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ORIGINAL ARTICLE

Saudi wastewater reuse standards for agricultural irrigation: Riyadh treatment plants effluent compliance

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Abstract In 2006, standards for wastewater reuse in agricultural irrigation were issued by the Ministry of Water and Electricity (MWE); these replaced the 2003 standards issued by the Ministry of Municipal and Rural Affairs (MMRA). Herein, a review of the current Saudi Arabian policies is presented. Effluent quality from six largest sewage treatment plants in Riyadh, Saudi Arabia was monitored for 10 months; the results are reported in this paper. Further, plant information are presented, effluent quality data, and their conformity to the recent standards are discussed. Upon analysis of the results, all of the studied plants produced effluents of acceptable quality, with only minor violations for restricted agricultural irrigation (RI); the effluents did not conform to the unrestricted agricultural irrigation (UR) standards. According to this study, standards for RI adopted are stringent and might be not suitable for local plants and either reviewing the standards or actions for

Acronyms and abbreviations: MWE, Ministry of Water and Electricity; MMRA, Ministry of Municipal and Rural Affairs; RI, Restricted Agricultural Irrigation; UR, Unrestricted Agricultural Irrigation; GDWR, General Directorate for Riyadh Water; NP-RSTP, The Northern Plant of Riyadh Wastewater Treatment Plant; SP-RSTP, The Southern Plant of Riyadh Wastewater Treatment Plant; KSUSTP, King Saud's University Wastewater Treatment Plant; AIUSTP, Al-Imam University's Wastewater Treatment Plant; DQSTP, Diplomatic Quarter Wastewater Treatment Plant; NGSTP, National Guards' Housing Compound's Wastewater Treatment Plant; WHO, World Health Organization

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upgrading the treatment processes are needed to overcome this violation. This raises the importance of adapting suitable standards for the local conditions without violating the public health requirements.

1. Introduction

Water reuse is implemented in many urban areas in the world to cope with this increasing water shortage. Currently, water conservation and the use of reclaimed wastewater are being considered as strategic solutions in Saudi Arabia and other arid and semi-arid countries. Wastewater reuse results in minimizing the environmental pollution as well as the demand for fresh water. In Saudi Arabia, there are several centralized and decentralized wastewater treatment plants, with some of the latter being owned by the government. The decentralized wastewater treatment plants are part of the decentralized wastewater management system, which consists of collection, treatment, and disposal/reuse of wastewater from individual homes, home clusters, and isolated communities, industries, and institutional facilities (Tchobanoglous, 1995).

In Riyadh there are five centralized treatment plants (with capacities ranging from 3000 to 200,000 m^3/d and total average capacity of 634,000 m^3/d) and more than 77 decentralized wastewater treatment plants (with a total capacity of 178,000 m^3/d) (MWE, 2006b). Two additional centralized sewage treatment plants are currently under construction, with capacities of 200,000 m^3/d (an extension to the Northern Plant of Riyadh Wastewater Treatment Plant) and 100,000 m^3/d. During the preparation of this manuscript, a contract was signed for the construction of a new sewage treatment plant to produce a tertiary treated effluent with an average capacity of 400,000 m^3/d and peak capacity of 640,000 m^3/d. There are plans for the plant to be expanded to 1,200,000 m^3/d in the near future, allowing it to replace three of the largest existing centralized treatment plants. All of the centralized sewage treatment plants in Riyadh belong to the General Directorate for Water (GDWR), part of the Ministry of Water and Electricity. GDWR is responsible for the construction and operation of the municipal centralized wastewater treatment plants in Riyadh. Monitoring the effluent quality from both the centralized and the decentralized wastewater treatment plants also falls under the jurisdiction of the GDWR. In the city of Riyadh, about 170,000–200,000 m^3/d of the treated effluent is used for landscaping and agricultural irrigation, 15,000–20,000 m^3/d is used by industries, and the remaining is discharged into Wadi Al-Batha, which contributes to groundwater recharge.

