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Environmental Monitoring and Assessment

An International Journal Devoted to
Progress in the Use of Monitoring Data
in Assessing Environmental Risks to
Man and the Environment

ISSN 0167-6369

Volume 186

Number 11

Environ Monit Assess (2014)

186:7709-7718

DOI 10.1007/s10661-014-3961-9

ENVIRONMENTAL MONITORING AND ASSESSMENT

An International Journal devoted to progress in the use of monitoring
data in assessing environmental risks to Man and the environment.

ISSN 0167-6369
CODEN EMASDH

Editor: G. B. Wiersma

Volume 186 No. 11 November 2014



 Springer

 Springer

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Quality of wastewater reuse in agricultural irrigation and its impact on public health

Bushra Ahmed Al-Hammad · Magda Magdy Abd El-Salam · Sahar Yassin Ibrahim

Received: 5 January 2014 / Accepted: 22 July 2014 / Published online: 2 August 2014
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Abstract This study is planned to perform a sanitary survey of the largest sewage treatment plant in Riyadh, KSA, fortnightly for 6 months to examine its effluent quality as an example for the growing dependence on reuse of treated municipal wastewater in agricultural irrigation purposes to cope with increasing water shortage. The biological and physico-chemical parameters of 12 wastewater samples from the plant were examined using standard methods. The physico-chemical analysis indicated that the surveyed municipal wastewater treatment plant contained some of the studied parameters, such as turbidity, total suspended solids, biochemical oxygen demand, chemical oxygen demand and residual chlorine above the maximum permissible wastewater limits set by the Saudi Standards. However, heavy metal concentrations in all samples were lower than the recommended standards. Total and faecal coliform counts were above the permissible limits indicating poor

sanitation level. Fifty percent of all wastewater samples were contaminated with faecal coliforms but, surprisingly, *Escherichia coli* were only detected in 8.3 % of the samples. Regular monitoring and enhancement of microbial and physico-chemical parameters of the wastewater quality served by different wastewater treatment plants for reuse in agricultural irrigation is recommended to preserve the environment and public health.

Keywords Wastewater reuse · Municipal wastewater · Wastewater quality · Wastewater treatment · Agricultural irrigation · Saudi Arabia

Introduction

The reuse of treated wastewater in agricultural irrigation applications is imperative in many arid and semi-arid regions where water resources are insufficient to satisfy development needs (Aljaloud 2010) in terms of quantity and the added benefits from contained nutrients (Rutkowski et al. 2007). The reuse of wastewater effluent could minimize both environmental pollution and the demand for fresh water (Alhumoud et al. 2003; Al-Jasser 2011).

The Kingdom of Saudi Arabia (KSA) is an arid country (Hussain and Al-Saati 1999). Fresh water supply in hot, dry regions is limited by scarce precipitation and high evapotranspiration (El Mahmoudi et al. 2011). With the rapid growth of the population coupled with increasing urbanization and agriculture, the demand for water increases continuously (Abu-Rizaiza 1999). The

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water supply increased from 1.75 billion m³ in 1975 to 22.93 billion m³ in 1992 to meet Saudi Arabia's growing agricultural requirements (Hussain and Al-Saati 1999). The main water source in the country comes from the desalination of sea water or from groundwater aquifers (Abu-Rizaiza 1999). Agriculture accounts for approximately 91 % of the total water consumed in the country, and the remaining 9 % is utilized for domestic and industrial purposes (Hussain et al. 2010). More than 70 % of the total cultivated lands depend on irrigation, whereas the remainder depend on rainwater (Hamoda 2004). Water is primarily distributed to consumers by a network of pipes, whereas the rest depends on private tank trucks. Small towns and rural areas depend on the valley's groundwater. In urban areas, domestic wastewater is discharged into sewerage systems, whereas rural areas still depend on septic tanks (Abu-Rizaiza 1999). The total amount of wastewater generated is approximately 1.32 million m³/day (Hussain and Al-Saati 1999). Approximately 30 % of all generated municipal wastewater is collected and treated by treatment plants in the KSA. A municipal wastewater management system consists of the collection, treatment and disposal/reuse of wastewater from residences, institutions and commercial establishments. Industrial wastewater may be discharged into municipal sewers after a specified degree of pretreatment (Al-Rehaili 1997). More than 75 % of the treated wastewater is discharged to the sea or left to evaporate in desert lagoons (Husain and Ahmed 1997).

