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Assessment of Effluent Quality of Tertiary Wastewater Treatment Plant at Buraidah City and Its Reuse in Irrigation

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Abstract: The present study aimed to examine effluent quality of the Tertiary Wastewater Treatment Plant at Buraidah City (TWTPB) and to demonstrate its compliance with regulations of the Ministry of Water and Electricity (MWE) for tertiary treated effluent. Wastewater samples were monthly obtained form the influent and effluent in TWTPB and analyzed for Total Suspended Solid (TSS), Electrical conductivity, pH, turbidity, NH_4^+ concentration, some heavy metals, Na concentration, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and counts of fecal and total coliforms over a period of three consecutive years. The maximum values obtained of TSS, NH_4^+, BOD and COD in the effluent were 5.85, 0.90, 5.75, 24.4 mg L^{-1}, respectively. Removal efficiency for TSS, BOD and COD exceeded 97% in the effluent indicating a high performance of TWTPB. Counts of fecal and total coliforms in the effluent were always less than 2 cfu 100 mL^{-1} in the effluent showing a high level of sanitation. Sodicity hazard indexes such as Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP), revealed that effluent salinity was of low to moderate potential problems when reused for irrigation. Residual Sodium Carbonate (RSC) exhibited a negative value implying that no residual carbonate or bicarbonate to react with Na to exacerbate the sodium hazard in soils was found. The effluent of TWTPB was found consistently to satisfy the stringent standards required by MWE for unrestricted irrigation in respect to all parameters measured in this study. It is, therefore, recommended to reuse TWTPB effluent for unrestricted irrigation, taking into consideration soil properties and leaching requirements.

Key words: Biological oxygen demand, sodium adsorption ratio, fecal coliforms, effluent quality, residual sodium carbonate

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INTRODUCTION

Water resources are becoming increasingly scarce in many arid and semi-arid areas such as Saud Arabia due to agricultural development and increased demand (Hussain and Al-Saati, 1999). In Saudi Arabia, more than 80% of the water is met from non-renewable ground sources (MAW, 1996). While water demands continue to increase, the limited amount of groundwater will always impose great challenges to water resources management in the region. In the last two decades the reuse of municipal wastewater has emerged as an important available alternative water source and a viable mean to meet water requirement for the agricultural sector in many of countries (Hussain and Al-Saati, 1999; Al-Turki, 2003; Bashaar, 2007) . In many instances, the reuse of municipal wastewater is promoted as a mean of limiting wastewater discharges to the environment (Huertasa *et al.*, 2008).

Wastewater reuse for agricultural practices depends mainly on the quality of wastewater effluent which has to be sufficient to protect environment and human health and also be suitable for soil and plants (Huertasa *et al.*, 2008). Therefore, many wastewater treatment plants in Saudi Arabia have implemented tertiary filtration of secondary-treated effluent to improve effluent quality and meet the requirements for its reuse in crop irrigation (Abu-Rizaiza, 1999; Abdel-Magid, 2001).

In Buraidah City, the capital of Qassim Region in central of Saudi Arabia, there was a secondary wastewater treatment plant which was stopped in 2006 because of its limited capacity and poor quality of its effluent. Abdel Magid and Al-Oud (2000) studied the effluent quality of this plant and concluded that the secondary treated effluent was of unacceptable quality and it might cause problems for environment, health and aesthetic when disposed to wadis in the vicinity of urban areas. A new tertiary wastewater treatment plant was recently constructed in Buraidah City with design capacity of 70,000 m^3 d^1. The influent wastewater in this plant is preliminary treated by semi-rotary mechanical bar screens and grit removal. This wastewater is then secondary treated by activated sludge process with a non-conventional continuous channel hydraulic design using carrousel system. Settlement tanks receive the secondary treated water to settle heavy activated sludge in the bottom of the tank while the clear treated water flows over a weir in to outlet pipe. The settled activated sludge coming from settlement tanks is then lift to an elevation for gravity return to the aeration tanks and the excess activated sludge disposed off to sludge thickeners. Clear water flows to the sand filtration unit for further removal of suspended solids, turbidity, organic matter and microbial populations. Filters are composed of 100 cm sand layer each, overlaying a 80 cm gravel layer acting as support media. Filters are designed and operated to provide an average filtrate rate of 5.7 m^3 m^2 h^{-1}. Backwashing of the filters is accomplished for 20 min daily using compressed air and pressurized water. Wastewater is then subject to chlorination after sand filtration. Three chlorinators are available with capacity of 25 kg h^{-1} each. Chlorine dosage rate is controlled by chlorine analyzer, which measures free residual chlorine and gives signal proportionally to the chlorine control valve provided on each chlorinator. Twelve contact tanks receive wastewater in the final stage of the plant in order to provide enough detention time to complete the chlorination reaction and destroy pathogenic bacteria present in the effluent water. No coagulants are used in any stage of this plant. The effluent water is continuously pumped out through a pipe to a part of Wadi Al-Rumma. Although huge amount of treated wastewater is disposed to Wadi Al-Romma, no clear strategy was developed for reusing the effluent wastewater for irrigation (Personal communication).

