Environ Monit Assess (2014) 186:2701–2716
DOI 10.1007/s10661-013-3572-x

Characterization of domestic wastewater treatment in Oman from three different regions and current implications of treated effluents

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Received: 30 April 2013 / Accepted: 28 November 2013 / Published online: 13 December 2013

Abstract Treated effluents become one of the most significant sources for irrigation and other activities in arid and semi arid countries such as Oman. This study focuses on characterizing the quality of domestic wastewater in chosen three regions: Muscat, Sohar, and Salalah. The knowledge on treatment processes, quality, and proper management of domestic wastewater reuse for various purposes is essential. Wastewater samples were collected from six different sewage treatment plants (STPs) over a period of 1 year in 2009 on a monthly basis. The raw sewage (RS) and treated effluent (TEs) samples were collected from different sampling points in each STP. Both types of samples were analyzed for physicochemical and microbiological assessment. All tests were conducted according to the standard method for the examination of water and wastewater. The results revealed that the TEs electrical conductivity, biological oxygen demand, chemical oxygen demand, heavy metals, sodium, potassium, and total dissolved solids values were found within Omani Standards (OS). The RS in all STPs was categorized as high strength concentration and samples exceeded the acceptable range for ammonia in most of the selected plants except Sohar and Salalah. Nitrate values in RS were also observed in higher concentrations. In general, the produced TEs have met most of regulatory limits stated by OS except for nitrate, *Escherichia coli* and total suspended solids (TSS). Furthermore, it should be noted that the performance of Salalah and Darsayt STPs can be classified as the best compared to the other four STPs studied in Oman.

Keywords Wastewater · Characterization · Physicochemical · Microbiological · Effluents · Oman

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Introduction

Domestic wastewater is water that has been used by human beings, which comprises all the materials added to the water throughout its use. It is therefore composed of human body wastes (feces and urine) together with the water utilized for flushing toilets, washing, laundry, food preparation, and cleaning of kitchen utensils (Mara 2004). More than 350 wastewater treatment plants (WWTPs) are distributed across different areas of Oman. These WWTPs belong to the government, private sectors, and individual owners. The accessible data indicated that Oman Wastewater Services Company operates 10 WWTPs in the governorate of Muscat (Ansab, Al-Khudh, Shati Al-Qurm, Al Amerat, Busher, Manumma, Muabaylah, Darsayt, Aynat, and Japrooh). The amount of produced treated wastewater anticipated to increase during the period from 2011 to 2016. Concurrently, an increase in demand by the municipality of Muscat is expected. Thus, the mean allowance of the surplus of these waters will be between 17,943 m^3/day in 2011 and 21,993 m^3/day in 2016. In Oman, wastewaters collected from domestic and commercial localities are transferred to either WWTPs or lagoons via sewer systems (very few) or through tankers from septic containers (majority). For example, there are collection and treatment systems for about 25 % of the Muscat municipal population (Al-Sulaimani 2003). Wastewater effluents of existing WWTPs have been used for landscape irrigation and recharging groundwater to resist salt water intrusion in coastal areas. Most of the sludge produced is sent to landfills. No comprehensive data is provided regarding the lagoon effluents and resulted sludge.

El-Gohary et al. (1998) determined the characteristics of the raw wastewater, the quality of the treated effluent, and the efficiency of the various treatment units in Egypt. The results showed that the concentration of the raw wastewater was considered moderate and the effectiveness of the treatment facility was good. Colmenarejoa (2006) evaluated eight small-scale municipal wastewater treatment plants over a period of 19 months in the suburb of Las Rozas in Madrid (Spain). The best results were obtained from the plants that utilized conventional technologies and the biodisk. Conventional activated sludge and extended aeration had higher removal efficiencies for ammonia, total suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD_5) and produced good quality effluents for final disposal in accordance with the discharge standards. Hussain et al. (1999) focused a study on the salinity and residual sodium carbonate of the treated effluents from different sewage treatment plants (STPs) in the Kingdom of Saudi Arabia. Their study outcomes showed that the quality of the wastewater ranges between low salinity–low sodium to very high salinity–very high sodium hazards.

Alaton et al. (2007) researched the current situation of urban wastewater treatment plants in Turkey. The results showed that the treated effluents were not appropriate for irrigation purposes according to the existing national irrigation water quality standards. Lou (2008) selected the Cheng-Ching Lake water treatment plant in southern Taiwan to talk about the feasibility of wastewater recycling and treatment efficiency of wastewater treatment units. The results showed that the treatment efficiency of suspended solids and turbidity were 48.35 to 99.68 and 24.15 to 99.36 %, respectively, showing the large removal efficiency of the wastewater process. On the other hand, the removal efficiencies of NH_3–N, total organic carbon and COD are inadequate by wastewater treatment processes and analytical outcomes indicated that reuse was feasible.

In the year 2001, a study obtained from Ministry of Health in Oman indicated that there were 728 deaths caused by water contamination (Al-Wahaibi 2004). Furthermore, it was approximated that about 14 million Rial Omani was expended on illness associated to water pollution. Recent study on groundwater quality near Muscat locality (Barka catchment) indicated elevated concentrations of inorganic constituents, COD, BOD_5, and bacteria (Al-Futaisi et al. 2007). Another study undertook by Yaghi (2007) showed high levels of lead and chromium in samples taken from private wells in the Batina area, which were attributed to uncontrolled industrial discharges.

Water quality results obtained from recharge wells in Salalah indicated the existence of increased organic and microbial contamination (Salalah Sanitary drainage Services Co. 2007). The outcomes of these studies require a strong attention by the decision makers as the environment, and public wellbeing are under a significant threat. It is the responsibility of the decision makers to set strategies and policies to control pollution sources and secure the protection of the environment and human health. Moreover, it is the responsibility of the scientific and qualified personnel in this country to provide decision makers with the complete picture of the situation and propose all likely means to overcome the problem and its consequences. Therefore, the objectives of this study were to (1) characterize domestic wastewater from treatment plants in Muscat, Salalah, and Sohar (2)

Table 1 Sewage treatment plants properties

STP	Type of treatment	Capacity (m^3/day)	TE (m^3/day)	End reuse
Rusayl	Secondary	300	285	LS[a]
Ansab	Secondary	25,000	21,000	LS
Darsayt	Secondary	21,000	18,000	LS
Sohar	Secondary	8,000	6,600	LS
Salalah	Secondary	22,000	20,000	RW[b]
SLL.lagoon	Secondary	3,800	1,480	WO[c]

[a] Landscaping

[b] Recharging wells

[c] Wadi overflow

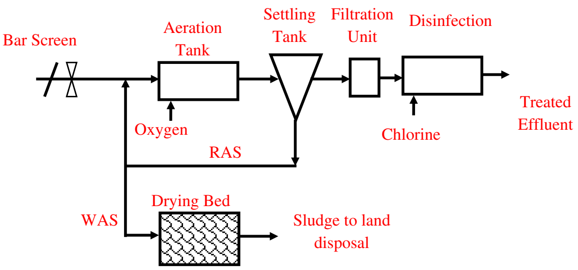


Fig. 1 Typical layout of STPs in Oman

investigate the applications of the treated effluents, and (3) suggest other technologies to be utilized for treatment processes to advance the quality of treated effluents.

Materials and methods

Study sites

The domestic wastewater samples were collected from six different STPs in the Sultanate of Oman to achieve the objectives of this study. These STPs are Rusayl STP, Ansab STP, Darsayt STP (in Muscat Governorate), Sohar STP, Salalah (SLL) STP and SLL lagoon. The following are brief information on each STP studied and Table 1 provides an overview about these STPs in Oman. Figure 1 illustrates typical STP layout in Oman.

Rusayl STP Rusayl is located in Muscat and it belongs to Al-Seeb Wilayat. This STP receives around 300 m^3/day received by a sewer network from the residential area of Knowledge Oasis. It produces 285 m^3/day of treated effluents used for landscape irrigation. This STP consists of four main units which are aeration tank, settling tank, filtration unit, and chlorine contact tank. The produced sludge is sent to the drying beds for several weeks then disposed to the dumping field.