Effluent must conform to reuse or discharge standards appropriate to its application; however, guidelines, such as those set forth by the World Health Organization (WHO), are not mandatory. Standards and guidelines vary at the state, federal, and international levels. With the increased concern over the environment and public health, more stringent discharge and reuse qualities have been put in place. Appropriate standards and guidelines for water reuse are an important requirement. In the United States, each individual state is responsible for setting its actual standards. For example, California has some of the strictest standards for UI (Blumenthal et al., 2000). In Riyadh, adequate effluent quality for agricultural purposes and conformation to criteria established in the new government code for reclaimed wastewater and reuse must be produced from sewage treatment plants. Different effluent qualities are expected due to the differing methods of treatment used for producing reclaimed wastewater. Processes used include activated sludge, trickling filters, and rotating biological contactors, followed by a single tertiary treatment method in the form of sand filters. In a previous study (Al-Rehili and Misbahuddin, 2001), the effluent from five major treatment plants in Riyadh met the 1986 tentative Saudi Arabian standards for restricted agricultural irrigation issued.

The research presented herein is intended to: illustrate the new Saudi Arabian standards for agricultural and landscape irrigation, both restricted and unrestricted, present a comparison between the latest two local wastewater reuse regulations, and study the effluent quality from the largest six sewage treatment plants in Riyadh, and their conformity to the new standards for treated wastewater use for agricultural and landscape irrigation.

2. Experimental methodology

2.1. Wastewater treatment plants

This study was performed on six major wastewater treatment plants in Riyadh, including:

- The Northern Plant of Riyadh Wastewater Treatment Plant (NP-RSTP).
- The Southern Plant of Riyadh Wastewater Treatment Plant (SP-RSTP).
- King Saud's University Wastewater Treatment Plant (KSUSTP).
- Al-Imam University's Wastewater Treatment Plant (AIUSTP).
- Diplomatic Quarter Wastewater Treatment Plant (DQSTP).
- National Guards' Housing Compound's Wastewater Treatment Plant (NGSTP).

Table 1 provides a more detailed description of these six plants. The first two are among the centralized sewage treatment plants serving Riyadh, while the others are decentralized. Primary and tertiary treatment schemes vary from plant to plant. Disinfection with chlorine is part of the treatments processes in all plants.

2.2. Sampling and analytical methodology

Assessment of wastewater quality is necessary when reusing the water for crop irrigation. Performance of the largest six wastewater treatment plants in Riyadh was studied by analyzing samples collected over ten months. For each plant, 24 h composite effluent, before chlorination, samples were used for analysis. Each composite sample consisted of at least 10 grab samples. Number of composite samples ranged from 5 to 9 for each plant distributed almost equally over the sam-

Table 1 Detailed description of the six major wastewater treatment plants in Riyadh.

Plant	Commissioning date	Design capacity, Ave (m^3/d)	Actual flow rate (m^3/d)			Preliminary and primary treatment	Secondary biological process	Tertiary/advanced treatment method	Owner and operator	Treated effluent reuse practices
			Peak	Ave	Min					
SP-RSTP	1983 (1976 for the first 40,000 m^3/day)	200,000	250,000	190,000	120,000	Mech. screens Aerated grit Chamber Primary sedimentation (4 tanks 46 m diam. and 3 m deep)	High-rate trickling filters with plastic random medium (two trains; C2 with 80,000 m^3/day and C3 with 120,000 m^3/day) and humus tanks (6 for C2 and 4 for C3) followed by aerated lagoons	Sand filters (52 filters) common for both SP-RSTP and NP-RSTP	Wastewater and water authority in Riyadh	Restricted irrigation, industrial purposes, flushing sewers, and disposal to Wadi Al-Batha
NP-RSTP	1994	200,000	320,000	309,000	264,670	Mech. screens Grit chamber Grease removal Primary sedimentation (4 tanks 46 m diam. and 3 m deep)	Activated sludge (4 aeration tanks) including nitrification and denitrification processes and secondary sedimentation (14 tanks)		Wastewater and water authority in Riyadh	
KSUSTP		9100	20,800	9000	3300	Pre-aeration commonuter bar screen Grit chamber and primary sedimentation (2 tanks)	Trickling filters (4 filters) and final sedimentation tanks (2 tanks)	Not used	King Saud University	Power plant cooling and landscape irrigation
AIUSTP		4800/11,520	11,500	1000	800	Coarse and fine screens pre-aeration Grit chamber and primary sedimentation (2 tanks)	Conventional activated sludge using aeration tanks (2 tanks) and final sedimentation tanks (2 tanks)	Sand filtration (gravity flow and pressurized sand filtration), activated carbon adsorption and R/O system.	Al-Imam University	Landscape irrigation
DQSTP		10,000	17,000	2000	1000	Coarse and fine screens, pre-aeration tank and grit chambers Two primary sedimentation tanks	Trickling filters and two final sedimentation tanks	Two sand filtration processes (one gravity flow and one a pressurized sand filtration system		Landscape irrigation
NGSTR		11,000	17,300	12,100	9700	Bar screens Aerated grit chamber Grease removal Comminuting Primary sedimentation (2 tanks # m diam. and # m deep)	RBC with aeration (4 module, each with 5 RBC) final sedimentation tanks (4 tanks)	Sand filtration and lagoon Pressure filters	National Guard	Landscape irrigation

All plants include a disinfection system using chlorine and chlorine contact tanks.

