projections of total TWE demands vs. total TWE supply

Year	TWE demands (m^3/d)	TWE supply (m^3/d)	Surplus (%)
2020	801,600	1,344,800	40%

The first set of standards was issued by the MPW, while the second one was proposed by the Kuwait Environmental Public Authority (KEPA). The MPW standard is intended for regulating the operation of the municipal plants; and thus, it is used only by municipal plants operators. KEPA set of standards was proposed for regulating the quality of treated wastewater used as irrigation water in Kuwait. Table 14 [11,13] compares these two sets of standards. As can be seen from this table, numerical values of the MPW standards are generally stricter than the KEPA standards. Since currently treated wastewater is used for irrigating only fodder crops and landscapes, the quality required even by KEPA standards is more than adequate.

Table 14
Comparison of standards of KEPA for use of treated sewage in irrigation in Kuwait to MPW guidelines for wastewater reuse in Kuwait

Parameter	Symbol	Unit	KEPA std's	MPW guidelines
Temperature	–	℃	–	31.9
Hydrogen ion concentration	pH	–	6.5–8.5	7.6
Electrical conductivity	EC	dS/m	–	2,057
Biochemical oxygen demand	BOD_5	mg/1	20	3
Chemical oxygen demand	COD	mg/1	100	54(dichromate)
Oil/grease	–	mg/1	5	–
Total suspended solids	TSS	mg/1	15	8
Volatile suspended solids	VSS	mg/l	–	6.2
Total volatile solids	TVS	mg/l	–	688
Total dissolved solids	TDS	mg/1	1,500	1,040
Total solids	TS	mg/l	–	2009
Ammonia nitrogen	NH_4–N	mg/l	15	15.1
Nitrate nitrogen	NO_3-N	mg/l	–	1.13
Nitrite nitrogen	NO_2-N	mg/l	–	0.77
Kajeldah nitrogen	KJN	mg/l	35	–
Organic nitrogen	Org-N	mg/l	–	0.73
Total nitrogen	TN	mg/l	–	17.3
Total phosphate	PO_4	mg/1	30	18.75
Sulfates	SO_4	mg/l	–	270
Fluorides	F	mg/1	25	–
Sulfide	S	mg/1	0.1	–
Dissolved oxygen		DO	mg/1	>2
Total coli form	–	MPN/100 ml	400	11
Escherichia coli form	–	MPN/100 ml	–	–
Fecal coli form	–	MPN/100 ml	20	8
Total count	–	CFU/100 ml	–	3.1E + 4
Egg parasites	–	Egg/l	<1	–
Worm parasites	–	Egg/l	None	–
Salmonella	–	CFU/100 ml	–	10
Fecal streptococci	–	CFU/100 ml	–	5
Fungi	–	CFU/100 ml	–	7

Source: Refs. [11,13].

Table 15
Comparison of secondary effluents to tertiary effluents of Kuwait's municipal plants

Test	Jahra effluent		Riqqa effluent		Um Al-Haiman effluent		Sulaibiya effluent	
	2ry	3ry	2ry	3ry	2ry	3ry	2ry	Advanced
TSS	21.9	5.8	13.6	4.7	6.4	4.2	33.7	0.0
COD	44.6	24.0	28.7	13.8	21.6	12.4	77.7	0.0
BOD_5	23.0	14.1	7.6	2.0	9.8	3.4	22.7	0.0

Note: 2ry: secondary; 3ry: tertiary.

Wastewater treated at municipal plants of Kuwait, at both secondary and tertiary/advanced levels, is generally of a very high quality. Table 15 compares quality of secondary effluents to that of the final effluents of the treatment. This table shows clearly that secondary effluents are suitable for agricultural reuse, as well as the tertiary effluents. With disinfection, the secondary effluents are also suitable for agricultural reuse. That is to say, the tertiary effluents of Kuwait's municipal plants receive more than the adequate treatment required for agricultural reuse. Specially, the advanced membrane (UF + RO) treatment at Sulaibiya plant deprives the irrigation water from the nutrients and other essential elements needed for good crop yield. In fact, the advanced effluent of the Sulaibiya plant, with its present quality, seems to be more suitable for other reuse applications than for agricultural reuse. Other possible reuse application of the Sulaibiya effluent can be groundwater recharge and/or replacing the brackish groundwater being distributed to residential areas through a special network that is underutilized.

10. Conclusion

The State of Kuwait has undertaken a pioneering step towards treatment and reuse of wastewater effluent in the country for beneficial use. The study showed that the treated effluents from Regga, Jahra and Um Al-Haiman plants are of excellent quality at a tertiary level of treatment and satisfy national and many international requirements for restricted irrigation. Moreover, treated effluent from Sulaibiya plant is of superior quality with insignificant traces of pollutants and is suitable for unrestricted irrigation, cooling water, and any other reuse except uses where prolonged human body exposure and risk of intake exist. Sulaibiya plant effluent has low levels of plant nutrients such as nitrogen, and phosphorus probably due to the effluent undergoing advanced refinement through UF and RO processes thus losing some natural fertilizer value.

References

[1] Shahalam, A. Al-Hadad, A. Abusam, S. Al-Shammari, H. Al-Naser, H. Safar, Development of a Wastewater Quality Database and Assessment of Effluent Quality for Potential Reuse in Kuwait, Final Report (KISR 9652), 2008.
[2] MEW, Statistical Year Book: Water the Ministry of Electricity and Water Kuwait, 2010.
[3] MPW, 2010, Process Yearly Reports, The Ministry of Public Work, Kuwait.
[4] M. Abdel-Jawad, S. Al-Shammari, F. Al-Atram, Municipal Wastewater Desalination by Reverse Osmosis, Kuwait Institute for Scientific Research, Report No. KISR5224, Kuwait, 1997.
[5] E. Al-Awadi, T. Rashid, Change in Treated Wastewater Quality Through Soil Aquifer Treatment. Kuwait Institute for Scientific Research, Report No. KISR5724, 1999.
[6] Metcalf and Eddy Inc., Wastewater Engineering, McGraw-Hill, New York, NY, 2003.
[7] KEPA (Kuwait Environmental Public Authority), Kuwait Al-Youm (In Arabic), 2001.
[8] M.J. Hammer, M.J. Hammer, Jr., Water and Wastewater Technology, third ed., Prentice Hall, Columbus, OH, 1993.
[9] M.A. Razzaque, et al, Master Plan for Development of Kuwait's Agricultural Sector (1995–2005), Kuwait Institute for Scientific Research, Appendix IV (Volume 5) (AG-67) Report No. KISR 4615, Kuwait, 1995.
[10] M.A. Razzaque, et al., Master Plan for Development of Kuwait's Agricultural Sector (1995–2005), Kuwait Institute for Scientific Research, Appendix III (Volume 4) (AG-67) Report No. KISR 4615, Kuwait, 1995.
[11] Parsons Engineering Science Inc. and Gulf Consult, Kuwait Sewerage Improvements Phase VIII/Part A and Other Works (Kuwait Treated Effluent Utilization Master Plan) Preliminary Report, Ministry of Public Works (MPW), Kuwait, 2001.
[12] MPW, Treatment Plant Data (Personal Communication, MPW staff), 2012.
[13] Kuwait Environmental Public Authority (KEPA), Kuwait Al-Youm (today) newspaper, Annex to Issue 533, Year 47, 2001.