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Comparative assessment of advanced membrane treatment of municipal wastewater for reuse in Kuwait

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ABSTRACT

This study compared characteristics of municipal sewage treated up to advanced level, using ultra filtration and reverse osmosis (UF+RO) membrane filtration, to that treated up to conventional tertiary level. Data from Kuwait's municipal wastewater treatment plants were used to assess the two types of effluents which are used as irrigation water in Kuwait. Obtained results revealed that conventional membrane treatment deprives the water from the essential nutrients and results in loss of higher amounts of water (>15%) than tertiary treatment (4%). Considering these observations, for agricultural irrigation, tertiary effluents should be preferred over conventional RO effluents. However, the advanced effluents can be utilized beneficially in other suitable urban, industrial or environmental applications.

Keywords: Municipal wastewater; Tertiary treatment; Advanced treatment; Reuse

1. Introduction

Kuwait is situated in a harsh environment which is characterized by little rainfalls (130 mm/yr) and high evaporation rates (4,000 mm/yr). Except the very limited amounts of brackish groundwater which is depleting fast, Kuwait has no other natural fresh water resources, and thus, it rely completely on the expensive desalination of seawater to meet its water demands which is increasing fast due to urbanization and population growth. To maintain sustainable development and lifestyle, therefore, Kuwait has recently adopted vigorous campaigns and actions to recycle treated wastewater effluents and use them as irrigation waters [1]. Thus, Kuwait will benefit from all the advantages of wastewater reuse that include: reducing the stress on water resources, having access to reliable supplies of irrigation waters in all seasons, reducing pollution loads on the environment and reducing the need for fertilizers. However, the country has to take care of the disadvantages of wastewater reuse which are mainly public and environmental health risks associated with disease vectors and toxic chemicals [2].

At the present time, Kuwait generates daily about 600,000 m^3 of municipal wastewater. About 60% of this amount (375,000 m^3/d) is treated to an advance level using ultra filtration (UF) and reverse osmosis (RO) membranes at Sulaibiya plant, while the rest (2,25,000 m^3/d) is treated up to tertiary level at three other conventional plants located at Jahra, Riqqa and Um-Al-Haiman areas of Kuwait. Tables 1 and 2 gives information about operation year, level of treatment, capacity, and type and number of treatment systems used at the four plants. As shown in Table 3, influent of these plants is generally medium strength domestic wastewater. In fact, wastewaters of the industrial areas

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Table 1
Information about Municipal Wastewater Treatment Plants in Kuwait

Plant	Operation year	Treatment level	Design capacity (m^3/d)
Jahra	1981	Tertiary	86,000
Riqqa	1982	Tertiary	180,000
Sulaibiya	2005	Advanced	375,000
Um-Al-Haiman	2001	Tertiary	20,000

are not allowed into these plants. Nonetheless, illegal discharges of industrial effluents are suspected to take place from time to time [3].

Sulaibiya plant is the world's largest membrane-based water reclamation facility. It uses oxidation ditches as secondary biological treatment units. Sulaibiya secondary effluents undergo disk and UF filtration before being fed to the RO system. The UF/RO systems remove residual pollutants, dissolved solids and pathogens; and thus, the produced water is of potable water quality which is more suitable for industrial uses or aquifer recharge than for agricultural reuse. However, Sulaibiya final effluents are presently used to irrigate mainly animal fodder crops. Notice that the tertiary effluents are also used for the same purpose. In fact, the practice of using Sulaibiya final product as agricultural irrigation water contradicts the main reason behind building this plant. The plant was actually designed with conventional RO system to basically satisfy the increasing demands for non-potable urban applications or for artificial groundwater recharge and not for reuse as irrigation water. In Kuwait, in fact, artificial groundwater recharge is still limited to experimental studies.

Kuwait currently reuses more than 50% of the treated municipal wastewaters mainly in irrigation of fodder crops and landscapes. Other urban, industrial, and environmental applications of wastewater are not widely practiced in Kuwait. Fig. 1 shows that amounts of treated wastewater used in Kuwait in agricultural and landscape irrigations are steadily increasing. As it is known that conventional RO treatment removes from water almost all nutrients and plants essential elements [4], use of Sulaibiya effluents as irrigation water raises questions about its suitability for that purpose. This study compares and assesses the suitability of Sulaibiya advanced effluents for agricultural irrigation versus that of tertiary effluents of the other plants in Kuwait.