Table 2 2003-MMRA and 2006-MWE maximum allowable contaminant levels in restricted and unrestricted irrigation waters.

Parameter	Unit	Unrestricted irrigation		Restricted irrigation	
		2003-MMRA	2006-MWE	2003-MMRA	2006-MWE
Physical parameters					
Floatable materials		Absent	Absent		Absent
Total suspended solids (TSS)	mg/L	10	10[a]	40	40[b]
pH		6–8.4	6–8.4		6–8.4
Turbidity	NTU		5		5
Chemical parameters					
Organic chemicals parameters					
Biochemical oxygen demand (BOD_5)	mg/L	10	10[a]	40	40[b]
Chemical oxygen demand (COD)	mg/L	50			
Total organic carbon (TOC)	mg/L	40			
Oil and grease	mg/L	Absent	Absent		Absent
Phenol	mg/L	0.002	0.002		0.002
Inorganic chemicals parameters					
Heavy metals					
Arsenic (As)	mg/L	0.1	0.1		0.1
Cadmium (Cd)	mg/L	0.01	0.01		0.01
Chromium (Cr)	mg/L	0.01	0.1		0.1
Copper (Cu)	mg/L	0.2	0.4		0.4
Cyanide (Cn)	mg/L	0.05			
Lead (Pb)	mg/L	5	0.1		0.1
Mercury (Hg)	mg/L	0.001	0.001		0.001
Nickel (Ni)	mg/L	0.02	0.2		0.2
Zinc (Zn)	mg/L	2	4		4
Aluminum (Al)	mg/L	5	5		5
Barium (Ba)	mg/L	1			
Manganese (Mn)	mg/L	0.2	0.2		0.2
Silver (Ag)	mg/L	0.5			
Selenium (Se)	mg/L	0.02	0.02		0.02
Molybdenum (Mo)	mg/L	0.01	0.01		0.01
Boron (B)	mg/L	0.75	0.75		0.75
Vanadium (V)	mg/L	0.1	0.1		0.1
Lithium (Li)	mg/L	2.5	2.5		2.5
Beryllium (Be)	mg/L	0.1	0.1		0.01
Iron (Fe)	mg/L	5	5		5
Cobalt (Co)	mg/L	0.05	0.05		0.05
Chemical compounds					
Total dissolved solids (TDS)	mg/L	2000	2500[c]	2000	2500[d]
Chloride (Cl_2)	mg/L	100			
Sulfate (SO_4)	mg/L	600			
Ammonia (NH_3–N)	mg/L	5	5		5
Nitrate (NO_3–N)	mg/L	10	10		10
Free residual chlorine	mg/L	0.2	0.5[e]		0.5[e]
Fluoride (F)	mg/L		1		1
Biological parameters					
Fecal coliforms per 100 mL		2.2[f]	2.2[g]	1000[h]	1000[b,h]
Intestinal nematodes per litre	No./L	1[i]	1[i]		1[j]

[a] Monthly average BOD_5, and TSS should not exceed 10 mg/L each. Weekly average BOD_5, and TSS should not exceed 15 mg/L each.
[b] Monthly average of BOD_5, and TSS should not be more than 40 mg/L, and Fecal coliforms 1000 colonies/100 mL.
[c] Tertiary treated effluents with TDS more than the stated concentration can be used if dilution with a water of less TDS is possible, or if it will be used for irrigating crops insensitive for high TDS.
[d] Secondary treated effluents with TDS more than the stated concentration can be used if dilution with a water of less TDS is possible, or if it will be used for irrigating crops insensitive for high TDS.
[e] Free residual chlorine should not be less than 0.2 mg/L if chlorine is used as a disinfectant.
[f] Fecal coliform organisms in the effluent should not exceed 2.2/100 mL (MPN method or equivalent).
[g] The wastewater effluent shall be considered adequately disinfected for unrestricted irrigation if the average fecal coliform organisms in the effluent do not exceed MPN 2.2/100 mL (or equivalent) as determined from the bacteriological test results of the last 7 days, and the number of fecal coliform organisms does not exceed MPN 23/100 mL (or equivalent) in any sample.
[h] Colonies.
[i] One live intestinal nematodes per litre.
[j] Secondary treated effluents with intestinal nematodes more than the stated number can be used if precautions for workers and consumers can be taken.