Ansab STP The Al-Ansab STP is located in Muscat, receives around 25,000 m^3/day of wastewater and produces 21,000 m^3/day of treated effluents that are used for landscape irrigation (Table 1). The raw sewage is received by collection tankers (designated by yellow color) from neighborhood areas. This STP consists of several treatment units: anoxic tank, aeration tank, settling tank, filtration unit, and chlorine contact tank. The produced sludge is sent to the thickening unit to reduce its volume and then to the dewatering unit to reduce its water content. The production rate of sludge is around 66 t/day.

Darsayt STP This STP receives around 21,000 m^3/day of wastewater through sewer network. It produces 18,000 m^3/day of treated effluents, which are utilized for landscape irrigation (Table 1). This STP consists of several treatment units such as balance tank, grit removal unit, aeration tank, settling tank, filtration unit, and

Table 2 Average obtained values of pH for domestic waste water samples

Unit		RS[a]	PT[b]	AT[c]	ST[d]	FT[e]	ClT[f]	TE[g]	Omani standard for pH
Rusayl N^h=8	Average[i]	6.3	NA	6.5	6.7	7.0	NA	6.9	6.0–9.0
	STD	0.3	NA	0.2	0.2	0.3	NA	0.4	
Darsayt N=6	Average	6.6	6.7	6.8	6.8	NA	7.1	6.9	
	STD	0.3	1.0	0.3	0.3	NA	0.2	0.4	
Ansab N=5	Average	6.5	NA	6.8	6.7	6.8	6.8	7.1	
	STD	0.3	NA	0.2	0.4	0.5	0.4	0.4	
SLL.STP N=6	Average	6.8	6.8	6.8	7.3	7.6	NA	7.4	
	STD	0.1	0.2	0.1	0.1	0.1	NA	0.2	
SLL. Lagoon N=6	Average	7.0	6.7	7.2	7.4	NA	NA	NA	
	STD	0.2	0.3	0.4	0.4	NA	NA	0.4	
Sohar N=5	Average	6.6	6.6	6.7	7.0	NA	7.1	7.2	
	STD	0.3	0.2	0.3	0.3	NA	0.2	0.2	
Overall average	Average	6.6	6.7	6.8	6.9	7.0	7.0	7.1	
	STD	0.1	0.4	0.1	0.1	0.2	0.1	0.1	

[a] Raw sewage
[b] Primary tank
[c] Aeration tank
[d] Settling tank
[e] Filtering tank
[f] Chlorination tank
[g] Treated effluent tank
[h] Number of samples
[i] Average pH was calculated by finding the molar concentration of H^+ from each pH measurement ($[H^+]$). Then, calculate average $[H^+]$ and determine the average pH by taking –log $[H^+]$

Table 3 Average obtained EC (μS/cm) values for domestic wastewater samples

Unit		RS	PT	AT	ST	FT	ClT	TE	Omani Standard for EC (μS/cm)
Rusayl	Average	1,073	NA	1,000	893	975	NA	950	2000–2700
	STD	466	NA	504	440	564	NA	398	
Darsayt	Average	1,121	1,111	1,071	1,022	NA	1,023	1,010	
	STD	66	41	123	45	NA	56	88	
Ansab	Average	1,518	NA	1,676	1,558	1,626	1,619	1,628	
	STD	219	NA	107	266	98	116	110	
SLL.STP	Average	2,153	2,078	1,890	1,911	1,815	NA	1,830	
	STD	67	29	115	156	31	NA	21	
SLL. Lagoon	Average	2,785	2,795	2,493	2,460	NA	NA	2,605	
	STD	1,172	101	76	90	NA	NA	21	
Sohar	Average	1,552	1,741	1,519	1,502	NA	1,477	1,336	
	STD	69	136	86	63	NA	131	430	
Overall average	Average	1,700	1,931	1,608	1,558	1,472	1,373	1,560	

chlorine contact tank (Fig. 1). The produced sludge is sent to the thickening and dewatering units to reduce its volume and water content, respectively. The production rate of sludge is around 33 t/day.

Sohar STP Sohar is one of the most developed cities in the Sultanate of Oman outside the capital, Muscat. It is about 200-km northwest of Muscat. Sohar STP receives around 8,000 m^3/day through sewer network and

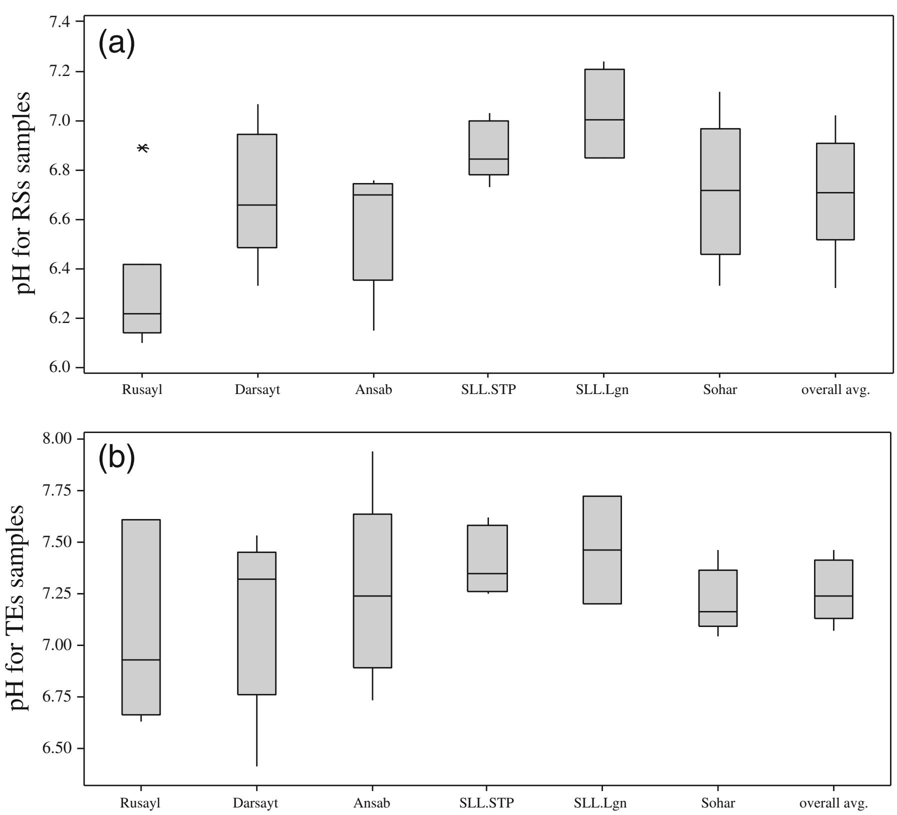


Fig. 2 pH results for RS and TEs (* denote extreme value/ outlier)