Current Saudi Arabia policies emphasize effective water conservation tools by reusing the reclaimed wastewater to augment the irrigation supplies (AL-A'ama and Nakhla 1995). Several standards for the reuse of wastewater for agricultural and landscape irrigation, both restricted and unrestricted, have been issued by the Ministry of Agriculture and Water (MAW 1989), the Ministry of Municipal and Rural Affairs (MMRA 2003) and the Ministry of Water and Electricity (MWE 2006), (Al-Jasser 2011). These standards aim to preserve the environment and public health by controlling the chemical and microbiological hazards that are harmful to plants, soil and people (AL-A'ama and Nakhla 1995).

Currently, there is growing concern regarding the environmental degradation and public health hazards related to the reuse of wastewater. Thus, there is a need for enhanced national policies and strategies that focus on stringent discharge standardization, manpower training, continuous monitoring and adequate quality

evaluation prior to wastewater being used for agricultural purposes. Therefore, this study assesses wastewater quality to be reused as a supplemental source of crop irrigation for agricultural expansion and compares it with standards for landscape irrigation.

Background information

Saudi Arabia has adopted stringent wastewater reuse guidelines similar to those employed in some states in the USA (e.g. faecal coliforms less than 2.2 most probable number (MPN)/100 ml). It has established the treatment infrastructure needed to achieve those requirements (Choukr-Allah 2010).

In Riyadh, there are seven centralized treatment plants (with capacities ranging from 3,000 to 200,000 m³/day and a total average capacity of 634,000 m³/day) and more than 77 decentralized wastewater treatment plants (with a total capacity of 178,000 m³/day) (Al-Jasser 2011). The quantity of wastewater processed is 420,000 m³/day (Hussain and Al-Saati 1999). Approximately 170,000–200,000 m³/day of the treated effluent is used for landscaping and agricultural irrigation; another 15,000–20,000 m³/day is used by industries, and the remainder is discharged into Al-Batha valley, which contributes to groundwater recharge (Al-Jasser 2011).

Material and methods

Data collection

A survey of the largest municipal wastewater treatment plant located in Riyadh, KSA, was conducted using a predesigned questionnaire to collect information about design capacity (m³/day), actual flow rate (m³/day), wastewater treatment operations, treated effluent produced (m³/day), wastewater characteristics, methods of wastewater disposal, effluent utilized for irrigation (m³/day), treated effluent discharged to the sea (m³/day), locations of sampling points, etc.

Sampling and analysis

Bimonthly wastewater grab samples were collected for a period of 6 months amounting to a total of 12 samples to identify which of their quality indicators were not in

compliance with the required Saudi Arabia specifications (MWE 2006) and determine the appropriate wastewater discharge methods. Collection, preservation, physical and chemical analyses and bacteriological examination of the samples were performed according to the Standard Methods for the Examination of Water and Wastewater (Eaton et al. 2005).

Physical and chemical parameters used to evaluate the quality of wastewater for use in agriculture are pH, turbidity, electrical conductivity, total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), alkalinity, free residual chlorine, chlorides (Cl⁻¹), total nitrogen, ammonia (NH₃^{-N}), nitrate (NO₃^{-N}), sulphates (SO₄⁻²) and total phosphorus.

Heavy metal concentration for nine elements [cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), zinc (Zn), chromium (Cr) and cobalt (Co)] were determined using the Atomic Absorption Spectrophotometer Shimadzu model AA-6650 flame system (Eaton et al. 2005). The bacteriological examination was performed for the total viable count (TVC), total and faecal coliforms count and *Escherichia coli*.

Bacteriological examination performed on grab samples from the final effluent in downstream chlorine contact tanks was collected in sterile plastic bags containing sodium thiosulfate pellets for dechlorination of the samples and transferred to the laboratory and tested immediately. The faecal coliform MPN per 100 ml were

determined using the multiple tube fermentation technique.

