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Original Article

Characterization of Domestic Wastewater Sludge in Oman from Three Different Regions and Recommendations for Alternative Reuse Applications

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Abstract

Background: There are more than 350 wastewater treatment plants distributed across different parts of Oman. Some of them produce large quantities of domestic sewage sludge, particularly this study focused on characterizing domestic sludge of six treatment plants that may contain various pollutants, therefore the proper management of domestic sewage sludge is essential.

Methods: Samples of domestic sewage sludge were collected for each month over a period of one year in 2010.Samples of retained/ recycled activated sludge (RAS) and waste activated sludge (WAS) were analyzed for electrical conductivity (EC), potential of hydrogen (pH), cations, anions and volatile content. All tests were conducted according to the Standard Method for the Examination of Water and Wastewater.

Results: Monitoring ofelectrical conductivity, nitrite and nitrate, the presence of chloride, sulfate and phosphate were higher than the other anions, the phosphate was found very high in all domestic STPs. The average obtained values of the cations in both domestic RAS and WAS samples were within the Omani Standards.

Conclusion: The study showed the very high concentration of phosphate, it might be worth to further investigate on the sources of phosphate. Cations in both domestic RAS and WAS samples were low and suggest that the domestic sludge can be re used in agriculture. A regular maintenance should be performed to prevent any accumulation of some harmful substances which may affect the sludge quality and the sludge drying beds should be large enough to handle the produced sludge for better management.

Keywords: Characterization,Domestic sludge, Quality, Environmental monitoring, Oman

Introduction

In Oman, two types of wastewater treatment plants widely appeared, industrial wastewater treatment plant and domestic wastewater treatment plant. Industrial wastewater is the water produced from industrial activities such as process water and cooling water. On the other hand, domestic wastewater is the water consumed by a human being and contains all the materials added to the water throughout its use. It is composed of the human body wastes together with the water utilized for flushing toilets, washing, laundry, food preparation, and cleaning of kitchen utensils (1). This wastewater is transferred to treatment plants either via sewer systems or through tankers from the septic containers. The domestic wastewater is mostly treated by biological process such as activated sludge process, aerobic pond, and anaerobic treatment. Usually, wastewater treatment plants in

Oman use activated sludge process. Activated sludge process is an efficient technology to meet stringent standard if properly operated. This process results in the generation of a large amount of waste activated sludge (2). The cost for surplus sludge treatment has been estimated to be up to 60% of the total operating cost of a wastewater treatment plant (3). Moreover, the traditional disposal method of landfilling causes secondary pollution problems. Thus, an interest in methods to reuse the sludge rather than dumping it has been grown rapidly. Before studying the best method to reuse wastewater sludge, characteristics and types of sludge produced in biological treatment plants should be identified.

There are more than 350 wastewater treatment plants distributed across different parts of Oman. During site visits and reviewing of database for thirty seven sewage treatment plants (STP) consisting of fifteen main STPs and twenty two small STPs, it has been observed that roughly 96% of STPs were operating as extended aeration processes, with the remainder operating as stabilization ponds which do not produce sludge at monthly and annual intervals (4). Roughly 60% of the visited STPs treat the sludge in drying beds. Many of these STPs were functioning without proper planning and were poorly maintained, with either too much sludge being supplemented to the beds without providing the opportunity for the sludge to dry or allowing the sludge to remain too long in beds with resultant growth of weeds. Around 8% of covered STPs utilized filter press. The remaining percentage of the visited STPs had no sludge treatment processes, and in general, these sites periodically collected the sludge in trucks and dumped it at landfills. Within Muscat Municipality, the dried sludge is transported from the Municipality STPs to Al-Ansab STP. Then, it is collected by Oman Fertilizer Company which transports this sludge to Al-Khabourah (west of Muscat area) for composting. Approximately around 69% of sludge is dispatched to discarding sites (4).