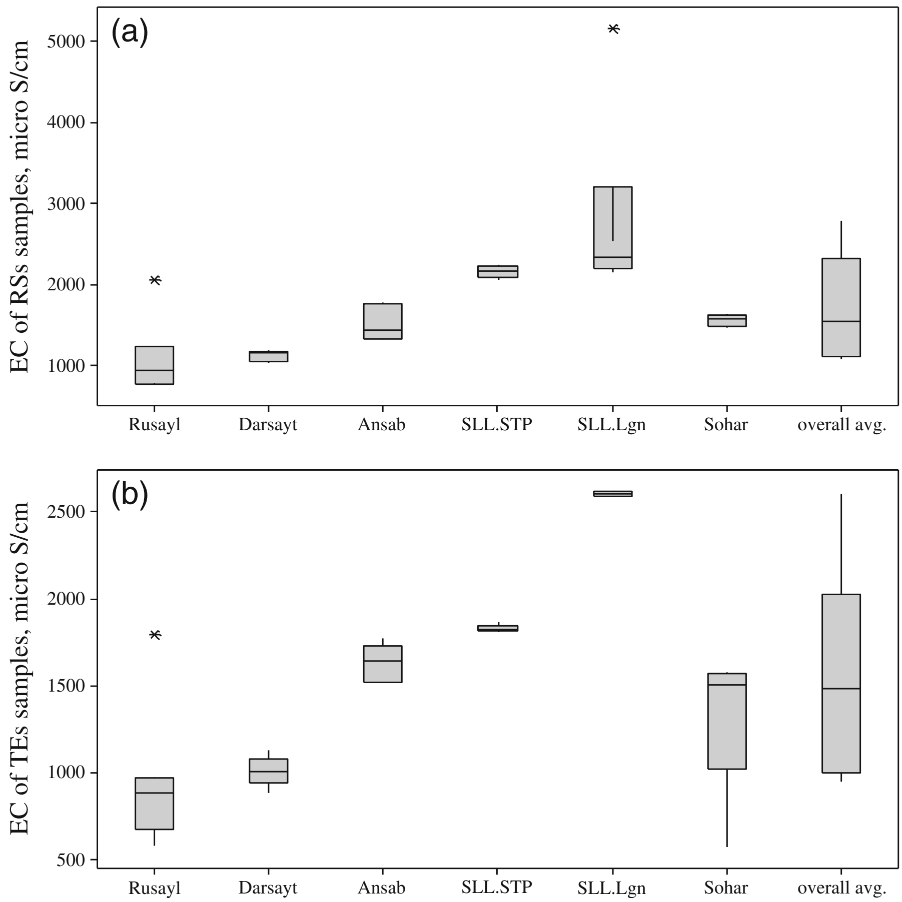


Fig. 3 EC results of RS and TEs (* denote extreme value/ outlier)

collection tankers and produces 6,600 m^3/day of treated effluents that are used for landscaping irrigation. Sohar STP consists of the following treatment units: balance tank, aeration tank, settling tank, and chlorine contact tank. The produced sludge is sent to drying beds for several weeks before disposal to dumping sites.

Salalah STP Salalah is the second largest city in the Sultanate of Oman, and the largest city in the Dhofar Governorate. Salalah STP receives around 22,000 m^3/day via sewer network. It produces 20,000 m^3/day of treated effluents that are used for landscaping irrigation and recharging groundwater through designated wells along the coastline. This STP is composed of several

Table 4 Average obtained values of BOD_5 and COD (mg/L) for RS and TE samples

STP		Rusayl	Darsayt	Ansab	SLL. STP	SLL. Lagoon	Sohar	Overall average	Omani Standard
RS, BOD_5	Average	187	195	176	248	207	174	198	NA
	STD	72.5	86.0	67.8	97.4	79.7	67.6	25.1	
TE, BOD_5	Average	2.69	1.04	0.73	2.44	1.58	1.89	1.73	15–20
	STD	1.67	1.05	0.94	1.79	2.73	1.04	0.70	NA
RS, COD	Average	407	579	574	2,508	973	336	896	NA
	STD	225	537	284	3,099	530	193	820	
TE, COD	Average	9.6	6.3	27.6	59.2	5.0	22.7	21.7	150–200
	STD	12.8	5.9	40.8	140	2.3	31.2	21.4	NA

NA Not applicable

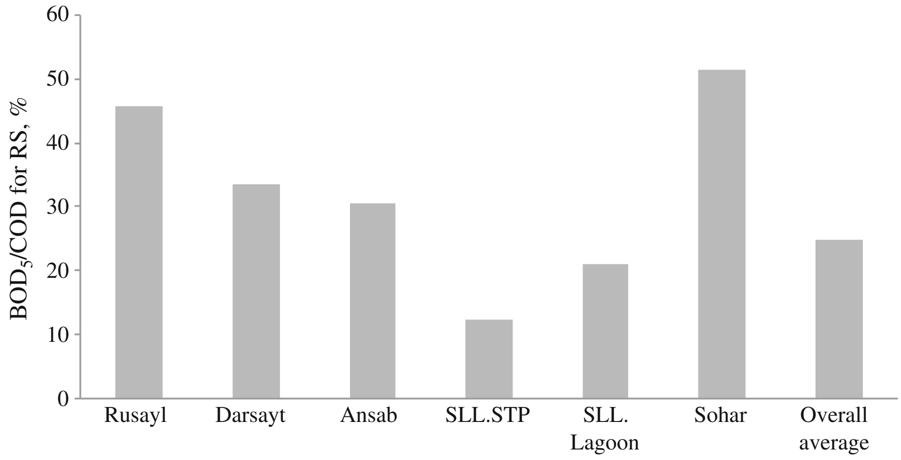


Fig. 4 Ratio of BOD_5/COD (%) for average values of RS from different STPs

treatment units such as primary settling tank, aeration tank, secondary settling tank, filtration unit, and chlorine contact tank. The produced sludge (approximately 35.5 t/day) is sent to thickening and dewatering units before sending it to a designated dumping area.

Salalah Lagoon STP Salalah Lagoon is a wetland treatment plant that contains different basins or ponds. The raw sewage is received by yellow tankers and transferred directly to the balance tank with quantities of 3,000 m^3/day. The second unit is an anaerobic pond

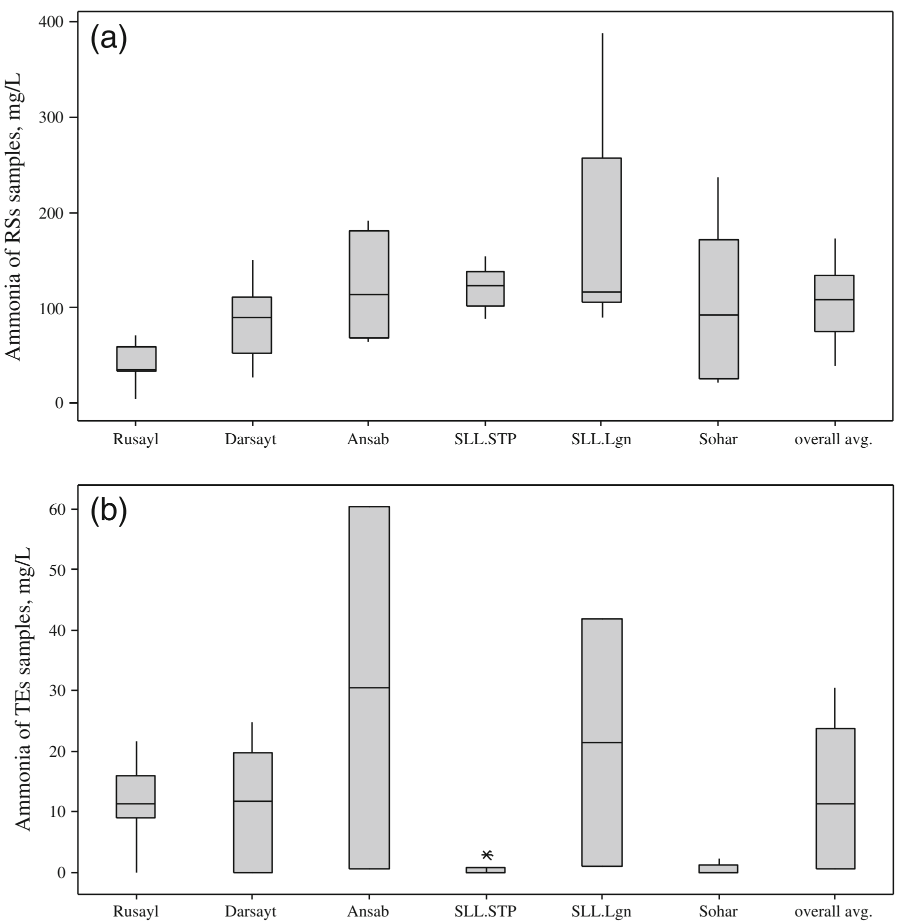


Fig. 5 Ammonia values of RS and TEs (* denote extreme value/outlier)

followed by an aerobic pond, then facultative pond, and finally, grass gate unit. The duration time for the whole process is around 1 month. It produces about 1,480 m^3/day of treated effluent to be discharged to the nearby valley (Wadi).