Statistical analysis

Data were tabulated and analyzed using the Statistical Package for Social Sciences (SPSS) version 11.0 computer software package (Forthofer and Lee 1995). The cut-off point for statistical significance was *P* value <0.05, and all tests were two sided.

Results and discussion

Design and description of the selected municipal wastewater treatment plant

Specifications for the design and operations of the selected municipal wastewater treatment plant are presented in Table 1. It is evident from this table that the surveyed municipal wastewater treatment plant produced treated effluents with a design capacity of 200,000 m³/day. The treated wastewater characteristics exhibited a BOD and TDS removal efficiency of 86 and 7.2 %, respectively. This plant is located in the north of Riyadh. It is owned and operated by the General Directorate for Water in Riyadh (GDWR). Higher removal percentages of BOD and TDS (91–97 % and 96–99 %, respectively) were designed in a municipal

Table 1 Specifications for design and operations of the selected municipal wastewater treatment plant in Riyadh, KSA

Parameters	Unit	Northern municipal wastewater treatment plant
Design flow capacity	m ³ /day	200,000
Actual flow rate	m ³ /day	282,000
Actual biochemical oxygen demand (5 days)	mg/l	360
Actual total dissolved solids	mg/l	1,403
Design BOD ₅ load	kg/day	300
Design dissolved solids load	kg/day	2,000
Percentage of BOD ₅ removal	%	86.0
Percentage of dissolved solids removal	%	7.2
Treated effluent produced	m ³ /day	184,000
Effluent utilized for irrigation	m ³ /day	3,789,791
Primary treatment process		Mechanical screens, aerated grit chamber and sedimentation tanks
Secondary treatment process	–	Conventional activated sludge ^a
Tertiary treatment process	–	Granular media filtration and chlorination

^aactivated sludge (four aeration tanks) including nitrification and denitrification processes and secondary sedimentation (14 tanks)

wastewater treatment plant in Jubail, KSA, which was studied by AL-A'ama and Nakhla (1995).

The survey results revealed that municipal wastewater was treated in three processes as shown in Fig. 1. The primary, secondary and tertiary treatment schemes included (1) preliminary treatment of the influent wastewater using screening and grit chambers; (2) secondary treatment by an activated sludge process; (3) sedimentation tanks that receive the secondary treated wastewater to settle heavy activated sludge in the bottom of the tank while the purified treated wastewater is expelled into an outlet pipe; (4) diffused air aeration tanks that receive the settled activated sludge and disposed of the excess to be treated via sludge thickeners; (5) filtration of purified water through rapid sand filters to remove the suspended matter load, turbidity, organic matter and microorganisms; and (6) disinfection using chlorine to destroy pathogenic bacteria.

Using the treated water, sprinklers are used for the irrigation of grass areas and the drip method is used for trees (AL-A'ama and Nakhla 1995).

Wastewater collection and disposal

The municipal wastewater receives primary, secondary and tertiary treatments with post-chlorination. A high percentage of treated effluent is pumped into the irrigation system of the city for landscape development, and the remainder is disposed into the sea after many advanced treatment steps. The sewerage network used for the collection and disposal of the wastewater lies beneath the roads and sidewalks with a total length of 900 km (AL-A'ama and Nakhla 1995).

Characteristics of wastewater

Table 2 shows the mean values and the range for the different physico-chemical parameters of the municipal wastewater treatment plant studied in north Riyadh,

KSA. The results show that the surveyed municipal wastewater treatment plant was not in full compliance with the Saudi Standards specified by the Ministry of Water and Electricity (2006) regarding the reuse of treated sanitary wastewater for the irrigation of agricultural land or in landscaping. It was also found that although the wastewater in the northern plant is subjected to secondary and tertiary treatments with chlorination, the treated wastewater may only be used for restricted landscape irrigation. The effluent quality from the northern plant is poor because it operates at a flow rate higher than its design capacity as shown in Table 1. Technical problems in some processes (e.g. bad settling properties in the secondary sedimentation tanks associated with sludge bulking during the period of samples collection) used in the plant were also reported (Al-Jasser 2011). These findings are in agreement with Al-Jasser (2011) who monitored the effluent quality from six sewage treatment plants in Riyadh, KSA, and revealed that all effluents' parameters were of an acceptable quality for restricted irrigation, whereas certain parameters exceeded the unrestricted irrigation standards as stipulated by the Ministry of Water and Electricity (2006). The parameters that violated the limits included NO_3^- -N, turbidity, TSS and faecal coliform.