Several parameters are commonly employed to evaluate the quality of treated wastewater including Total Suspended Solid (TSS), turbidity, salinity, Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (Alberta Environment, 2000; Huertasa *et al*., 2008). Heavy metals such as cadmium (Cd), lead (Pb), Zink (Zn) and Nickel (Ni) are measured in wastewater as an indicator for effluent quality (Mensah *et al*., 2009). Microbiological quality of wastewater is usually indicated by quantification of fecal and total coliforms (Fattouh and Al-Kahtani, 2002; Wand *et al*., 2007; Srinivasan and Reddy, 2009). Other paramount wastewater criteria affecting plant growth and soil properties depend on specific ion concentrations in particular sodium, calcium magnesium, chloride, carbonate and bicarbonate. Wastewater contents of these ions can be used to calculate sodicity hazard indices such as Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Exchangeable Sodium Percentage (ESP) and Soluble Sodium Percentage (SSP) (Hussain and Al-Saati, 1999; Harussi *et al*., 2001; Al-Shammiri *et al*., 2005).

For safe reuse, standards have been established by different institutions to control the quality of the irrigation water. Current legislations in Saudi Arabia have been recently set and issued by Ministry of Water and Electricity (MWE, 2006). Regulations identify two types of irrigations: restricted and unrestricted irrigations which depend mainly on kind of crops. Stringent regulations have been set to meet unrestricted irrigation which is intended for any crop and any type of soil without limitations (Alberta Environment, 2000). Such tight standards cannot be met unless tertiary treatment is applied (Abu-Rizaiza, 1999). More flexible standards, however are proposed for restricted irrigation depending on the type of soil, the proximity of the irrigated area to a potable aquifer, irrigation method, crop harvesting technique and fertilizer application rate (Abdel Magid, 2001; Huertasa *et al*., 2008). Regulations of restricted irrigation can be achieved normally by applying secondary wastewater treatment.

The objective of this study was to evaluate the performance of tertiary treatment plant in Buraidah City (TWTPB) with respect to physiochemical and biological characteristics of effluent and to examine its suitability for unrestricting irrigation.

MATERIALS AND METHODS

This study was conducted in Buraidah City, the capital of Qassim Region in central of Saudi Arabia to evaluate TWTPB over a period of three successive years, starting from January, 2006 until December, 2008.

Sampling: Grab samples of influent and effluent of TWTPB were collected on monthly basis, in jars of one liter each and preserved at 4°C during transporting to the laboratory. For bacteriological analyses, jars were sterilized prior to sampling. All analyses were performed immediately after arrival to laboratory.

Analyses: All samples were analyzed for the followings:

- Physiochemical parameters including total suspended solid (TSS), turbidity, pH, Electrical Conductivity (EC)
- Biochemical parameters including BOD and COD
- Heavy metal contents including Zn, Mn, Cu, Pb, Cd, Ni (only in the effluent)
- Concentration of Na^+, Ca^{+2}, Mg^{+2}, CO_3^{-2}, HCO_3^- (only in the effluent)
- Microbiological analyses by the quantification of fecal coliforms and total coliforms population

All above measurements were conducted following the Standard Methods for the Examination of Wastewater and Waters (APHA, 1998). Some analyses were carried out by the staff of the Central Laboratory of TWTPB and results were rendered available upon the author's request while other analyses were carried out in Water Laboratory, College of Agriculture and Veterinary Medicine.

Removal efficiency: The effectiveness of removal of TSS, BOD, COD, NH_4^+ and fecal coliform was calculated using the following formula:

$$\text{Removal effeicency of } P = \frac{\text{Pinf} - \text{Peff}}{\text{P inf}} \times 100$$

where, P is the measured parameter, inf stands for influent and eff stands for the effluent.