Sources of wastewater influents in Oman

In general, the sources of wastewater treated by the studied STPs in Oman are from domestic activities. However, most of the visited STPs received their raw wastewater through tankers. Therefore, there are chances where these tankers may convey different types of wastewater from different sources such as garages, workshops, and washing stations. The only STP that receives raw wastewater through sewer network is Salalah STP.

Sampling and analysis

In this study, samples of wastewater were collected for each month over a period of 1 year in 2009 (in a monthly manner). Once a sample is collected, it is stored in a cool box to make certain that it will not be subjected to change as a result of chemical reaction, chemical degradation, absorption, or adsorption onto the walls of the containers or to other substances in the container (Woodard 2001). Wastewater sampling was performed by grab sampling method. The grab sampling is simple, cheap, and widely used. The choice of a sampling procedure is related to the sampling objective in these treatment plants' efficiency. The reliability of measurement and analysis carried out from a grab sample is thus limited to the composition of wastewater for a given control point at one instant. Regardless, grab sampling is

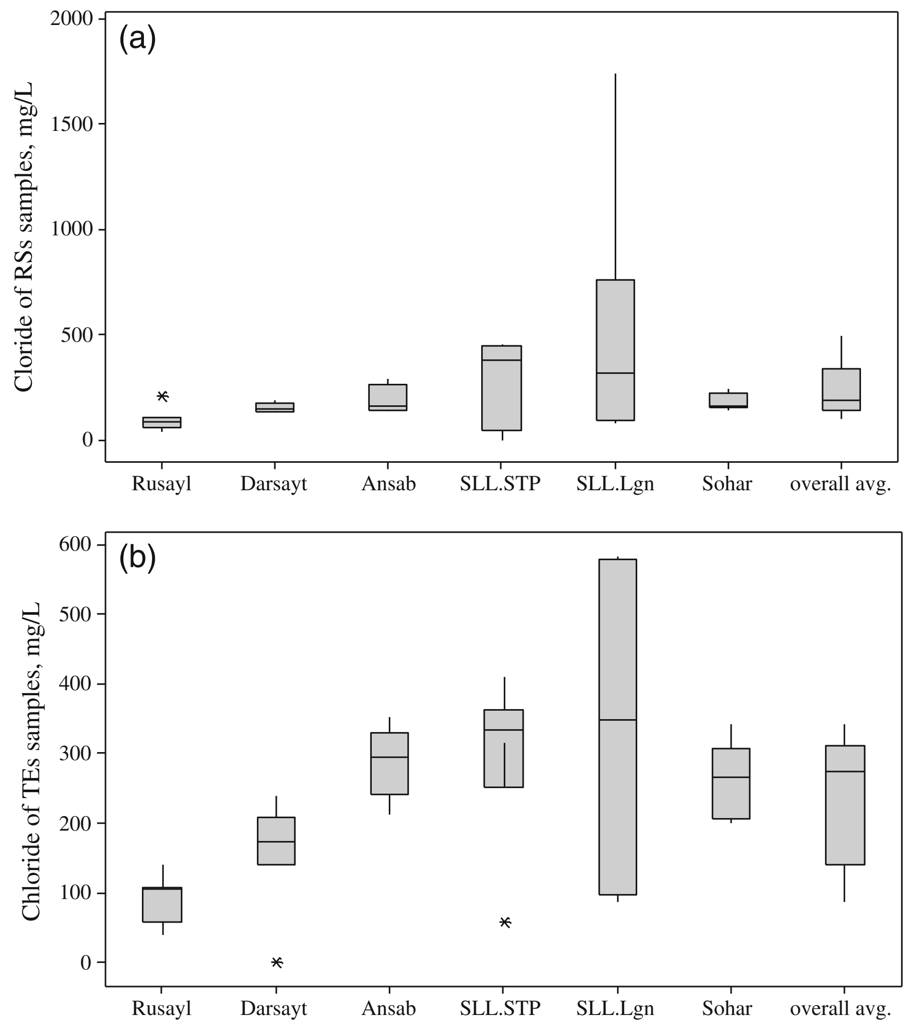


Fig. 6 Chloride values of RS and TEs

extensively utilized for water and wastewater quality monitoring and can be highly useful (Quevauviller et al. 2006). The collected wastewater samples were analyzed in the Environmental Engineering laboratory at Sultan Qaboos University. All tests were conducted according to the standard methods for the examination of water and wastewater (Greenberg et al. 1995).

The parameters studied are potential of hydrogen (pH), electrical conductivity (EC), total solids (TS), BOD_5, COD, ammonia, cations such as aluminum, iron, manganese, copper, molybdenum, lead, nickel, silicon, zinc, vanadium, barium, and cobalt. Anions such as Chloride, nitrate, phosphate, and sulfate. In addition, tests were conducted for determination of sodium, potassium, and microbiological tests such as total coliform (TC) and fecal coliform using Qanty tray method.

The obtained values of raw sewage (RS) and treated effluent (TEs) samples are presented using box plots which show the maximum, minimum, median, first quartile, and third quartile of the results. The statistical analysis was done by using MiniTab software. According to the used software, extreme values/outliers were shown in the box plots as asterisks.

Results and discussion

pH and electrical conductivity

The average values of pH and EC from different sampling points within the studied treatment plants are presented on Tables 2 and 3, respectively. The obtained values for RS and TE samples are represented using box plots which show the maximum, minimum, mean, first quartile, and third quartile of the outcomes.

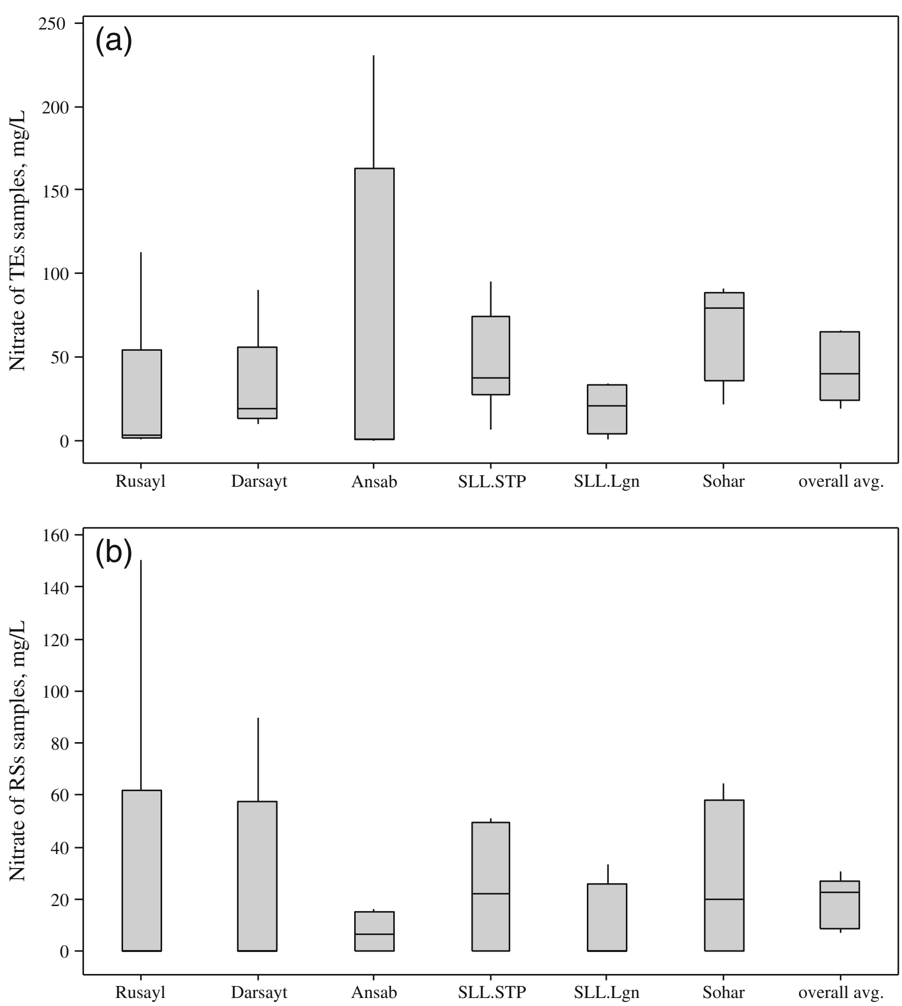


Fig. 7 Nitrate values of RSs and TEs

The values of pH for RS are in the range of 6 to 7.5 for the entire sampling points in the six STP covered in this study. The seasonal change does not have significant effects on this parameter, and that interprets the narrow range of the relevant STD values (Table 2). According to the statistical analysis using MiniTab software, there is an outlier issue for Rusayl RS results as shown in (Fig. 2) indicates a likely mistake during the sampling or measurement phases.