In the present study, the pH values in the majority (83.3 %) of samples collected from the surveyed municipal wastewater treatment plant were in agreement with the Saudi Ministry of Water and Electricity (2006) (6–8.4). The mean values of pH ranged between 7.3 and 7.5. In the KSA, approximately similar results were obtained by Al-Jasser (2011) in Riyadh and AL-A'ama and Nakhla (1995) in Jubail who studied the quality of wastewater reuse and found that the range values of pH were 7.1–7.3 and 6.0–6.7, respectively. This finding is consistent with that reported by Alhumoud et al. (2003) indicating that all pH values (6.5–7.5) in samples from three wastewater plants in Kuwait were below the

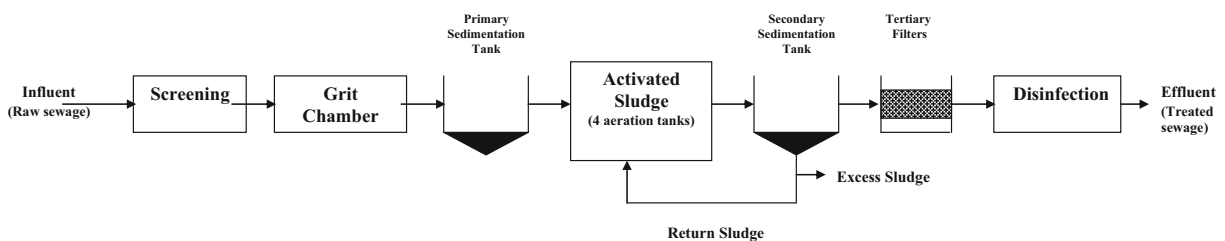


Fig. 1 Flow diagram of municipal wastewater treatment plant in Riyadh, KSA

Table 2 Physico-chemical analyses of wastewater samples collected from the surveyed municipal wastewater treatment plant in Riyadh, KSA

Parameters	Unit	Northern municipal wastewater treatment plant			Limits stated by Ministry of Water and Electricity in 2006 regarding the use of treated sanitary wastewater in irrigation for landscaping and agricultural irrigation	
		Min	Max	Mean	Unrestricted irrigation ^a	Restricted irrigation ^b
PH	–	7.3	7.5	7.36	6–8.4	6–8.4
Turbidity	NTU	3.4	8.2	6.7	5.0	5.0
Conductivity	μs/cm	1,500	2,050	1,700	Not included	Not included
Total dissolved solids (TDS)	mg/l	1,100	1,400	1,220	2,500	2,500
Total suspended solids (TSS)	mg/l	40	60	52	10	40
Biochemical oxygen demand (BOD)	mg/l	38	65	56	10	40
Chemical oxygen demand (COD)	mg/l	119	328	213	50	Not included
Alkalinity as CaCO ₃	mg/l	90	177	160	Not included	Not included
Phosphates (PO ₄ ³⁻ -P)	mg/l	2.3	4.5	3.4	Not included	Not included
Sulphates (SO ₄ ²⁻)	mg/l	135	155	146	600 ^c	Not included
Chloride (Cl ⁻)	mg/l	145	260	319	100 ^c	Not included
Free residual chlorine	mg/l	0.3	0.5	0.4	0.5	0.5
Ammonia (NH ₃ ⁻ -N)	mg/l	1.1	3.2	2.0	5.0	5.0
Nitrates (NO ₃ ⁻ -N)	mg/l	5.8	11.2	9.0	10	10
Total organic nitrogen	mg/l	8.0	14.3	9.8	Not included	Not included

^a Unrestricted irrigation allows watering of crops likely to be eaten uncooked, sports fields, public parks

^b Restricted irrigation is limited to watering of trees, fodder, fiber and seed crops

^c Limits stated by Ministry of Municipal and Rural Affairs in 2003 regarding the use of treated sanitary wastewater in irrigation for landscaping and agricultural irrigation

desirable limits. Al-Turki (2010), Aljaloud (2010) and Hussain et al. (2010) evaluated the effluent quality of wastewater treatment plants at Buraidah City, Riyadh, and Al-Kharj in the KSA, and revealed that the mean pH values were 7.7, 7.26 and 7.06, respectively. In contrast, Alobaidy et al. (2010) evaluated the treated municipal wastewater quality for irrigation in Baghdad City, Iraq and found that the values of pH varied from 6.87 to 8.40 with an average value of 7.70, which indicates that the treated municipal wastewater is slightly alkaline in nature.