Sodicity hazard calculation: Concentrations of Na^+, Ca^{+2}, Mg^{+2}, CO_3^{-2} and HCO_3^- were transferred to millequivalent concentrations and employed to evaluate sodicity hazard by calculating SAR, SAR adj, SSP, ESP and RSC according to Eaton (1950), Richards (1954) and Suarez (1981) using the following equations:

$$\text{SAR} = \frac{\text{Na(meq L}^{-1})}{\sqrt{(\text{Ca} + \text{Mg})/2 \text{ (meq L}^{-1})}}$$

$$\text{SAR adj} = \text{SAR}\{1 + (8.4 - \text{PHc})\}$$

where, PHc = [PK + PK calcite] + p[Ca + Mg] + p[HCO_3]
PK = log(second dissociation constant of the carbonic acid).
PK calcite = log (solubility equilibrium constant of calcite).

$$\text{SSP} = \frac{\text{Na(meq L}^{-1})}{(\text{Ca} + \text{Mg} + \text{K} + \text{Na})\text{meq L}^{-1}}$$

$$\text{ESP} = \frac{100.(-0.0126 + 0.01475)}{1 + (0.0126 + 0.01457.\text{SAR})}$$

$$\text{RSC} = (\text{CO}_3 + \text{HCO}_3) - (\text{Ca} + \text{Mg}) \text{ (meq L}^{-1})$$

Statistical analysis: Means, maximum values, minimum values and standard deviations of parameters measured in this study during three successive years were calculated using Microsoft Excel Program 2007.

RESULTS AND DISCUSSION

Volume of disposed effluent: The average volume of monthly effluent of Buraidah Tertiary Treatment Plant (TWTPB) during the three years ranged from 1.5×10^6 m^3 in 2006 to 1.9×10^6 m^3 in 2008 (Table 1). Annual effluent volume reached 2.28×10^7 m^3 in 2008. Currently MWE is expanding the TWTPB to increase its capacity to 140,000 m^3 day^{-1} in 2014. This means that TWTPB will discharge about 4.56×10^7 m^3 $year^{-1}$. Reuse of such large quantities of treated wastewater for irrigation can potentially participate in saving groundwater, the main source of irrigation in Saudi Arabia. This application is of great importance since the total cropped area in Buraidah City has dramatically increased during the last two decades resulting in exploitation of the Saq aquifer which sets the warning for an imminent water crises (Badr, 1984; Al-Saati, 1995). Currently, wastewater effluent is totally disposed to Wadi Al-Romma forming a large swamp, which may result in microbial regrowth and considered as a source of mosquitoes breeding and a potential source of hazardous drinking water for animals and undesirable odors.

Physiochemical characteristics: Table 2 summarizes the physiochemical characteristics of raw and treated wastewater during the period of study. Means of TSS concentrations of raw influent were 163.40, 165.47 and 225.61 mg L^{-1} in 2006, 2007 and 2008, respectively, while means of TSS of tertiary treated effluent were found to sharply decline to 5.14, 5.96 and 4.66 mg L^{-1} in 2006, 2007 and 2008, respectively. Although TSS concentration of raw influent had a great variations (between 167.01 and 263.90 mg L^{-1}), a small variation was observed in TSS concentrations of tertiary treated effluent (between 4.54 and 5.58 mg L^{-1}) during the three years (Table 2) which implied that the performance of TWTPB is independent on the influent characteristics. Hamoda *et al.* (2004) and Pollice *et al.* (2004) reported similar results when sand filter was used in the tertiary wastewater treatment in Kuwait and Italy, respectively. In contrast, Colmenarejoa *et al.* (2006) carried out a survey of eight wastewater treatment plant with different technology in Spain and found that TSS range from 40 to 139 mg L^{-1} indicating low quality of the effluent in respect to TSS. As shown in Fig. 1, TWTPB achieved high removal efficiency

Table 1: Monthly wastewater influent and effluent volume (m^3) in TWTPB

	Influent				Effluent			
Year	Mean	Max.	Min.	SD	Mean	Max.	Min.	SD
2006	1.5×10^6	1.6×10^6	1.4×10^6	5.7×10^3	1.5×10^6	1.6×10^6	1.4×10^6	5.3×10^3
2007	1.7×10^6	1.8×10^6	1.6×10^6	9.6×10^4	1.6×10^6	1.8×10^6	1.5×10^6	8.5×10^4
2008	1.9×10^6	2.6×10^6	1.6×10^6	2.8×10^5	1.9×10^6	2.6×10^6	1.6×10^6	2.6×10^5

Table 2: Some physiochemical properties of row influent and tertiary effluent in TWTPB