The paths to reuse sludge are composting and recovering energy and the main parameters to ascertain are heavy metals, anions, and volatile content. A study investigated the effect of metal ions, anions, ortho-phosphate, polyphosphate and organic phosphorus on the activity and kinetics of alkaline phosphates in aerobic activated sludge (5). Results showed that there were three influence models of heavy metals on alkaline phosphates activity (APA) and most inorganic anions were somewhat innocuous at concentrations from 0 to 5.0 millimolar (mM). Although phosphorus had an inhibitive effect on APA, pyrophosphate was the most effective inhibitor. A study conducted on concentrations of heavy metal in crops irrigated with wastewater and sewage sludge admixtures (6). The crops investigated in the study were heavily contaminated with the four regulated elements: Cd, Cu, Pb and Zn and their concentrations exceeded maximum values considered safe for human consumption. A study identified concentrations of Al, Cd, Co, Cu, Cr, Fe, Mn, Hg, Mo, Ni, Pb, Ti and Zn in sludge samples from five municipal activated sludge plants by using inductively coupled plasma atomic emission spectrometry (7). By comparing all cation concentrations with International Legislation for the use of sludge for agricultural purposes, none of metal concentrations exceeded maximum allowed levels.

Two sewage sludge samples collected from wastewater treatment plants in Brazil and one sludge sample produced from South Germany were investigated in terms of heavy metals, (Polychlorinated dibenzodioxin/furon) PCDD/F, and Polychlorinated biphenyls (PCB) (8). The concentrations of PCDD/F found in the samples were below specified legislation for final disposal or agricultural use in soils. On the other hand, PCB and heavy metal values exceeded this limit. The extraction for heavy metals Cu and Zn and for competing metals Ca and Fe was studied (9). The main findings showed that Cu can be extracted for 60-70% and Zn for 90-100% by citric acid at pH 3-4. Some physicochemical methods for reducing the heavy metal content of waste activated sludge was investigated (10). Acid thermal hydrolysis effectively reduced the concentrations of most heavy metals, excepted Cu and Pb while alkaline thermal hydrolysis is most effective in solubilizing these two metals. Fenton peroxidation released Cd, Cu, Ni and Zn to a large extent, but it cannot be used for a reduction of Pb and Hg. The analyses of the sludge from STP of Oman in 2001 indicated that none of them could be utilized for application to land under current International Regulations. However, only some of them exceeded the maximum concentration according to Omani Regulations. It should be noted that metals content would be reduced in admixture with non-hazardous domestic wastes in composting processes and may therefore be suitable for land spreading (4). This sludge can be reused instead of current dumping practice which may pose a great risk to the environment. However, the reuse of contaminated sludge as fertilizer may harm life by affecting the crops which we consume. Furthermore, dumping of contaminated sludge to landfills might cause problems to the groundwater and hinder its suitability for different applications. So, it is the responsibility of the decision makers to set strategies and policies to control the pollution source to protect the environment and human health.

Therefore, the objective of this study was to characterize domestic wastewater sludge collected from different wastewater treatment plants in Muscat, Sohar, and, Salalah, as well as to recommend alternate ways to reuse this sludge.

Materials and Methods

Study Sites

The covered STPs were classified as domestic according to the source of the raw sewage and samples were collected from the following six domestic STPs covering three different regions (Muscat, Sohar and Salalah) in the Sultanate of Oman (Fig. 1):

1. Rusayl STP (RSL.D) in Muscat Governorate.
2. Darsait STP (DST) in Muscat Governorate.
3. AnsabSTP in Muscat Governorate.
4. Sohar STP (Sohar.D) in North Al-Batina Governorate.
5. Salalah STP (SLL.STP) in Dhofar Governorate.
6. Salalah Lagoon (SLL.LGN) in Dhofar Governorate.

Table 1 shows detailed information about the domestic STPs which include capacity, treated effluent, sludge quantity and sludge conditioning method for each domestic STP.