2. Materials and methods

Influents and effluents data used in this study were obtained from the records of the main municipal wastewater treatment plants for year 2005. Suitability of the effluents for reuse as irrigation water was assessed using the standards proposed by Kuwait Environmental Public Authority (KEPA) for agricultural reuse (Table 4). Water quality parameters used in the assessment were TSS, BOD, COD, TN, and TP. Table 4 presents the KEPA proposed standards. Notice that standards proposed by KEPA for heavy metals are given in Table 7.

As concentrations of heavy metals in the effluents are not recorded by individual plants, they were obtained from the records of the Data Monitoring Center (DMC). DMC records reports as total heavy metals concentrations. DMC records give heavy metals concentrations for Sulaibiya advanced effluents as well as for Jahra and/or Riqqa tertiary effluents, depending on which effluent being pumped to DMC. Since Um-Al-Haiman effluents are not pumped to the DMC, records of DMC give no information about heavy metals concentration in effluents of this plant.

There are no records about heavy metals concentrations in the influents of any of the four plants. For

Table 2
Treatment systems of Kuwait's Municipal Wastewater Treatment Plants

Plant	Secondary treatment systems	Tertiary treatment systems	Advanced treatment systems
Jahra	6 conventional activated sludge systems operated in extended aeration mode	Sand filtration + chlorination	–
Riqqa	12 conventional activated sludge systems operated in extended aeration mode	Sand filtration + chlorination	–
Sulaibiya	9 BNR activated sludge systems	–	Disc Filtration +UF + RO + chlorination
Um-Al-Haiman	4 oxidation ditch systems	Sand filtration + UV + chlorination	–

Table 3
Average influent wastewater in 2005 of Kuwait's municipal plants

Plant	COD	TSS	NH4-N	TP
Jahra	243	180	27	23
Riqqa	393	357	30	21
Sulaibiya	492	227	32	30
Um-Al-Haiman	436	243	24	23

simplicity, however, it was assumed that heavy metals in the influents of the four plants were approximately of the same concentration magnitude. Influents of all Kuwait municipal plants are generally domestic wastewater (Table 3), except some instances of illegal discharges of industrial wastewater [3]. The assumption of same influent heavy metals concentrations justifies comparing heavy metals concentration of the effluents.

The function of DMC facility is to store the treated wastewater before pumping it to the main farming areas in Sulaibiya, Abdallai and Wafra areas. The DMC facility consists of effluent storage tanks, pump houses, chlorination units and a laboratory for water analysis. The total storage capacity of DMC is nearly 38,000 m^3 [7]. All treated effluent of municipal plants, except Um-Al-Haiman plant, is usually pumped to the DMC.

3. Results and discussion

Table 5 compares quality of tertiary and RO treated effluents to KEPA requirements. It is clear from this table that TSS, COD and BOD concentrations of the RO permeate are superior to that of tertiary effluents and far less than KEPA proposed upper limits. However, the same table also shows that tertiary effluents also meet the KEPA requirements.

Table 5 also shows that RO advanced treatment greatly reduced TN and TP concentrations in the final product. In contrast, tertiary effluents are relatively rich with nutrients. In fact it is known that

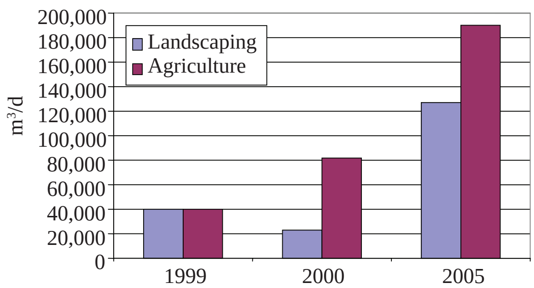

Fig. 1. Agriculture and landscape demands for treated wastewater in Kuwait [5].

Table 4
KEPA Proposed Standards for Treated Sewage Effluents [6]

Parameter	Standards
pH	6.5–8.5
BOD_5	20 mg/l
COD	100 mg/l
O&G	5 mg/l
TSS	15 mg/l
TDS	1,500 mg/l
PO_4	30 mg/l
NH_4	15 mg/l
TN	35 mg/l
Phenol	1 mg/l
F	25 mg/l
S	0.1 mg/l
Cl_2	0.5–1.0 mg/l
DO	>2 mg/l
HC's	5 mg/l
Total Coli form	400 MPN/100 ml
Fecal Coli form	20 MPN/100 ml

* Proposed standards for heavy metals are given in Table 7.