The range of pH values for TEs is 7.0 to 7.4, and the maximum overall average value is 7.2 (Fig. 2). This range clearly meets the suggested pH range in Omani standard (OS) for TEs of 6.0 to 9.0. These limits are comparable to most natural surface waters and considered causing no restraint to irrigation use. A continued long-term use of waters outside this pH range may finally alter naturally occurring pH levels in surface soils to which they are applied. Therefore, it could probably lead to micro nutrient imbalances for potential future crop production and fertility problems (Guidelines for Municipal Wastewater Irrigation 2000).

The average values of EC for the entire six STPs are within the OS range of 2,000 to 2,700 μS/cm as shown in (Fig. 3). In general, the differences between maximum and minimum values are not significant for both RS (Fig. 2) and TE (Fig. 3). However, there are outlier points in Rusayl and Salalah Lagoon. The overall average for TE is 1,560 μS/cm.

Biological and chemical oxygen demand

In all chosen STPs, both BOD_5 and COD values of TE are within the recommended limits by OS of 15 to 20 mg/L for BOD_5 and 150 to 200 mg/L for COD.

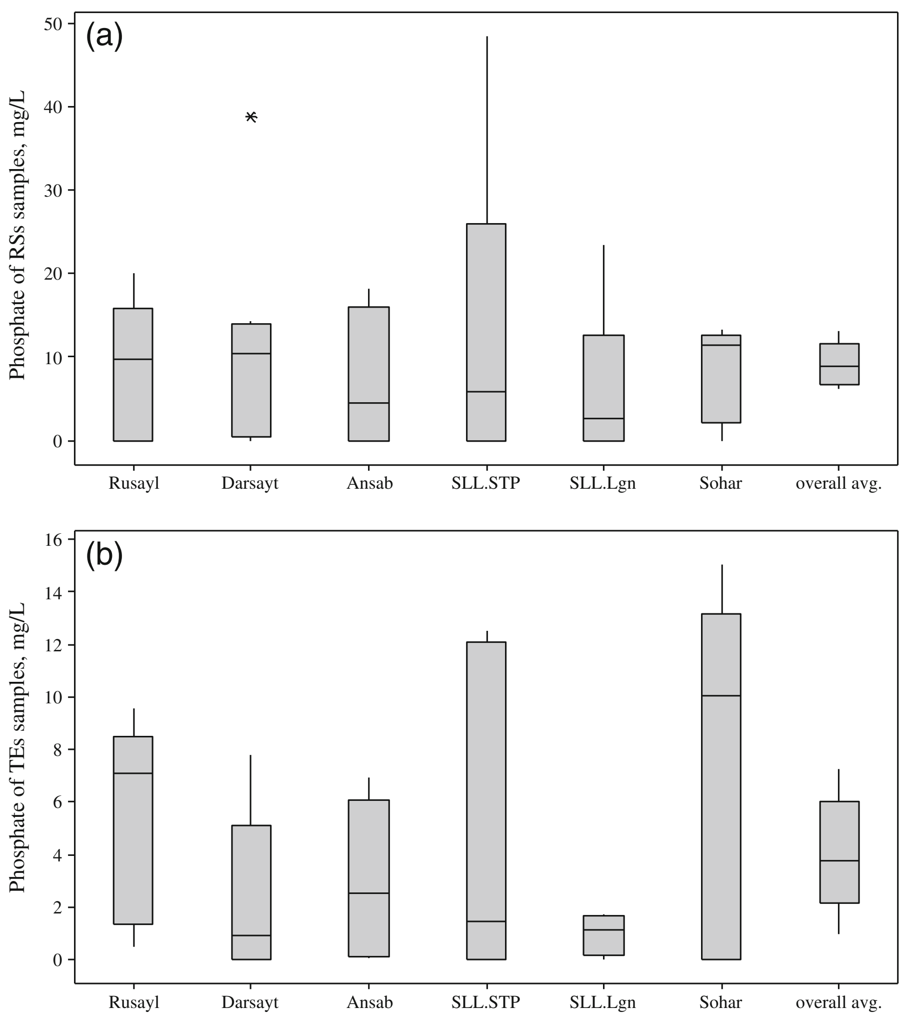


Fig. 8 Phosphate values of RS and TEs

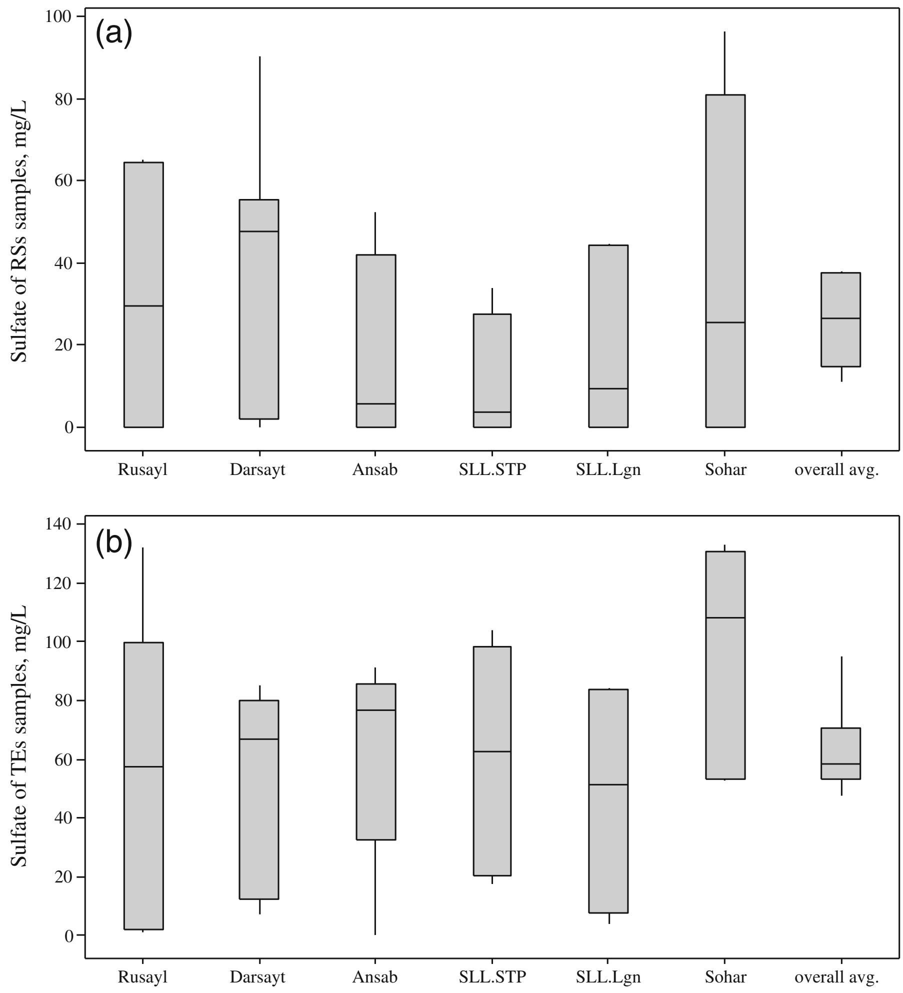


Fig. 9 Sulfate values of RS and TEs

The overall average value for TE is 1.73 mg/L for BOD_5 and 21.7 mg/L for COD (Table 4). The fluctuations of the values of both tests are very high and that can be observed from standard deviation values. Such fluctuations in the TE could be attributed to seasonal consequences and population activities. According to Metcalf and Eddy (2002), the obtained average BOD_5 values of raw sewage in Oman can be classified as medium strength concentration. However, the mean COD values categorize the raw sewage as high strength. This might be associated to the introduction of non-biodegradable organics such as oils. The highest reported average value for BOD_5 is 240 mg/L in Rusayl STP in the aeration unit. Salalah STP had the highest average COD value of 8,304 mg/L in the aeration tank. On the other hand, the minimum reported average values for BOD_5 and COD are in Ansab and Darsayt STPs, respectively.