		Wastewater type							
		Row influent				Tertiary effluent			
Year	Parameters	Mean*	Max.	Min.	SD**	Mean	Max.	Min.	SD
2006	TSS (mg L^{-1})	163.40	188.21	147.6	11.56	5.14	5.84	4.38	0.37
	EC	2.80	2.90	2.61	0.09	3.34	3.41	3.26	0.05
	Turbidity NTU	ND***	ND	ND	-	2.47	2.6	2.1	0.15
	NH_4^+ (mg L^{-1})	18.75	27.08	12.97	5.60	0.45	0.87	0.16	0.25
	Cl^- (mg L^{-1})	ND	ND	ND	-	0.57	0.72	0.43	0.11
	pH	7.52	7.67	7.38	0.14	7.64	7.76	7.38	0.13
2007	TSS	165.47	167.01	150.50	7.73	5.96	4.54	4.45	0.47
	EC	2.77	2.87	2.65	0.07	3.32	3.40	3.19	0.058
	Turbidity NTU	ND	ND	ND	-	2.40	2.90	2.10	0.21
	NH_4^+ (mg L^{-1})	22.27	33.40	14.51	4.73	0.45	0.91	0.12	0.28
	Cl^- (mg L^{-1})	ND	ND	ND	-	0.52	0.81	0.36	0.10
	pH	7.57	7.72	7.42	0.11	7.68	7.84	7.55	0.09
2008	TSS	225.61	263.90	186.30	25.50	4.66	5.50	4.16	0.47
	EC	2.80	2.89	2.66	0.069	3.33	3.43	3.21	0.070
	Turbidity NTU	ND	ND	ND	-	2.33	2.70	2.10	0.19
	NH_4^+ (mg L^{-1})	21.91	41.10	12.71	9.71	0.32	0.85	0.14	0.27
	Cl^- (mg L^{-1})	ND	ND	ND	-	0.47	0.62	0.31	0.07
	pH	7.67	7.82	7.42	0.11	7.73	7.91	7.6	0.12

*Each value represents a mean of 12 replicates taken monthly during the year. **Standard deviation; ***Not determined

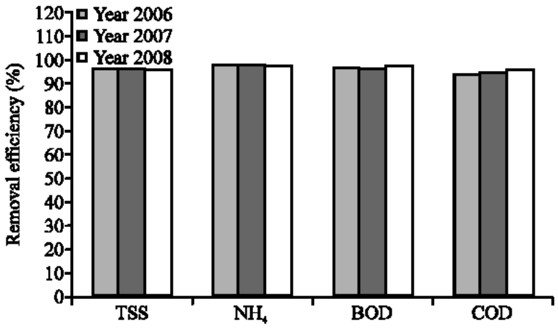

Fig. 1: Removal efficiency of selected tested parameters of effluent in TWTPB. Each value represents a mean of 12 replicates taken monthly during the year

of TSS exceeding 96.8% of raw influent TSS. Healy *et al.* (2006) and Al-Jlil (2009) found that sand filter was able to remove 97% of wastewater TSS. However, in another study, removal efficiency of TSS using sand filter was low and ranged between 58 to 71% (Hamoda *et al.*, 2004). The maximum turbidity of tertiary treated effluent recorded during the period of study was 2.90 NTU (in 2007), while the highest mean of turbidity was 2.47 NTU in 2006 (Table 2). This low level of turbidity is a good indicator of the high performance of the plant in the removal of organic and inorganic suspended materials (Alberta Environment, 2000; MWE, 2006). TSS and turbidity are indicators of the aesthetic aspects of water and are increasingly accepted as physiochemical parameters for monitoring performance of wastewater treatment plant and quality in water reuse. They are of low cost, easy to analyze and they are informative (Hamoda *et al.*, 2004; Arevalo *et al.*, 2009).

In the present study, the concentration of NH_4^+ decreased dramatically in tertiary treated effluent compared to that in the influent . The highest value of NH_4^+ concentration was 41.10 mg L^{-1}, while the highest value in the tertiary effluent was found to be 0.91 mg L^{-1} (Table 2) which may indicate a high rate of ammonium oxidation. Removal efficiency of NH_4^+ was 97.98, 98.54 and 97.60% in 2006, 2007 and 2008, respectively (Fig. 1). Free chlorine, used for disinfection, is routinely measured in the effluent to ensure the presence of certain concentrations capable of disinfection. Results of this work revealed that the concentration of free chlorine ranged between 0.81 and 0.31 mg L^{-1} in the tertiary effluent (Table 2). The minimum accepted level of active chlorine residue in wastewater effluent to inhibit any microbial re-growth is 0.5 mg L^{-1} (MWE, 2006; Wand *et al.*, 2007). Accordingly, active chlorine level should be maintained at this level and continuous microbial assessment of the disposed wastewater is imperative in order to ensure water sanitation prior to reuse. Generally, pH values of the influent and the effluent were slightly alkaline ranging from 7.32 to 7.82 and from 7.38 to 7.91, respectively during the period of the study (Table 2). The increase in effluent pH compared to influent pH is attributed to the decrease in dissolved CO_2 concentration through a reduction in the concentration of organic matter due to oxidation during the treatment (Colmenarejoa *et al.*, 2006).