Fig. 1: Location map of study sites in Oman

Table 1: Domestic STPs information

STP	Capacity	Treated Effluent	Sludge	Sludge
	(m³/day)		(ton/day)	conditioning
Ansab	25,000	21,000	33	Filter Press
DST	21,000	18000	33	Filter Press
RSL.D	300	285	0.57	Drying Beds
SLL. STP	22,000	20,000	35.5	Filter Press
SLL.LGN	3000	1,480	3	Drying Beds
Sohar.D	8000	6,600	13	Drying Beds

Sampling and Analysis

In this study, the samples were collected over a period of one year approximately in monthly manner in the year 2010. Samples of retained/ recycled activated sludge (RAS) and waste activated sludge (WAS) were collected through grab sampling procedure, and the collected samples were kept inside special bags until reaching the lab. Samples were first dried by utilizing sun heat and then each sample was grinded to increase the surface area to have better extraction. All tests were conducted according to the Standard Method for the Examination of Water and Wastewater (11). It should be noted that there was no RAS samples from Salalah Lagoon (SLL.LGN) as no recycling line of sludge is practiced in this treatment plant.

Parameters studied are electrical conductivity (EC), potential of hydrogen (pH), cations (zinc, chromium, copper, lead, cadmium and molybdenum), anions (fluoride, chloride, nitrite, nitrate, bromide, phosphate and sulfate) and volatile content. Anions and cations were determined based on the dry weight. The obtained values of RAS and WAS 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.

Method followed for determining pH and EC

Electrometric determination of pH involves measuring the electromotive force (EMF) of a cell comprising of an electrode, responsive to hydrogen ions such as a glass electrode, and a reference electrode. The EMF of this cell is measured using a high impedance electrometer calibrated in terms of pH. Approximately a mass of 1 g of each powdered samples were weighed and 100 ml distilled water was added. When the mass of the powered sample is 0.5 g, only 50 ml distilled water was added. Then, the samples were put in Ultrasonicator instrument for 15 minutes to atomization particles by vibration because the sound is faster in water and it can separate the particles fast. After that, the samples were taken out of the Ultrasonicator instrument. The samples were then filtered, and pH tests were conducted using the pH meters. After same procedure of sludge digestion mentioned in measuring pH the EC tests were conducted by using EC meter.

Methods followed for analysis of Anions

Anions were analyzed using a Metrohm Professional Compact Ion Chromatography (IC) system 881 with conductivity detector and packed bed suppressor unit and Metrohm 858 Professional Sample Processor. After same procedure of sludge digestion mentioned in measuring pH the anions were measured by using a Metrohm Professional Compact Ion Chromatography (IC) system 881.

Methods followed for analysis of Cations

Approximately a mass of 0.5 g of each sample was taken. Then, agents were added to each sample (nitric acid - 5 ml and hydrochloric acid - 15 ml) and digested using classical wet digestion methods. During the process of digestion, the containers were cooled by distilled water for half an hour until the contents transferred to 100 ml capacity bottles. Finally, they were put in the laboratory at the room temperature for a whole day before the filtration. After the filtration, the samples were put in closed plastic containers and sent to be analyzed by an Inductively Coupled Plasma (ICP) spectrometer at the Soil & Water Laboratory, College of Agricultural and Marine Sciences.

Methods followed for analysis of Volatile Content

First, the solid sludge samples were dried in the sun in small containers for three days to a week. Then, the samples were grinded into powder or fine materials. After weighing the empty containers, the weight of them was taken again with the samples in to have in total approximately 4 g (the weight of samples with containers should not exceed 4 g). Next, the containers were put in the oven at a temperature of 550 ˚C for fifteen to thirty minutes to remove some of organic contents and to simplify digesting process. After this ashing process, the samples were weighed again to find out the weight lost to calculate volatile content. The volatile content of the sludge is an indication of the organic content of the sludge.

Results

pH and EC

The mean values of pH for RAS samples were in the range of 6.08 to 7.8 (Fig. 2). The range of pH values of WAS in DST samples was relatively wide compared to Ansab samples. This might be because the results accessible for pH in Ansab were only two readings (Fig. 3). The overall average of pH results for primary sludge in SLL.STP was 6.5. Figure 4 shows EC values of RAS samples for different domestic STPs. In Fig. 5, the range of WAS in SLL.LGN is narrow with one outlier point. Furthermore, standard deviation (STD) values in all STPs for RAS and WAS being high showing a possible effect of seasonal change. The general EC average for RAS, WAS and primary sludge samples are 933 μS/cm, 702 μS/cm and 404 μS/cm, respectively.