Table 5 Average obtained values of heavy metals (mg/L) for RS samples

STP	Rusayl	Darsayt	Ansab	SLL. STP	SLL. Lagoon	Sohar	Overall average
Al	0.1	0.3	0.1	ND	0.3	ND	0.1
Fe	0.16	0.23	0.30	0.10	0.18	0.26	0.20
Mn	0.02	0.03	0.04	0.04	0.08	0.05	0.04
Cu	0.02	0.03	0.01	0.01	0.01	0.01	0.01
Mo	0.04	0.01	0.02	0.03	0.04	0.02	0.03
Pb	0.06	0.03	0.08	0.05	0.04	0.08	0.06
Ni	0.06	0.03	0.08	0.05	0.04	0.08	0.06
Zn	0.01	1.70	0.01	0.01	0.03	0.02	0.30
V	0.02	0.03	0.03	0.02	0.03	0.01	0.02
Ba	0.02	0.05	0.18	0.05	0.21	0.04	0.09
Co	0.20	0.10	0.02	0.02	0.02	ND	0.07

Table 6 Average obtained values of heavy metals (mg/L) for TE samples

STP	Rusayl	Darsayt	Ansab	SLL. STP	SLL. Lagoon	Sohar	Overall average	Omani Standards (mg/L)
Al	0.1	0.1	0.7	ND	ND	ND	ND	5.0
Fe	0.36	0.07	0.21	0.10	0.04	0.16	0.16	1.0–5.0
Mn	0.01	0.02	0.05	0.01	0.01	0.02	0.02	0.1–0.5
Cu	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.05–1.0
Mo	0.02	0.02	0.06	0.04	0.07	0.02	0.04	0.01–0.05
Pb	0.03	0.01	0.02	0.04	0.03	ND	0.02	0.1–0.2
Ni	0.03	0.01	0.02	0.04	0.03	ND	0.02	0.1
Zn	0.02	0.04	0.02	ND	ND	0.01	0.02	5.0
V	0.02	0.03	0.03	0.02	0.02	0.01	0.02	0.1
Ba	0.02	0.02	0.04	0.03	0.04	0.03	0.03	1.0–2.0
Co	0.01	0.02	0.02	0.01	0.02	ND	0.02	0.05

The average raw sewage BOD_5/COD ratio of all STPs is 25 % (Fig. 4) which is just underneath the usual range of 30 to 80 % as described by Metcalf and Eddy (2002). This ratio shows that either the wastewater may contain some toxic constituents or acclimated microorganisms may be needed in its stabilization. Thus, toxic

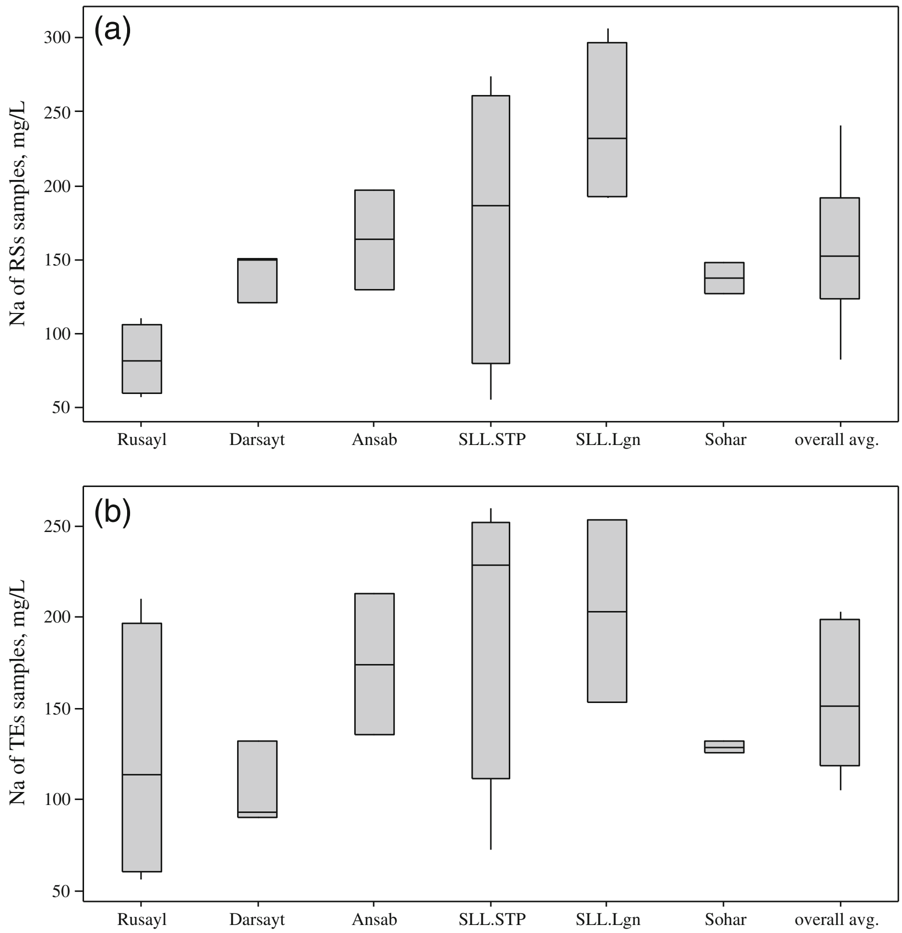


Fig. 10 Sodium values of RS and TEs

evaluation might be needed to confirm this assumption particularly for Salalah STP and Salalah Lagoon which have 12 and 21 % of BOD_5/COD ratios, respectively.

Ammonia

The ammonia average values varied from one plant to another as apparently shown in Fig. 5. The average value of ammonia for RS in all STPs is 106 mg/L which falls within the high strength class. The highest ranges are reported in Ansab STP (5 to 60 mg/L) followed by Salalah Lagoon (5 to 40 mg/L). The wide range of variations could be explained by different reasons such as deficiency of the oxidation process and/or the shortage of the detention time in the aeration tank. Therefore, the process of converting NH_3 to NO_2 and NO_3 is not undertook properly. The overall average value of ammonia is 10.53 mg/L for TE which is just outside the recommended range in the OS for treated wastewater of 5 to 10 mg/L. Enhancing the aeration process and detention time, some biological processes can be utilized to decrease ammonia content in wastewater. For example, studies have indicated that the contrail, *Ceratophyllum demersum*, a submerged *macrophyte*, is highly effective at eliminating ammonia (97 %) from the raw sewage (Reddy and De Busk 1987).