pling period. The parameters most pertinent to these studies included pH, alkalinity, turbidity, conductivity, chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), total nitrogen (TN), ortho phosphorus, chloride content, sulfates (SO_4), nitrates (NO_3–N), residual chlorine, sodium content, calcium content, magnesium content, and fecal coliform content. Determination of certain parameters required on-site testing of grab samples (e.g., turbidity, pH, and free residual chlorine). Sample preservation was carried out when needed to avoid an effect from the delay between sample collection and testing. Bacteriological examination was carried out on grab samples from the final effluent downstream chlorine contact tanks, collected in sterile plastic bags containing sodium thiosulfate pellets for dechlorination of the samples and transferred to the laboratory and tested immediately. Fecal coliform most probable numbers (MPN) per 100 mL were determined using the multiple tube fermentation technique. The physicochemical and biological analyses of the wastewater were performed according to the Standard methods for the examination of water and wastewater (1998).

3. Results and discussion

3.1. Recent vs. previous reuse standards for agricultural irrigation in Saudi Arabia

Several standards for the reuse of wastewater for agricultural and landscape irrigation, both restricted and unrestricted, have been issued in Saudi Arabia. Initially, the Ministry of Agriculture and Water (MAW) issued several draft and tentative standards (MAW, 1986, 1989), all of which were stringent, and prevented agricultural use of the treated effluent (Abu-Rizaiza, 1999). In 2003, the Ministry of Municipal and Rural Affairs (MMRA) issued new standards (MMRA, 2003), which were replaced in 2006 by the latest standards (MWE, 2006a), set by the Ministry of Water and Electricity (MWE). Table 2 shows the maximum allowable contaminant levels for both MWE and MMRA standards for the reuse of wastewater for agricultural irrigation. The MWE is currently responsible for issuing the standards pertaining to water and wastewater.

Certain parameters pertaining to standards for unrestricted agricultural irrigation were added to the new standard (turbidity and fluoride), while others were excluded (COD, TOC, cyanide, barium, silver, chloride, and sulfate). Moreover, limits for some parameters were increased (Cr, Cu, Ni, Zn, TDS, and free residual chlorine), but decreased for Pb. In general, the 2006-MWE standards for UI are less stringent than the MMRA-standards. With respect to RI, the new standards included additional parameters. Among these were pH, turbidity, phenol, some of the heavy metals, ammonia, nitrate, free residual chlorine, and fluoride. As for unrestricted irrigation, the TDS limit was increased from 2000 to 2500 mg/L. Thus, the MWE standards for restricted agricultural irrigation are more stringent than the MMRA standards for restricted agricultural irrigation.

Such less stringent standards for unrestricted agricultural irrigation in an arid country, Saudi Arabia, would encourage water reuse. Conversely, MWE standards for restricted agricultural irrigation may need to be reviewed to be less stringent to promote reclaimed water reuse for irrigation purposes and reduce the increased demand on drinking water supply. It should be noted that beyond the treatment plant, the quality of the treated wastewater might be fluctuating depending on the length of the transportation line and the number of regulation reservoirs and ponds through which the water passes. Bahri et al. (2001) observed a decrease in nutrient and bacteria content during transportation from the wastewater treatment plant to the irrigation site.

3.2. Conformity of effluents with the new standards

Effluent characteristics at all plants are presented in Table 3. Discussion of the main points of the results for each plant is presented below. The effluents from the six wastewater treatment plants are judged based on the possibility of restricted and unrestricted reuse for agricultural irrigation as per the new Saudi Arabian standards for agricultural and landscape irrigation.