Volatile Content (VC)

The range of VC in RAS samples was from 49.5 to 84.3% (Fig. 6) and from 32.2 to 83% for WAS samples (Fig. 7). The general VC averages of RAS, WAS and primary sludge were 68%, 65% and 71%, respectively.

Anions

Fluoride concentrations were the lowest compared with the other anions. The overall averages of fluoride concentration for RAS and WAS samples were 12 mg/kg and 11 mg/kg, respectively. The range of chloride concentration in RSL.D was broader than the other STPs with a maximum concentration of 35910 mg/kg for RAS samples (Fig. 8). The nitrite values of RAS and WAS in Ansab were the least significant (Fig. 9-11). Furthermore, the ranges of nitrite in WAS values were small in all STPs except for Sohar.D (Fig. 11). The values of STD in RAS, WAS and primary sludge were very high. The ranges of nitrate in RAS samples were narrow except for Sohar.D and SLL.STP as shown in Fig. 12. Besides, for WAS samples the ranges were narrow except for Sohar.D (Fig. 13). There was one outlier point of WAS samples in SLL.LGN.

The ranges of Bromide in RAS, WAS and primary sludge compared to other anions was very low. The concentration of phosphate compared to other anions was somewhat high with the highest range in RAS samples in SLL.STP (26 to 33861 mg/kg) as shown in (Fig. 14). On the other hand, the range in RSL.D for WAS being wider than the other STPs and the highest value was 32745 mg/kg (Fig. 15). The range of general mean of sulfate concentration was from 832 to 37998 mg/kg in RAS samples (Fig. 16). The Sulfate concentrations in WAS samples were from 550 to 48649 mg/kg (Fig. 17) which were very wide ranges. The overall sulfate mean for all STPs for RAS, WAS and Primary Sludge were 6670 mg/kg, 7024 mg/kg and 2512 mg/kg, respectively. Furthermore, sulfate STDs were very high in all sludge samples with some outlier points in RAS in SLL.STP and in WAS in RSL.D and Sohar.D.

Cations

The average values for specific cations across different domestic STPs for RAS and WAS listed in Table 2 and 3 along with Omani and EPA standards. By comparing these results to the typical values for metals in biosolids of EPA standards, all the results were found within the typical range except Zn in Ansab's RAS samples and Zn in Sohar.D's WAS samples. Also, the values of cations in primary sludge were low.

Table 2: Average obtained value of cations (dry weight mg/kg) for RAS samples

Sample	Cd	Cr	Cu	Pb	Mo	Ni	Zn
RSL.D	0.21	11.63	302.15	343.05	2.10	66.71	448.57
DST	0.20	7.40	366.43	24.58	10.12	139.76	855.31
Ansab	0.20	1.00	596.70	71.80	14.80	129.40	2161.30
Sohar.D	NA	NA	NA	NA	NA	NA	NA
SLL.STP	0.20	1.00	173.80	30.56	6.80	80.48	704.48
Overall average	0.20	5.26	359.77	117.50	8.46	104.09	1042.41
EPA standards	85	Not available	4300	840	75	420	7500
Omani Standards	20	1000	1000	1000	20	300	3000