Biochemical and microbial characteristics: Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are two of the most important biochemical

Table 3: Some biological properties of row influent and tertiary effluent in TWTPB

		Wastewater type							
		Row influent				Tertiary effluent			
Year	Parameters	Mean*	Max.	Min.	SD**	Mean	Max.	Min.	SD
2006	BOD (mg L^{-1})	156.96	168.01	142.50	6.67	4.80	5.54	4.07	0.663
	COD (mg L^{-1})	290.50	308.30	261.70	13.44	17.38	18.60	16.34	0.74
	TCF (cfu 100 mL^{-1})	4.7×10^7	5.1×10^7	4.3×10^7	2.4×10^6	1	2	0	-
	FCF (cfu 100 mL^{-1})	6.1×10^6	6.9×10^6	5.4×10^6	5.2×10^5	1	2	0	-
2007	BOD (mg L^{-1})	159.62	200.10	109.30	22.19	4.98	5.75	4.2	0.48
	COD (mg L^{-1})	350.98	390.90	293.07	37.81	18.59	21.4	16.51	1.29
	TCF (cfu 100 mL^{-1})	4.5×10^7	5.1×10^7	4.3×10^7	2.1×10^6	1	2	0	-
	FCF (cfu 100 mL^{-1})	6.1×10^6	6.8×10^6	5.3×10^6	4.4×10^5	1	2	0	-
2008	BOD (mg L^{-1})	208.51	233.50	185.3	15.70	4.32	5.01	3.67	0.46
	COD (mg L^{-1})	420.87	452.70	391.01	17.86	16.27	18.50	13.70	1.53
	TCF (cfu 100 mL^{-1})	4.6×10^7	5.1×10^7	4.1×10^7	2.9×10^6	1	2	0	-
	FCF (cfu 100 mL^{-1})	5.7×10^6	6.8×10^6	4.8×10^6	6.3×10^5	1	2	0	-

*Each value represents a mean of 12 replicates taken monthly during the year. **Standard deviation

parameters commonly used to examine wastewater quality since they reflect the organic load in wastewater (Uz *et al*., 2004; Huertasa *et al*., 2008). As indicated in Table 3, TWTPB was able to reduce BOD concentrations from 156.96, 159.62 and 208.51 to 4.80, 4.98, 4.32 mg L^{-1} and to reduce COD concentrations from 290.50, 350.98 and 420.87 to 17.38, 18.59 and 16.27 mg L^{-1} in 2006, 2007 and 2008, respectively. Efficiency of BOD removal was 96.93, 96.8 and 97.95%, while efficiency of COD removal was 94.11, 94.66, 96.12% in 2006, 2007, 2008, respectively (Fig. 1). The large reduction in BOD and COD was due to effectiveness of sand filter. Results obtained in the current study are in agreement with those of Hamoda *et al*. (2004) and Al-Jlil, (2009) who reported BOB and COD removal of up to 97% when sand filter was used. However, Colmenarejoa *et al*. (2006) observed low removal efficiency of BOD and COD in final effluents in six plants using different technologies other than sand filtration , which ranged between 39 and 84 and between 37 and 70.4 mg L^{-1}, respectively.

The BOD/COD ratio has been proposed as indicator for biodegradation capacity (Metcalf and Eddy Inc., 1985). If BOD/COD ratio is more than 0.5, biodegradation will readily take place, if between 0.2 and 0.4 biodegradation will occur only in favorable thermal situation and if the ratio is below 0.2 biodegradation will not proceed (Contreras *et al*., 2003). It was found that domestic wastewater has typically a BOD/COD ratio between 0.4 and 0.8 (Metcalf and Eddy Inc., 1985) and as reference, a BOD/COD ratio of 0.4 is generally considered the cut-off point between biodegradable and not biodegradable waste (Uz *et al*., 2004). In the present study, BOD/COD ratio in row influent was around 0.5, which indicates the presence of considerable amount of organic materials vulnerable to biodegradability. This ratio decreased during the different stages of treatment to reach 0.25 which reveals a high stability of the effluent and no further biodegradation is expected to occur. As shown in Fig. 1, the average removal efficiency of BOD was above 97% and of COD was above 96% during the period of study indicating a very high performance of TWTPB, which lies within the highest values of BOD and COD removal efficiency reported in the literature for wastewater tertiary treatment plant in different countries (Hamoda *et al*., 2004; Colmenarejoa *et al*., 2006; Tyagi *et al*., 2009). It is clear from Fig. 2 that the monthly variations in tertiary treated effluent for BOD concentrations remain always below 6 mg L^{-1} in spite of high variations in BOD concentrations of the raw influent. Monthly variations for COD hade similar pattern observed for BOD (data not shown). These findings clearly revealed consistency and stability in TWTPB performance in respect to BOD and COD removal.