It is evident that the range of turbidity value showed great fluctuations in the investigated municipal wastewater treatment plant where four samples had turbidity values (3.4–5.0 nephelometric turbidity unit (NTU)) in compliance with the recommended value specified by the Saudi Ministry of Water and Electricity (2006), whereas more than half (8 out of 12) of the analyzed samples were shown to have turbidity range values (6.0–8.2 NTU) that violated the standard (5.0 NTU). Lower results were obtained from surveys of the municipal

wastewater treatment plants in the KSA (Jubail and Buraidah) conducted by AL-A'ama and Nakhla (1995) and Al-Turki (2010) stating that the turbidity values ranged from 0.7 to 4.2 NTU and from 2.1 to 2.7 NTU with mean values of 1.6 and 2.3 NTU, respectively. Similar results were recorded in another study with a mean turbidity value of 6.2 NTU (Al-Jasser 2011).

Furthermore, the results presented in Table 2 revealed that the wastewater samples collected from the surveyed municipal wastewater treatment plant had a high mean of TDS (1,220 mg/l) but within the permissible limits (2,500 mg/l) of the use of treated sanitary wastewater in agricultural irrigation according to the Saudi Ministry of Water and Electricity (2006). The high TDS mean values could be attributed to rinsing of softeners, washing of reactors and backwash of filters. The finding is consistent with studies in the KSA (Jubail and Riyadh) and in the Iraq (Baghdad) conducted by AL-A'ama and Nakhla (1995), Al-Jasser (2011) and Alobaidy et al. (2010) where the mean values of TDS (936, 1,114 and 1,234 mg/l, respectively) were below the recommended

standards. Higher results were obtained by Al-Turki (2010) and Hussain et al. (2010) who analyzed the TDS at wastewater treatment plants in Buraidah City and Al-Kharj City, KSA, where the recorded mean values of TDS were 2,300 and 4,540 mg/l, respectively.

Lower levels of TSS (\bar{x} = 4.4 mg/l, \bar{x} = 5.3 mg/l and \bar{x} = 9.6 mg/l) were reported in other studies (AL-A'ama and Nakhla 1995; Al-Turki 2010; Al-Jasser 2011) than were measured in the current study (\bar{x} =52 mg/l), and the majority (83.3 %) of samples were above the enforcement level for TSS (10 and 40 mg/l for unrestricted and for restricted irrigation, respectively) according to the Saudi Ministry of Water and Electricity (2006) standards. These results are consistent with findings of previous studies conducted in the KSA (1999) and in the Iraq (2010) indicating that all wastewater samples (50 and 49.30 mg/l, respectively) exceeded the permissible TSS limits (Abu-Rizaiza 1999; Alobaidy et al. 2010).

The BOD₅ recorded for the surveyed municipal wastewater treatment plant ranged between 38 and 65 with a mean value of 56 mg/l. This finding contradicts the results obtained by AL-A'ama and Nakhla (1995) and Abu-Rizaiza (1999) indicating that the mean BOD₅ values are either lower (2.7 mg/l) or higher (25 mg/l) than the Saudi Standards (10 mg/l) (MWE 2006). The results of the present study also contradict the results obtained by Al-Turki (2010) and Alobaidy et al. (2010), who found that the average BOD₅ of the effluents samples in Buraidah City, KSA and Baghdad City, Iraq, were 4.7 and 26.36 mg/l, respectively.