conventional RO treatment systems, as the one used in Sulaibiya plant, deprives water from nutrients and valuable crop elements [4]. In such a case, adequate amounts of nutrients and other essential elements have to be recycled into the permeate of RO or to be supplied from external sources. In pilot studies about utilizing the effluents of a conventional RO as irrigation water, Oron and his co-workers [9–11] have added fertilizers from external sources to make for the nutrients removed by the RO treatment, while Zou and his research team [4] have recycled the essential elements removed by NF into the RO final product. They added polyacrylic acid (PAA) to the feed of the NF system in order to increase the rejection of divalent ions and thus to enhance the RO pre-treatment. Therefore, the advanced treatment train of Sulaibiya plant (UF+RO) clearly needs to be modified in order to produce water appropriate for agricultural reuse.

Table 6 compares the concentrations of heavy metals in both tertiary and advanced effluents in Kuwait. As can be seen from this table, both the effluents generally meet the KEPA standards, except for Cd and Cr. Poor removal of some heavy metals was expected since removal of heavy metals by filtration generally differs from one element to another [12]. What unexpected are lower concentrations of Cd and Cr in the tertiary effluents in comparison to that in the advanced effluents. What unexpected is also the same magnitude of concentration of many heavy metals in the two effluents. As this may contradict the common belief about the higher removal efficiency of membrane

Table 5
Comparison of tertiary and advanced effluent quality of Kuwait's municipal wastewater treatment plants in 2005 [8]

Parameter	Tertiary treatment plants			Advanced treatment plants (Sulaibiya)	KEPA standards
	Riqqa	Jahra	Um-Al-Haiman		
TSS (mg/l)	4.7	5.9	3.7	2.95	15
COD (mg/l)	13.8	23.9	12.5	3.1	100
BOD (mg/l)	1.8	14.0	3.5	1.3	20
TN (mg/l)	10.4	4.3	9.0	1.6	35
TP (mg/l)	27.17	2.4	50.8	2.29	30

filtration in comparison to conventional sand filtration [13], there are needs for more controlled studies on the removals of heavy metal through membrane filtrations.

Table 7 shows that about 39% of water was lost in the Sulaibiya plant in comparison to less than 4% for any of the tertiary plants. Given that Sulaibiya plant treats more than half of raw wastewater generated in Kuwait (Table 1), the amount water lost there is almost one quarter (about 140,000 m^3/d) of the total generated municipal wastewater in Kuwait. It obviously unjustified for a country which has very limited amounts of fresh water to loose such a huge amount of water. Notice that the amount of water lost in Sulaibiya plant had decreased to about 20% in 2007 (data not included here), but that is still greater than the design value (15%). Even the 15% loss of water can not be justified if reuse of treated wastewater will continue to be mainly for agricultural irrigations, since tertiary effluents are more appropriate for that purpose than advanced effluents.

It should be taken into consideration that water quality is not the only factor that influences crop yield.

Table 6
Comparison of heavy metals concentrations in advanced and tertiary effluents of Kuwait's municipal wastewater treatment Plants in 2005 [8]

Metal element	Advanced effluent (mg/l)	Tertiary effluent (mg/l)	KEPA standards
Al	2.0573	0.5213	5.0
B	0.4402	1.0190	2.0
Cd	2.9000	0.0255	0.01
Cr	0.3788	0.1770	0.15
Co	0.1351	0.0155	0.2
Cu	0.0283	0.0307	0.2
Fe	0.0063	0.0071	5.0
Pb	0.2086	0.1715	0.5
Mn	0.0232	0.0452	0.2
Ni	0.1225	0.0169	0.2
Zn	0.0735	0.1002	2.0

Other factors, including salinity tolerance, soil type and drainage, method of irrigation (drip, sprinkler, furrow, etc), frequency and timing of irrigation and the climatic setting, are also affect crop yield. For a certain climate, soil type and a selected crop, however, water quality and irrigation technique are the important control variables that affect crop yield. Thus for Kuwait, where mainly fodder crops (salinity tolerant crops) are cultivated, high removal of salts (salinity) through RO treatment is actually not needed. In such a case, in general, level of wastewater treatment can be specified based the requirements of the selected crop for nutrients and other essential element. For example, permissible limits for EC and SAR values for the selected crops can be obtained from the FAO guidelines for irrigation [14].