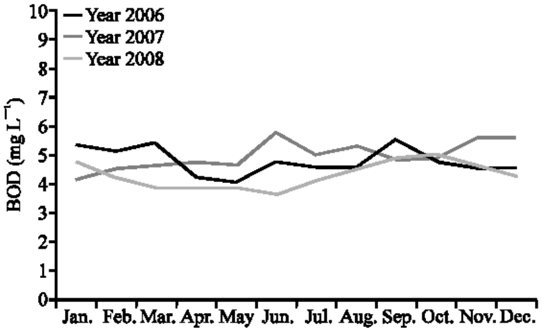

Fig. 2: Monthly variations in BOD of tertiary-treated effluents in TWTPB

The influent counts of Total Coliforms (TC) were found to vary during the period of study from 4.1×10^7 FCU 100 mL^{-1} (in 2008) to 5.1×10^7 FCU 100 mL^{-1} (2006), while counts of Fecal Coliforms (FC) were found to vary from 4.8×10^6 FCU 100 mL^{-1} (in 2008) to 6.9×10^6 CFU 100 mL^{-1} (in 2006) (Table 3). TC and FC counts in chlorinated effluent were substantially reduced to negligible counts that ranged from 0 to 2 FCU 100 mL^{-1}

(Table 3). This result indicates that disinfection process is highly effective and can completely inactivate both TC and FC in the tertiary treated effluent. Removal efficiency for TC and FC was almost 100% during the three years of the experiment. Such high level of microbial elimination from the effluent is rarely reported in the literature, where counts of FC in tertiary treated effluents of many plants range from 100 to 1000 FCU100 mL^{-1} (Fattouh and Al-Kahtani, 2002; Bhattacharjee *et al*., 2003; Wand *et al*., 2007; Srinivasan and Reddy, 2009). It worth mentioning that use of FC as indicator of wastewater sanitation was subjected to criticism since different pathogens such as protozoa and viruses are more resistant to disinfection compared to FC (Wand *et al*., 2007; Fattouh and Al-Kahtani, 2002). Therefore, it is advisable to examine the presence of these pathogens in the effluent, at least every two months, to assure microbial quality of the effluent.

Evaluation of effluent quality for reuse in irrigation: Several parameters related to human health, soil properties and plant types were considered to evaluate compliance of TWTPB effluent with MWE standards for unrestricted irrigation. The most important criteria affecting human health are presence of pathogens, BOD and COD concentration and heavy metal contents, whereas the most important criteria affecting soil properties and plant growth are salinity and concentration of sodium, calcium, magnesium, carbonate and bicarbonate and microorganism population. Results were compared to MWE standards in order to assess effluent quality and its suitability for irrigation.

The mean value of BOD concentration in the effluent was 4.70 mg L^{-1} which is 53% less than the highest permissible limit set by MWE for BOD concentrations in tertiary-treated effluent (10 mg^{-1}) for unrestricted irrigation (Table 4). It should be noted that BOD concentration in the effluent did not exceed the value of 5.54 mg L^{-1} during the period of study (Table 2), indicating the stability of BOD reduction in the effluent and its suitability for unrestricted irrigation. Mean value of COD concentration of the effluent was 17.04 mg L^{-1}. MWE did not specify a limit for COD for wastewater effluent, but other water associations such as those in Kuwait and Italy have set 75 mg L^{-1} as a maximum limit (Ayers and West cot, 1985; Environment, 2000; Hamoda *et al*., 2004) and accordingly the COD of effluent met this standard. Similarly, a high stability was observed in COD reduction in the effluent where the maximum COD concentration was 21.4 mg L^{-1} during the three years of study.