The mean COD value (213 mg/l) of the current study was high compared with the values obtained by Aljaloud (2010), Al-Jasser (2011), AL-A'ama and Nakhla (1995), Abu-Rizaiza (1999), Al-Turki (2010) and Alobaidy et al. (2010), who found that the COD concentration of the wastewater samples collected from the municipal treatment plants were 89, 24.6, 25, 122, 17.04 and 53.10 mg/l, respectively. It is noticed that COD values were higher than the BOD values where COD includes both biodegradable (organic) and non-biodegradable (inorganic) substances whereas BOD contains only biodegradable, but it varies greatly depending on the nature of the substances discharged in the effluent.

The mean value of alkalinity in the studied municipal wastewater treatment plant was 160 mg CaCO₃/l. This finding contrasts with the mean value of wastewater alkalinity (40 mg CaCO₃/l) obtained by AL-A'ama and Nakhla

(1995), whereas these results are in agreement with findings of a survey conducted in Riyadh, KSA (2011), indicating that all wastewater samples had an alkalinity mean value of 118 mg CaCO₃/l (Al-Jasser 2011).

In Riyadh, Abu-Rizaiza (1999) and Aljaloud (2010) collected wastewater samples from municipal treatment plants and revealed that the samples had a high mean concentration of total phosphorus (5.9 and 7.0 mg/l). This finding contradicts the results of the present study where the total phosphorus ranged between 2.3 and 4.5 mg/l with a mean value of 3.4 mg/l. However, the results of the current study agreed with Al-Jasser (2011) who found that total phosphorus values of the effluents ranged from 3.3 to 4.5 mg/l with a mean value of 3.9 mg/l.

In this study, the results showed that none of the effluent samples had SO₄⁻² concentrations that exceeded the Saudi guideline of 600 mg/l (MMRA 2003); all wastewater samples contained SO₄⁻² and Cl⁻¹ below the enforcement standards (Al-Jasser 2011; Aljaloud 2010). All wastewater samples analyzed by AL-A'ama and Nakhla (1995) and Alobaidy et al. (2010) had high mean concentrations of Cl⁻¹ (at least 275 and 205.25 mg/l, respectively), which violated the Saudi Standard (MMRA 2003) for Cl⁻¹ (100 mg/l). This finding is consistent with our results that found the effluent samples had high Cl⁻¹ concentrations with a mean value of 319 mg/l.

The mean value of residual chlorine for the investigated municipal wastewater treatment plant ranged between 0.3 and 0.5 mg/l. More than half (75 %) of the analyzed samples had a concentration of free residual chlorine that was less than 0.5 mg/l which is below the allowable mean value according to the Saudi Ministry of Water and Electricity (2006). These results are consistent with a survey conducted by Al-Jasser (2011) in Riyadh, KSA, who studied the quality of wastewater reuse and reported that the mean value of residual chlorine (0.26 mg/l) did not always comply with Saudi limits which stated that residual chlorine should be 0.5 mg/l (MWE 2006). In contrast, Al-Turki (2010) reported that all wastewater samples collected from the municipal treatment plant in Buraidah City, KSA, had a mean residual chlorine value (0.52 mg/l) within the allowable limits.

As presented in Table 2, all of the effluent samples tested had a mean NH₃^{-N} (2.0 mg/l) value and the majority of them (83.3 %) had a mean NO₃^{-N} (9.0 mg/l) value within the limits described by the

Saudi Standards (MWE 2006) (5 and 10 mg/l, respectively). These results are similar to those found in Riyadh and Jubail, KSA (Al-Jasser 2011; AL-A'ama and Nakhla 1995). These results contrasted with the findings from surveys conducted by Abu-Rizaiza (1999), Aljaloud (2010) and Al-Turki (2010) who found the mean concentrations of $\text{NH}_3^- \text{N}$ in the wastewater samples to be 25, 20.7 and 0.46 mg/l, respectively. In addition, the total organic nitrogen ranged from 8.0 to 14.3 mg/l with a mean value of 9.8 mg/l. This finding is consistent with the results obtained by Al-Jasser (2011) who monitored the wastewater reuse quality in Riyadh, KSA, and found that the total nitrogen ranged between 9.0 and 11.0 mg/l with a mean of 9.8 mg/l. A higher mean total nitrogen value (26 mg/l) than that of the present study was observed by Abu-Rizaiza (1999).