3.2.1. Riyadh Wastewater Treatment Plant (Northern Plant)

The Northern Riyadh Wastewater Treatments Plant (NP-RSTP) is owned and operated by the General Directorate for Water in Riyadh (GDWR). During the study period, the effluent turbidity was greater than the maximum allowable limit for unrestricted agricultural irrigation during the months of November, December, and March. Further, nitrate concentration (NO_3–N) did not meet the desired limits during the months of November and March, although nitrate excesses were minimal during other months of the year, not exceeding the limit by more than 0.25–1.2 mg/L.

This plant produces an effluent of acceptable quality for restricted irrigation. However, the effluent was considered unsuitable for unrestricted agricultural irrigation because certain parameters exceeded the maximum contaminant levels allowed by the new standards for the reuse of wastewater for agricultural irrigation. These parameters included: NO_3–N, turbidity during the month of November; turbidity, and TSS during the month of December; NO_3–N, and turbidity during the month of March; TSS during the month of April. For all samples, fecal coliform concentration exceeded the limit of 2.2 MPN/100 mL for unrestricted agricultural irrigation. The poor effluent quality from this plant is likely a result of operating the NP-RSTP at flows higher than its design capacity, as seen in Table 1. Furthermore, technical problems with some processes (e.g., bad settling properties, in the secondary sedimentation tanks, associated with sludge bulking during period of samples collection) used in the plant were also reported.

3.2.2. Riyadh Wastewater Treatment Plant (Southern Plant)

The SR-RSTP is also owned and operated by the GDWR (under the authority of MWE). Despite being operated above its designed load capacity during the period of study, the effluent quality was suitable for restricted irrigation according to the new Saudi Arabian standards. During the course of the study period, turbidity was slightly greater than the desired limit, and nitrate concentration exceeded the desired limit during the month of March. However, this plant produced an effluent with unacceptable quality for unrestricted agricultural irrigation during the same period of study. The parameters that did not conform to the Saudi standards included: turbidity during the months of November, December, and May; TSS, NO_3–N, and turbidity during the months of March and April; and fecal coliform concentration, which was over the accepted limit during the entire duration of the study.

Table 3 Effluent qualities of the six largest wastewater treatment plants in Riyadh, Saudi Arabia.

	Units	NP-RSTP		SP-RSTP		KSUSTP		AIUSTP		DQSTP		NGSTP	
No. of samples		9		9		8		7		7		5	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Ave. Q	m^3/d	209,328	188,510 244,050	285,786	265,612 301,020	5363	4840 5992	2011	1824 2340	8474	6836 10,320	13,589	12,301 15,235
Floatable		Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
TSS	mg/L	9.6	6–13	10	8–12	11.8	9–16	8.4	6–11	9.2	7–12	8.02	5.2–17
TDS	mg/L	1114.4	1020–1190	1166.4	1090–1250	751	660–820	1130.4	922–1350	1090.6	995–1220	1070.2	898–1340
COD	mg/L	24.6	20–30	17	12–25	28	23–33	27.4	20–40	39.2	35–42	23	18.6–26
T–N	mg/L	9.774	9–11	18.4	15–21	19.5	18–20.7	26.184	22–30	31	27–35		
EC	mg/L	1335.2	1180–1470	1382	1300–1520	1120.4	1090–1167	1178.8	1122–1232	787	680–995	942	733–1132
pH	mg/L	7.202	7.1–7.3	7.19	7.1–7.4	7.24	7.1–7.5	7.04	6.9–7.25	7.26	6.95–7.4	7.1	6.9–7.4
Cl_2	mg/L	38.6	35–42	50.2	28–66	34.6	23–44	37.2	33–42	28.8	20–39	37.44	24.4–55.1
SO_4	mg/L	40.8	10–60	58	15–79	102.8	95–112	158.6	143–180	141	100–190		
NO_3–N	mg/L	9.01	4.8–11.2	9.67	5.5–14.15	7.38	4.29.8	4.01	3.3–4.5	5.46	4.7–6	7.64	7.2–8.1
HCO_3	mg/L	118.1	89–136	127.6	107–145	86.5	83–88	96.1	85–102	64.2	36–81	99.52	80.3–130.1
Na	mg/L	104.6	85–162	87.6	82–94	74.4	68–81	74.4	67–82	65	60–70	88.86	64.7–104
Ca	mg/L	89.4	48–130	73.4	28–108	102.2	36–160	122	52–200	117.6	48–200	73.38	49.3–102.1
Mg	mg/L	46.6	38–60	41.2	39–44	81.6	40–200	74.2	39–160	48.4	39–80	55.02	41.4–70.4
Turb.	mg/L	6.174	4.75–8	7.202	5.2–9	4.386	4.1–4.7	4.236	4–4.5	2.74	2–3.2	4.34	3.1–6.2
Re.Cl	mg/L	0.26	0.2–0.3	0.3	0.3–0.3	0.32	0.25–0.4	0.36	0.25–0.4	0.27	0.2–0.3	2.22	1.2–3
P	mg/L	3.95	3.25– 4.5	4.33	3.95–4.5	3.31	2–4.2	2.4	0.8–3.7	2.07	1.2–2.85		
F.C	MPN/ 100 mL	71	41–110	84	64–130	164	120–210	258	210–350	139	95–170	25	14–32
SAR		2.324	1.18–4.06	2.04	1.78–2.58	1.58	1.37–1.93	1.51	1.12–1.85	1.324	1.17–1.5		
Adj R_{Na}		2.412	1.82–4.06	2.104	1.84–2.53	1.584	1.4–1.82	1.566	1.26–1.76	1.262	1.03–1.43		