Anions

Tested anions are chloride, nitrite, bromide, nitrate, phosphate and sulfate. The details of average anion values for different sampling points of the studied STPs are shown in Figs. 6, 7, 8, and 9. The overall average value of chloride for RS is 234 mg/L (Fig. 5) which is exceedingly larger than 90 mg/L and hence, the wastewater can be classified as high strength according to Metcalf and Eddy (2002). Commonly, the differences in RS values are small except Salalah Lagoon STP in which the maximum value is too far away from the median, and the source of the high concentration of chloride in RS samples might be attributed to different reasons such as high quantities of detergents and

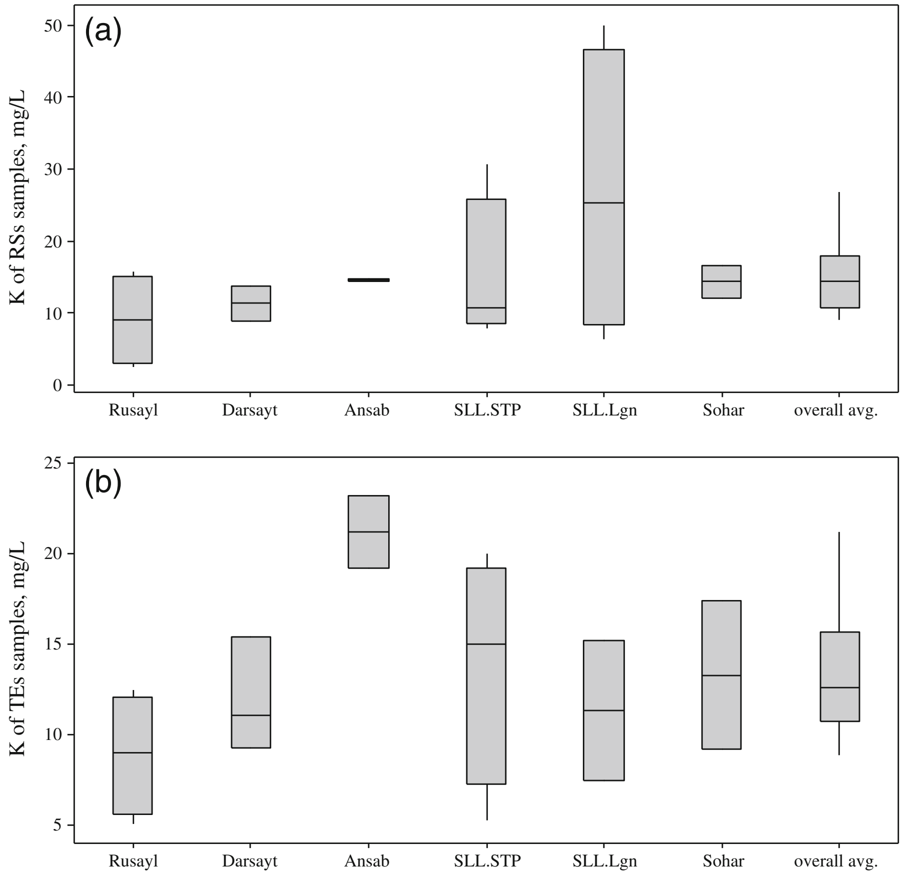


Fig. 11 Potassium values of RS and TEs

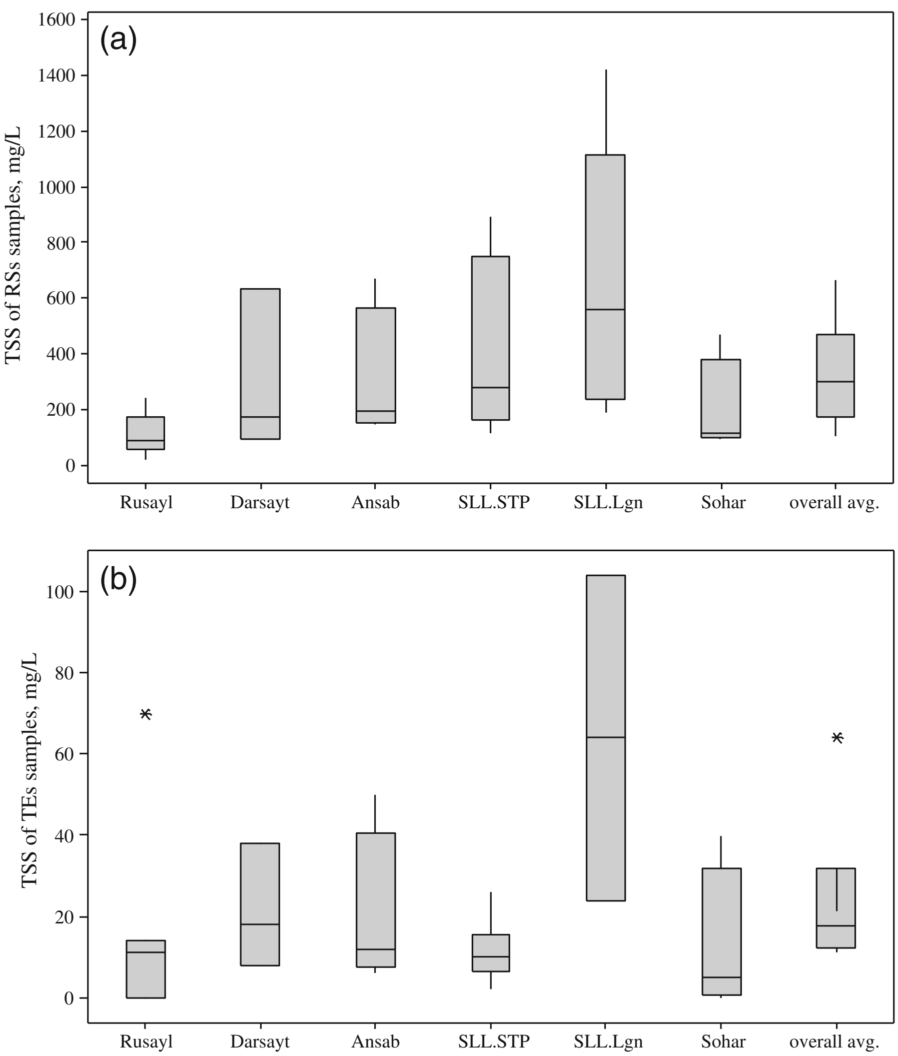
disinfectants that can be comprised in the influents. The average chloride values for TEs are found within OS standards of 650 mg/L (Fig. 6).

The values of nitrate in the RS are in the range of 0 to 60 mg/L comparing with 0 to 150 mg/L for TEs (Fig. 7). The overall average values of the nitrate for the TEs are lesser than 40 mg/L which is within the acceptable range stated by OS of 50 mg/L. The increments of nitrate concentrations in TEs might be due to the aeration process in which most of NH_3 is converted to NO_2 and NO_3. Nitrate in Ansab and Sohar STPs are in the range of 0 to 150 mg/L which exceeds the recommended value by OS. This problem can be solved by adding a denitrification treatment unit to reduce the nitrate values in the TEs.

A comparison between the average values of ammonia and nitrate for the TE in Sohar STP shows that the average value of ammonia is within the acceptable range which means good aeration has taken place to alter most NH_3 to NO_2 and NO_3. On the other hand, Ansab STP has unaccepted values for both ammonia and nitrate according to OS which indicates a problem in the aeration system. It should be mentioned that Ansab STP has a problem of overloading which might contribute considerably to this problem.

The concentrations of phosphate for RS vary from 0 to 50 mg/L (Fig. 8). The average values of phosphate for the TE are in the range of 0 to 15 mg/L which meet the standard value of 30 mg/L in OS (Fig. 8). The maximum and the minimum average values of phosphate for TE

Fig. 12 TSS values of RS and TEs (* denote extreme value/outlier)



are reported in Sohar STP as 7.3 and 0.4 mg/L, respectively.

The maximum concentration of sulfate is just below 100 mg/L for RS as shown in Fig. 9. The average values of sulfate for the TEs are in the range from 0 to 140 mg/L which is within the stated value by OS of 400 mg/L (Fig. 9). The maximum average value of sulfate for TE is reported in Sohar STP as 95.3 mg/L. The minimum average value is 12.2 mg/L in Salalah Lagoon. Furthermore, there are minor increments in the concentrations of the sulfate in all STPs which might be attributed to accumulation during the treatment processes.