The mean concentrations of Ni, Pb, Mn, Cr, Zn and Fe were 0.002, 0.005, 0.017, 0.001, 0.103 and 0.141 mg/l, respectively. None of the municipal wastewater samples contained Cu, Cd or Co. All of these samples were within the Saudi Standards stated by the Ministry of Water and Electricity in 2006 as shown in Table 3. Higher mean values of Ni, Mn and Fe concentrations (0.04 and 0.003 mg/l, 0.019 and 0.04 mg/l and 0.18 and 0.24 mg/l, respectively) than those reported in the present study were obtained by Al-Turki (2010) and Al-Jasser (2011).

The results of the biological examination of the samples collected bimonthly over 6 months from the investigated municipal wastewater treatment plant in north Riyadh, KSA, are presented in Table 4. As shown in the table, the TVC has been detected in all examined wastewater samples and has a geometric mean of $8.0 \times 10^1 \pm 6.1$ colony-forming units (CFU)/ml at 35–37 °C for 24 h. Nine (75 %) of the 12 examined wastewater samples had total coliforms (TCs) with a geometric mean of $2.4 \times 10^3 \pm 1.31 \times 10^2$ MPN/100 ml, and 66.7 % (six samples) of these samples were positive for faecal coliforms (FCs). However, 50 % of the examined wastewater samples were unacceptable with respect to FC (1,000 MPN/100 ml and 2.2 MPN/100 ml for restricted and unrestricted irrigation, respectively) (MWE 2006) with a geometric mean value of $9.2 \times 10^2 \pm 3.71 \times 10^1$, and only one sample (8.3 %) contained *E. coli*. Lower geometric means of TC and FC (8.0×10^2 and 2.0×10^2 MPN/100 ml, respectively) than those examined in the present study were obtained by Abu-Rizaiza (1999). This finding is consistent with the results found by Al-Jasser (2011), whose effluent samples from the wastewater treatment plant in Riyadh, KSA, had a FC count with a geometric mean of 7.1×10^1 MPN/100 ml, which is lower than that detected in the current study ($9.2 \times 10^2 \pm 3.71 \times 10^1$

Table 3 Heavy metal concentrations of wastewater samples collected from the surveyed Northern municipal wastewater treatment plant in Riyadh, KSA

Heavy metals	Unit	Wastewater samples			Required criteria ^a	
		Min	Max	Mean	Unrestricted irrigation ^b	Restricted irrigation ^c
Nickel	mg/l	0.001	0.003	0.002	0.2	0.2
Lead	mg/l	0.002	0.006	0.005	0.1	0.1
Copper	mg/l	Not detected	Not detected	Not detected	0.4	0.4
Manganese	mg/l	0.001	0.025	0.017	0.2	0.2
Chromium	mg/l	Not detected	0.005	0.001	0.1	0.1
Cadmium	mg/l	Not detected	Not detected	Not detected	0.01	0.01
Zinc	mg/l	0.041	1.972	0.103	4.0	4.0
Iron	mg/l	0.054	1.737	0.141	5.0	5.0
Cobalt	mg/l	Not detected	Not detected	Not detected	0.05	0.05

^a Limits as mentioned by Ministry of Water and Electricity in 2006 regarding the use of treated sanitary wastewater in irrigation for landscaping and agricultural irrigation

^b Unrestricted irrigation allows watering of food crops for human consumption eaten uncooked

^c Restricted irrigation is limited to watering of trees, fodder, fiber and seed crops

Table 4 Biological examination of wastewater samples collected from the selected Northern municipal wastewater treatment plant in Riyadh, KSA

Parameters	Intestinal nematodes (no. of eggs/l)	Total viable count (CFU/ml) at 37 °C for 24 h	Total coliform count (MPN/100 ml)	Faecal coliform	
				Count (MPN/100 ml)	<i>E. coli</i> % positive
	\bar{x}	Geometric mean	Geometric mean	Geometric mean	
$\bar{x} \pm SD$	2.0	$8.0 \times 10^1 \pm 6.1$	$2.4 \times 10^3 \pm 1.31 \times 10^2$	$9.2 \times 10^2 \pm 3.71 \times 10^1$	8.3
Ministry of Water and Electricity Specifications (2006) for unrestricted irrigation	1.0 viable egg/l	Not included	1,000 MPN/100 ml	2.2 MPN/100 ml in a 7-day period	Not more than 23 MPN/100 ml in a 30-day period
Ministry of Water and Electricity Specifications (2006) for restricted irrigation	1.0 viable egg/l	Not included	Not included	1,000 MPN/100 ml	