In view of the aforementioned, advanced effluents is unsuitable for use as irrigation water. However, such high quality waters can be utilized beneficially in other reuse applications, e.g., urban (e.g. toilet flushing, vehicle washing, fire protection), industrial (e.g. cooling water, boiler feed water, process water), environmental (e.g. irrigation of golf courses, irrigation of hunting and equestrian clubs) or for artificial recharge of groundwater. However, amounts of wastewater that will be treated in such advanced treatment plants needs to be optimized based on the actual wastewater reuse applications that require such high quality water.

4. Conclusions and recommendations

- Use of the final product of a conventional RO system for agricultural irrigation, which is currently practiced in Kuwait, is inappropriate because conventional RO treatment deprives the water from the essential nutrients.
- Amounts of wastewater that will be treated up to advanced RO levels should be specified based on actual reuse applications that require such high quality water.

Table 7
Comparison of lost water during treatment at Kuwait's municipal wastewater treatment plants in 2005 [8]

Parameter	Tertiary treatment plants			Advanced treatment plants (Sulaibiya)
	Riqqa	Jahra	Um-Al-Haiman	
Influent (m^3/d)	132691	68455	10694	340497
Effluent (m^3/d)	131969	67600	10302	207245
Water lost (%)	0.54	1.24	3.67	39.13

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References

[1] H. Al-Rashidi, A.M. Shahalam and S. Alam, Centralized management of treated wastewater reuse in Kuwait: collection, storage and distribution, Proceedings of the 7th Gulf Water Conference, Water in the GCC – Towards an Integrated Management, 19–23 November, 2005 Kuwait, pp. 633-643.

[2] S. Al-Shammari and A.M. Shahalam, Water demand and wastewater management in Kuwait, Proceedings of the 7th Gulf Water Conference, Water in the GCC – Towards an Integrated Management, 19–23 November 2005, Kuwait, pp. 701-709.

[3] R.S. Ayers and D.W. Westcot, Water quality for agriculture, FAO Irrigation and Drainage, paper 29, FAO, Rome, 1985.

[4] F. Ghobrial, M. Lionel, B. Patel and A. Awad, Assessment of raw sewage and treated effluents characteristics in Kuwait, Final Report, KISR 2468, Kuwait Institute for Scientific Research, Kuwait, 1987.

[5] J.N. Lester, Significance and behavior of heavy metals in wastewater treatment plants: I – Sewage treatment and effluent discharge, Sci. Total Environ., 30 (1983) 1-44.

[6] MetCalf and Eddy, Wastewater Engineering Treatment, Disposal, Reuse, 3rd ed., New York, McGraw-Hill Publishing Company Ltd, 2003.

[7] Ministry of Public Works (MPW), Kuwait sanitary master plan, Prepared by Parrsons Engineering-Science, Inc and Gulf Consult, Sanitary Engineering Department, Kuwait, August, 2002.

[8] G. Oron, L. Gillerman, A. Bick, N. Buriakovsky, Y. Manor, E. Ben-Yatshak, L. Katz and J. Hagin, A two stage membrane treatment of secondary effluent for unrestricted reuse and sustainable agricultural production, Desalination, 187 (2006) 335-345.

[9] G. Oron, L. Gillerman, A. Bick, Y. Manor, N. Buriakovsky and J. Hagin, Advanced low quality waters treatment for unrestricted use purposes, imminent challenges, Desalination, 213 (2007) 189-198.

[10] G. Oron, L. Gillerman, N. Buriakovsky, A. Bick, M. Gargir, Y. Dolan, Y. Manor, L. Katz and J. Hagin, Membrane technology for advanced wastewater reclamation for sustainable agriculture production, Desalination, 218 (2008) 170-180.

[11] A.M. Shahalam, S. Al-Shammari, A. Abusam and H. Al-Naser, Present and future wastewater quantities and reuse demand in Kuwait, Kuwait Institute for Scientific Research, KISR 8954, Kuwait, 2007.

[12] A.M. Shahalam, A. Al-Haddad, A. Abusam, S. Al-Shammari and H. Al-Naser, Development of wastewater quality database and assessment of effluent quality for potential reuse in Kuwait, Kuwait Institute for Scientific Research, KISR WT013C, Kuwait, 2008.

[13] S. Toze, Reuse of effluent water, benefits and risks, Agr. Water Manag., 80 (2006) 146-159.

[14] L. Zou, P. Sanciolo and G. Leslie, Using MF-NF-RO train to produce low salt and high nutrient value recycled wzater for agricultural irrigation, Water Sci. Tech., 58 (2008) 1837-1840.