Re. Cl, residual chlorine; SAR, sodium adsorption ratio; Adj R_{Na}, adjusted sodium adsorption ratio.

Based on the study, it is recommended that the plant could improve removal of TSS, NO_3–N, turbidity, and fecal coliform if the effluent is intended for use in unrestricted agricultural irrigation. Suggested means of improvements include; improvement of nitrification/denitrification process, control of sludge bulking phenomenon, improvement of the final sedimentation process. Chlorine dosage increase and longer contact time are suggestions for improving disinfection process to control microbiological quality. Furthermore, correcting for some operational problems, such as overloading, may also improve the effluent quality.

3.2.3. King Saud University Wastewater Treatment Plant

The King Saud University Wastewater Treatment Plant produced an effluent of better quality than both the SP-RSTP and the NP-RSTP. The effluent conformed to the 2006-MWE standards for restricted agricultural irrigation. However, this plant failed to produce effluent conforming to the standards for unrestricted agricultural irrigation. The effluent fecal coliform concentration was higher than the maximum allowable level for unrestricted agricultural irrigation during the full period of study (ranging from 120 to 210 fecal coliform/100 mL as compared to 2.2 coliform/100 mL). In addition, TSS was greater than the maximum allowable levels during the months of December, April, and May. Furthermore, this plant is operated at 53–65% of the design capacity during the whole year and specially the summer months (July–September) due to the academic holiday. This raises the doubts about the plant capability to conform to the 2006-MWE standards for RI when operated at around the design capacity.

3.2.4. Al-Imam University Wastewater Treatment Plant

The Al-Imam University Wastewater Treatment Plant used more advanced processes for treating part of the secondary effluent than all other plants studied. These processes included a pressurized sand filtration system, activated carbon adsorption, and a reverse osmosis (R/O) system.

At this plant, samples collected after the gravitational flow sand filtration process were of an acceptable quality for RI use according to the 2006-MWE standards (Table 3). However, this effluent was unacceptable for unrestricted irrigation due the presence of fecal coliform beyond the maximum allowable limit, analogous to the other plants studied. To meet the stipulated effluent standards for unrestricted agriculture use, elimination or reduction of fecal coliform is necessary.

3.2.5. Diplomatic Quarter Wastewater Treatment Plant

Much like the four wastewater treatment plants discussed thus far, the Diplomatic Quarter Wastewater Treatment Plant achieved sufficient effluent quality to be used for restricted irrigation. The effluent was considered suitable for restricted agricultural irrigation. As for unrestricted irrigation, TSS exceeded the limit by a small margin (6 mg/L) during the month of December, which could be due to a failure in the operation of the trickling filter or the final sedimentation tanks during that month. Fecal coliform concentration also exceeded permissible levels for unrestricted irrigation during the entire study, requiring additional disinfection before reuse.

3.2.6. National Guard Wastewater Treatment Plant

The National Guard Wastewater Treatment Plant is 20 years old and among the few plants utilizing rotating biological contactors (RBC) in Saudi Arabia. The investigation indicated that turbidity was not within the acceptable range for one of the samples. In general, the results indicate that the effluent complies with the current reuse standards for restricted agricultural irrigation. Free residual chlorine concentration exceeded acceptable limits; however, this was expected to decrease due to a drop in the chlorine levels in the system (Al-Jasser, 2007) that transports the treated effluent to the irrigation area, 3 km from the plant.