MPN most probable number, CFU colony-forming units

MPN/100 ml). Neither TC nor FC counts were detected in the municipal wastewater treatment plant samples examined by AL-A'ama and Nakhla (1995) and Al-Turki (2010). In this study, one quarter (25 %) of the municipal wastewater samples had intestinal nematodes with a mean of 2.0 viable eggs/l, which exceeded the permissible limits (1.0 viable egg/l) (MWE 2006).

Public health aspects

Health hazards associated with the inappropriate treatment and uncontrolled reuse of reclaimed wastewater can be broadly grouped into the following: (a) the risk that humans or animals will develop infectious disease from the consumption of reclaimed wastewater that contains various waterborne pathogens and (b) the occupational hazard to field workers who come in contact with wastewater (Husain and Ahmed 1997; Al Salem and Abouzaid 2006). Helminthic infections (intestinal nematodes) pose the greatest risk to farm workers as well as to consumers of farm produce (Al Salem and Abouzaid 2006).

Control measures aimed at protecting agricultural field workers and crop handlers include the provision (and insistence on the wearing) of protective clothing, the maintenance of high levels of hygiene and immunization against (or chemotherapeutic control of) selected infections. Examples of these measures are given in a previous study. It is found that risks to consumers can be reduced through cooking the agricultural produce before consumption and by high standards of food hygiene, which should be emphasized in the health education associated with wastewater use schemes. Local residents should be kept fully informed on the use of wastewater in agriculture so that they, and their children, can avoid these areas. Although there is no evidence to suggest that those living near wastewater-irrigated fields are at significant risk, sprinklers should not be used within 100 m of houses or roads (Pescod 1992).

Special care must always be taken in wastewater use schemes to ensure that agricultural workers or the public do not use wastewater for drinking or domestic purposes by accident or for lack of an alternative. All wastewater channels, pipes and outlets must be clearly marked and preferably painted a characteristic colour. Wherever

Table 5 Correlation between total viable count and total coliform count with turbidity and residual chlorine parameters of the selected municipal wastewater treatment plant in Riyadh, KSA

Bacterial indicators	Turbidity		Free residual chlorine	
	Correlation coefficient	Sig. (two-tailed)	Correlation Coefficient	Sig. (two-tailed)
Total viable count	0.390 ^a	0.001	-0.150 ^a	0.011
Total coliforms	0.427 ^a	0.003	-0.612 ^a	0.026

^a Correlation is significant at 0.05 level (two tailed). $n=12$

possible, outlet fittings should be designed/selected so as to prevent misuse (Pescod 1992).

The results of the statistical analysis showed a positive correlation of microbial indicators with the turbidity of treated wastewater and a negative correlation with free residual chlorine (Tables 5).

Conclusion and recommendations

According to the findings of this study, the surveyed municipal wastewater treatment plant was not in full compliance with the Saudi Standards specified by the Ministry of Water and Electricity (2006) regarding the reuse of treated sanitary wastewater for the irrigation of agricultural land or in landscaping. So, wastewater treatment and reuse for landscape irrigation at the northern plant in Riyadh, KSA, is not effectively established regarding unrestricted irrigation.

Considering the relationship between wastewater contamination with microbial indicators and low chlorine and high turbidity levels detected in the current study, stricter inspection procedure by the Ministry of Water and Electricity should be achieved and focused on periodical monitoring and effluent quality improvement to avoid deleterious effects on public health.

Protection the health status of the workers should be considered through regular health education campaigns regarding the practice of appropriate wastewater treatment and increased budgetary allocations and in-service training. Also, health education of community on the proper reuse of reclaimed wastewater should be launched.

Acknowledgments This project was supported by the deanship of scientific research at Salman bin Abdulaziz University under the research project #63/H/33.

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