As shown in Table 4, the average values of TSS, pH, turbidity and NH_4^+ of the effluent were 5.25 mg L^{-1}, 7.73, 2.4 NTU and 0.64 mg L^{-1}, respectively which clearly satisfied the maximum accepted limits required by MWE Standards for unrestricted irrigation. Concentrations of heavy metals detected in the effluent were below the permissible limit except that of Pb which was 50% above the limit set by MWE (Table 4), thus Pb may accumulate with time in soil and inhibits plant cell growth at high concentrations (Bhattacharjee *et al*., 2003; Mensah *et al*., 2009). However, solubility and mobility of Pb is pH dependent and its adsorption to soil constituents increases as soil solution pH increases and reaches a maximum at pH 6 (Bhattacharjee *et al*., 2003). Therefore adsorption process will be presumably predominant for effluent Pb when reused for irrigation since pH of effluent and soils in Buraidah City is always more than 7, which may reduce its toxicity to environments and plants.

For hygiene purposes, MWE regulations required that the maximum count of FC in tertiary treated effluent should be 2.2 CFU100 mL^{-1} to be accepted for unrestricted irrigation. TWTPB effluent strongly met this regulation and always contained no more than

Table 4: Compression of characteristics of final tertiary effluent in TWTPB to Saudi guidelines for agriculture irrigation proposed by MWE (2006)

Parameters	Tertiary-treated effluent*	Guidelines for restricted- irrigation	Guidelines for non- restricted- irrigation
TSS (mg L^{-1})	5.25	40.0	10
BOD (mg L^{-1})	4.70	40.0	10
COD (mg L^{-1})	17.04	-	-
Free chlorine (mg L^{-1})	0.52	0.50	0.5
pH	7.73	6-8.4	6 -8.4
TDS (mg L^{--1})	2300	2500	2500
Turbidity (NTU)	2.4	5.00	5.0
NH_4^+ (mg L^{-1})	0.46	5.00	5.0
Fe (mg L^{-1})	0.18	5.00	5.00
Mn (mg L^{-1})	0.019	0.20	0.20
Zn (mg L^{-1})	0.0183	4.00	4.00
Cu (mg L^{-1})	Nil	0.40	0.40
Pb (mg L^{-1})	0.15	0.10	0.10
Cd (mg L^{-1})	Nil	0.01	0.01
Ni (mg L^{-1})	0.04	0.20	0.20
Total fecal coliforms MPN/100 mL	1	1000	2.2

*Each value represents a mean of 36 replicates taken during three successive years (2006, 2007 and 2008)

Table 5: Salinity properties of tertiary treated effluent in TWTPB

Parameters	Average values*
EC (dS m^{-1})	3.34
(Ca+Mg)/2 (meq L^{-1})	9.00
Na (meq L^{-1})	16.50
SSP (%)	46.78
SAR	5.50
SAR adj	9.35
ESP (%)	6.41
RSC	-17.50

*Each value represents a mean of 36 replicates taken during three successive years (2006, 2007 and 2008)

1 cfu 100 mL^{-1} (Table 5) indicating a very high degree of sanitation. Therefore, no microbial contamination hazard is expected from irrigation reuse of the effluent.

Water salinity, expressed as Electrical Conductivity (EC), is perhaps one of most important parameters affecting soil characteristics and plant growth. The upper limit proposed by MWE for reuse of wastewater effluent is 3.5 dS m^{-1}. The mean of salinity level of the effluent was 3.34 dS m^{-1} (Table 4) indicating its suitability for irrigation. According to Ayers and Westcot (1985) guidelines for interpretations of water quality for irrigation, no serious problems are expected from using the effluent with this salinity level for irrigation. Saline water with EC value of 5.3 dS m^{-1} was used in a similar condition in Qatar Country to grow fodder for milking cows with no adverse effect (Arab Water World, 1991). Gratten and Oster (1993) indicated that the threshold irrigation water salinity for a 100% yield potential for crops varied from 1 dS m^{-1} for salinity sensitive crops to 2.7 dS m^{-1} for salinity tolerant crops. However, several classifications were suggested for irrigation waters for salinity hazard ranging from an EC value of 0.75 dS m^{-1} (no salinity problems) to an EC value of 7 dS m^{-1} (sever salinity problems) (US Salinity Laboratory, 1969). Therefore, soil properties, crop types and irrigation technique should be taken into consideration when evaluating water salinity for irrigation.