Although this plant reduced fecal coliforms concentration, the treated wastewater did not meet the 2006-MWE UI standards. Additional contact time in the chlorine contact tank to reduce fecal coliforms in the effluent will be necessary to comply with the standards.

3.3. Specific ion toxicity and water infiltration rate

Crop yield and soil properties are affected by the concentration of certain ions in the treated effluents used for irrigation, and thus the constituents of the treated effluent could affect plant growth and soil characteristics. *Specific ion toxicity* and *water infiltration rate* are two important parameters used to qualify treated effluents. Sodium (Na^+), chloride (Cl^-), and boron are the ions of most concern among the specific toxic ions. Salinity directly affects the availability of crop water, while sodium causes clay soil to disperse (Chang et al., 2005). A limit on sodium content is not included in the 2006-MWE standards, while chloride limits are not included in either the previous or the 2006-MWE standards. Boron limit is included in the 2006-MWE standards. For water use in a surface irrigation method, all of the studied treatment plants produced effluent of an unacceptable quality with respect to sodium ion content, based on the guidelines developed by the University of California Committee of Consultants (UCCC) (Metcalf and Eddy, 2003). Furthermore, if a sprinkler irrigation method were to be used, the DQSTP was the only plant among the six for which there would be no restriction in the use of its effluent, whereas the other five sewage treatment plants would have low-to-moderate degrees of restriction for this form of irrigation.

Water permeability (infiltration) rate in the soil is affected by the concentration of sodium in the water. Potential infiltration problems can be predicted by the *sodium adsorption ratio* (SAR). However, the *adjusted sodium adsorption ratio* (adj R_{Na}) is preferred if reclaimed water is used because it reflects the changes in calcium in the soil water more accurately (Metcalf and Eddy, 2003).

$$\text{adj } R_{Na} = Na^+/[(Ca_x^{2+} + Mg^{2+})/2]^{0.5}$$

where the concentrations of the cations are expressed in meq/L, and Ca_x^{2+} is the concentration of calcium adjusted for HCO_3^- concentration and the electrical conductivity of the reclaimed water. The value of adj R_{Na} was determined for the effluent of the six wastewater treatment plants (Table 3). As the electrical conductivity increases, the value of adj R_{Na} must increase to reduce the degree of restriction on the use of the reclaimed water for irrigation. *Adjusted sodium adsorption ratio* is not included in either of the Saudi standards, the new and the previous. According to the UCCC guidelines, all plants produced effluents with no irrigation use restrictions with respect to the adj R_{Na} during the study period. Boron concentration measurement must be considered in studies on water reuse for agricultural irrigation. The adj R_{Na} is used only when the water quality and the soil chemical characteristics are likely to affect the equilibrium concentration of calcium significantly.

Heavy metals are part of the standards for wastewater reuse in agricultural irrigation, however, they were not measured in the effluent from the plants considered in this study. Some or all of these metals could be taken up by crops.

4. Conclusions

The 2006 standards for wastewater reuse for agricultural irrigation set by the MWE, Saudi Arabia, replaced the previous standards set by the MMRA in 2003. As discussed, for some parameters the maximum allowable contaminant levels were changed, and certain parameters were added, whereas others were excluded in the new standards. The 2500 mg/L limit for the TDS in the 2006-MWE standards is very high, to irrigate with more than 1000 mg/L, good drainage is recommended. The MWE standards for unrestricted agricultural irrigation are less stringent than the MMRA standards, while the MWE standards for restricted agricultural irrigation are more stringent than the MMRA standards. In a review of the effluent qualities of the six largest wastewater treatment plants in Riyadh, Saudi Arabia, effluent suitable for restricted irrigation was produced. Minor violations of the maximum allowable contaminant levels with respect to RI were observed in the effluent from some of these plants. Unfortunately, none of the plants was successful in producing effluents suitable for unrestricted irrigation. Fecal coliform exceeded the maximum allowable limit for unrestricted agricultural irrigation; this might be due to improper operation of the existing disinfection units. The study showed that the standards for restricted irrigation adopted are stringent and might be not suitable for local plants and either reviewing the standards or actions for upgrading the treatment processes is needed to overcome this violation. Furthermore, the 2006-MWE standards are more stringent than the WHO guidelines. This raises the importance of adapting suitable standards for the local conditions. Effluents quality was also assessed using international guidelines for use in agricultural irrigation.

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