Cations

The average value of heavy metals in the whole set of tested cations are within the stated limits by OS for TEs except for Mo. The obtained values of heavy metals for RS and TE samples are presented in Tables 5 and 6. In Ansab and Salalah Lagoon STPs, the average concentrations of Mo were found 0.06 to 0.07 mg/L which exceeded the acceptable range of 0.01 to 0.05 mg/L as stated by OS. Furthermore, the overall average of Mo is 0.04 mg/L which exceeds the lower limit of OS.

Sodium and potassium

Sodium and potassium have been analyzed individually because of their significance in effluents utilized for irrigation or recharge applications. The values of Na in RS are in the range of 50 to 300 mg/L. In Salalah Lagoon, the concentration of Na is in the highest range, and this might be due to the distinct nature of influents. It is apparently shown that the Na values in TEs are within the recommended range by OS 200 to 300 mg/L (Fig. 10). The range of K values in RSs is from 5 to 50 compared to a range of 5 to 25 mg/L in TEs (Fig. 11) and there is no standard value for this parameter in OS.

Solids analysis

Analysis was carried out for three main parameters which are total suspended solids (TSS), total dissolved solids (TDS), and TS. The removal efficiency of TSS varied from one STP to another (Fig. 12) that could be due to the nature of the raw sewage and the effectiveness of the filtration systems. The range of TSS in RS is from 100 to 1,200 mg/L. The range of TSS values in TEs is exceeding the acceptable range of 15 to 30 mg/L (Fig. 12b). In Ansab STP, the filtration unit is very old, and it is suggested to be replaced by a more effective one. In Salalah Lagoon, there is no filtration unit, and it should be added to reduce the level of suspended solids. The overall average value of TSS for TEs is 74 mg/L which could be brought down by applying the necessary modifications in Ansab STP and Salalah Lagoon.

Table 7 Average obtained values of total coliform (MPN/100 ml) for domestic wastewater samples

Unit		ST	FT	CIT	TE
Rusayl	Average	638,746	183,209	NA	122,659
	STD	999,058	117,542	NA	130,728
Darsayt	Average	155,013	NA	2,414	361
	STD	188,657	NA	1,421	238
Ansab	Average	NA	469,519	7,453	788
	STD	NA	842,254	6,366	1,101
SLL.STP	Average	35,713	70,961	NA	1,065
	STD	16,927	69,295	NA	1,248
SLL. Lagoon	Average	1,003,466	NA	NA	4,839
	STD	1,294,628	NA	NA	0
Sohar	Average	30,298	NA	600	978
	STD	21,275	NA	1,023	1,316
Overall average	Average	372,647	241,230	3,489	21,782
	STD	599,975	433,013	2,976	53,054

Table 8 Average obtained values of E Coli (MPN/100 ml) for domestic wastewater samples

Unit		ST	FT	CIT	TE
Rusayl	Average	146,972	151,592	NA	82,736
	STD	109,507	115,234	NA	123,379
Darsayt	Average	188,429	NA	874	18
	STD	249,837	NA	1,046	18
Ansab	Average	NA	107,569	7,346	700
	STD	NA	118,354	6,509	1,157
SLL.STP	Average	11,426	25,419	NA	4
	STD	10,138	39,212	NA	2
SLL. Lagoon	Average	390	NA	NA	333
	STD	543	NA	NA	399
Sohar	Average	7,047	NA	6	348
	STD	7,981	NA	5	774
Overall average	Average	70,853	94,860	2,742	14,023
	STD	107,237	44,819	3,493	50,179

Microbiology test

In general, average TC values are very high for the TEs in most of the analyzed samples (Table 7). The lowest value was 360.7 MPN/100 mL in Darsayt STP TE. The overall average value of TC for TE is 21,781 MPN/100 mL. In the OS, there are no standard limits for the TC.

There is no standard value in OS for the *Escherichia coli* in TE but it can be compared with the fecal coliform of the range 200 to 1,000 MPN/100 mL. In Rusayl STP, the average *E. coli* value for TE is 82,736.0 MPN/100 mL (Table 8). This problem may be due to the lack of chlorination or the contact time is not long enough to reduce the specified bacteria to the agreeable limits.

Conclusions

Based on the results obtained from the analyses undertook on the collected wastewater samples from Rusayl, Darsayt, Ansab STPs in Muscat, Sohar STP, Salalah STP, and Salalah Lagoon STPs, the following can be concluded:

- The RS in all STPs can be categorized as high strength concentration.
- The values of pH for RS ranged from 6 to 7.5 for the entire sampling points in the six chosen STPs. The range of pH values for treated effluents (TEs) was found to be from 6.5 to 7.5.
- The values of EC for TEs ranged from 500 to 2,500 μS/cm which met the standard values of 2,000 to 2,007 μS/cm according to OS.
- Both BOD_5 and COD values of TEs were from 0 to 7 and 0 to 100 mg/L, respectively. These ranges are within the recommended limits by OS (15 to 20 mg/L for BOD_5 and 150 to 200 mg/L for COD).
- The average ratio for raw sewage BOD_5/COD in the six STPs was 25 %. This ratio indicates that either the wastewater may contain some toxic constituents or acclimated microorganisms may be required in its stabilization (Metcalf and Eddy 2002).
- Ammonia concentrations (10 to 60 mg/L) had exceeded the acceptable range (5 to 10 mg/L) in most of the selected plants except Sohar and Salalah STPs (0 to 3 mg/L).
- Chloride (0 to 600 mg/L), phosphate (0 to 16 mg/L), and sulfate (0 to 140 mg/L), concentrations were within the acceptable ranges of OS.
- Nitrate in Ansab and Sohar STPs showed a wide range of 0 to 150 mg/L which clearly exceeds the recommended value by OS (50 mg/L).
- The average obtained values of the entire set of tested heavy metals were lower than stated limits by OS for TEs except for Mo. In Ansab and Salalah Lagoon STPs, the average concentrations of Mo were found to range from 0.06 to 0.07 mg/L which exceeded the acceptable range of 0.01 to 0.05 mg/L as stated by OS.
- The values of Na in RS were in the range of 50 to 300 mg/L. The highest Na concentration was observed in Salalah Lagoon.
- The Na values of TEs samples (50 to 250 mg/L) were within the suggested range by OS (200 to 300 mg/L).
- The K values ranged from 5 to 50 in RSs and from 5 to 25 mg/L in TEs.
- TSS in RS showed high variability as they ranged from 100 to 1,200 mg/L. Furthermore, most values of TSS in TEs were within the acceptable range of 15 to 30 mg/L.
- The values of TDS for RSs varied from 500 to 2,000 mg/L approximately. On the other hand, the values of TDS for TEs were found to be lower than 1,600 mg/L which is within the acceptable range of 1,500 to 2,000 mg/L according to OS.
- The obtained values for *E. coli* were in the acceptable range except for Rusayl STP.

In general, the produced treated effluents have met most of regulatory limits stated by OS. However, there are couples of exceptions for certain parameters such as nitrate, *E. coli*, and TSS. Furthermore, it should be documented that the performance of Salalah and Darsayt STPs can be classified as the best compared to the other four STPs studied.

Recommendations

The following are some recommendations in order to expand the level of reusing treated effluents and to improve the performance of the treatment plants in Oman.

- In Ansab STP, the filtration unit is old and it is recommended to be replaced by a more effective one. Also, in Salalah Lagoon, a filtration unit should be added to reduce the level of suspended solids.
- A disinfection unit should be installed and activated in Salalah Lagoon. Furthermore, the disinfection

unit in Rusayl STP should be advanced to accomplish the required levels of reducing the microorganisms. Ozonation and/or ultraviolet units can be utilized.

- Balance tank and denitrification unit should be supplemented to Ansab STP to reduce ammonia and nitrate.

For reusing practices of treated effluents, a number of studies should take place through universities and research institutes to provide the technical views for expanding the reuse of such effluents safely beyond the current implications which are limited to landscape irrigations and groundwater recharge. Treated effluent practices should be expanded to the new industrial applications which cover cooling water, boiler feed and heavy construction.

Acknowledgments The authors would like to acknowledge the financial support received from Sultan Qaboos University through His Majesty Strategic Research Grant number SR/ENG/CAED/08/01.

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