Sodium is the most dangerous of the major constituents of irrigation water causing what so called Sodicity hazard. Although it is a limiting factor for wastewater effluent reuse, MWE Standards did not specify regulations for sodicity parameters. The upper limit of Na in water irrigation in Kuwait was suggested by some regulatory agent to be 185 mg L^{-1} (Al-Shammiri *et al*., 2005). Excessive concentration of Na can reduce water uptake by plant roots and effectively disperse soil colloids, resulting in a loss of soil structure. Concentration of Na in tertiary treated effluent under investigation was 16.5 meq L^{-1} (379 mg L^{-1}) (Table 5), which exceeded the upper limit of Na by more than 200%. It is, seemingly, evident that when tertiary treated effluent is used as the sole source of water for irrigation, the soil will accumulate injurious amounts of exchangeable Na with time. However, Na concentration *per se* is insufficient indicator for evaluating such water suitability for irrigation. The adverse impact of sodium on soil and plant growth depends on replacing sodium ions for both calcium and magnesium ions (Leal *et al*., 2009). Therefore, different sodicity hazard indices including SAR, SAR adj, SSP and ESP have been suggested to describe the extent of this substitution and hence effect of sodium hazard (Eaton,1950; Richards, 1954; Suarez, 1981).

SAR value is the ratio of sodium to calcium and magnesium concentrations. U.S. Salinity Laboratory, (1969) considers SAR less than 4 to be safe, form 4-9 to be possibly safe, more than 9 to be hazardous. The average SAR of the effluent was 5.5 (Table 5) which is in the category of low risk to soil and plant. The SAR adj is an SAR value corrected to account the removal of Ca^{+2} and Mg^{+2} by their precipitation with HCO^{3-} and CO_3^{-2} ions in the water added (Eaton, 1950). To avoid salinity toxicity, the adjusted SAR of irrigation water should be less than 10 (Rowe and Abdel-Magid, 1995), hence sodium ions are not expected to cause any problems when used for irrigation purposes since its SAR adj was 9.35 (Table 5).

The SSP indicator is the ratio of Na to other cations including Ca, Mg, K and Na. When it exceeds a value of 60%, the treated water is considered harmful and not suitable for irrigation (Hoffman *et al*., 1980). As indicated in Table 5, the SSP of the effluent under study was 46.78% which can be considered of low risk for irrigation purpose. ESP is an important indicator showing the effect of sodium on soils physical properties. High value of ESP means high sodium concentration in the effluent water which causes dispersing soils by replacing the Ca^{+2} and Mg^{+2} ions from soil exchange complex (Leal *et al*., 2009). The desired value of ESP is less than 5%, while values between 6 and 9% mean the possibility of increasing problems with soil infiltration and permeability and ESP value above 15% mean sever problems for soil (Rowe and Abdel-Magid, 1995; Al-Shammiri *et al*., 2005). The ESP calculated for the effluent was 6.41% (Table 5) which is of moderate risk in respect to soil physical properties.

Another index for examining quality of irrigation water is the Residual Sodium Carbonate (RSC) (Eaton, 1950). The RSC is an accurate indicator for the assessment of sodicity hazards because it considers the hazard of carbonate and bicarbonate water irrigation (Barbiero *et al*., 2001). High level of HCO^{3-} and CO_3^{-2} will result in precipitation of calcium and magnesium leading to alkali condition. Water is not suitable for irrigation when RSC value is greater than 2.5 and is of critical side when RSC is between 1.25 and 2.5 and is safe when RSC is less than 1.25 (Eaton, 1950). The effluent under investigation exhibited negative value for RSC (Table 5), implying that the cumulative concentration of HCO^{3-} and CO_3^{-} ^{2}is lower than the combined Ca^{+2} and Mg^{+2} concentration and hence there is no residual carbonate or bicarbonate to react with Na and increase sodicity hazard. It worth mentioning that all sodicity hazard indices other than RSC are expected to underestimate sodicity hazard since they do not take into consideration carbonate and bicarbonate concentration. It is, therefore, evident that the reuse of TWTPB effluent for irrigation will not impose any sodicity problems to soil properties or plant growth provided that suitable irrigation techniques and leaching requirements are taken into consideration.

CONCLUSIONS

The present study indicated that TWTPB is capable of producing a high quality effluent with respect to both physiochemical and biological parameters. Final effluent consistently meets the stringent regulations proposed by MWE for unrestricted irrigation in particular those set for TSS, EC, turbidity, BOD and total fecal coliforms. Sodicity hazard parameters of the effluent were in the category of low risk. The RSC exhibited always a negative value which implies that reuse of the effluent for irrigation will not cause soil dispersion or infiltration problems. However, soil properties, plant type and irrigation techniques should be taken into consideration to avoid salts accumulation with time upon reuse. Since concentration of Pb is higher than the permissible limit, there is a need to monitor its concentration in the effluent, irrigated soil and planted crops.

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