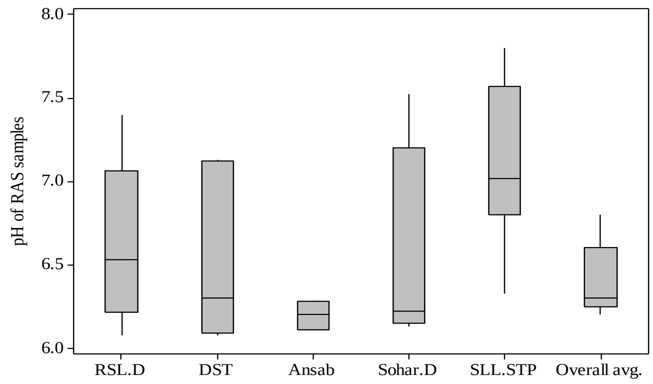

Fig. 2: Obtained pH results of RAS

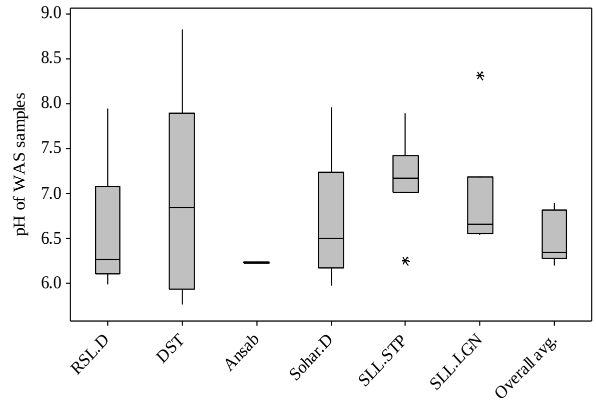

Fig. 3: Obtained pH results of WAS (* denote extreme value/outlier)

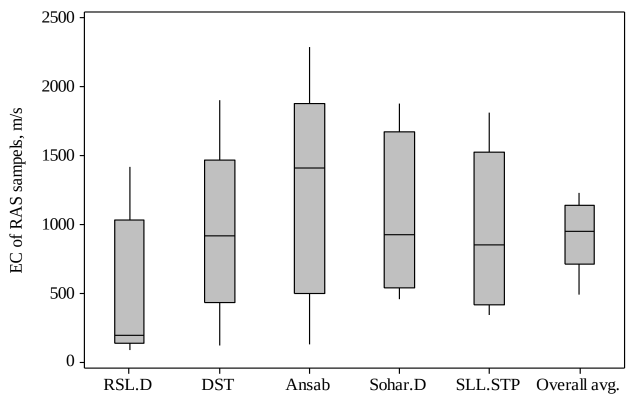

Fig. 4: Obtained EC results of RAS

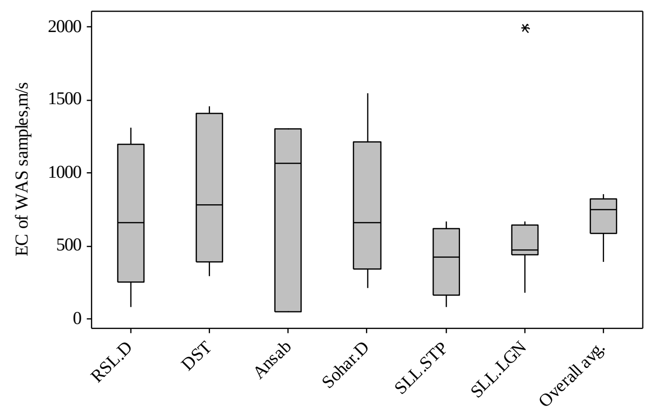

Fig. 5: Obtained EC results of WAS (* denote extreme value/outlier)

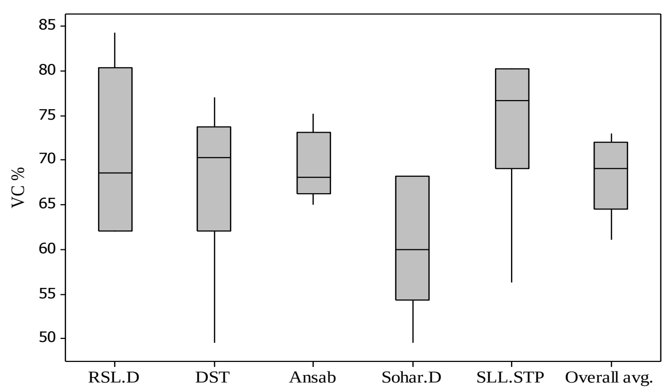

Fig. 6: Obtained VC of RAS

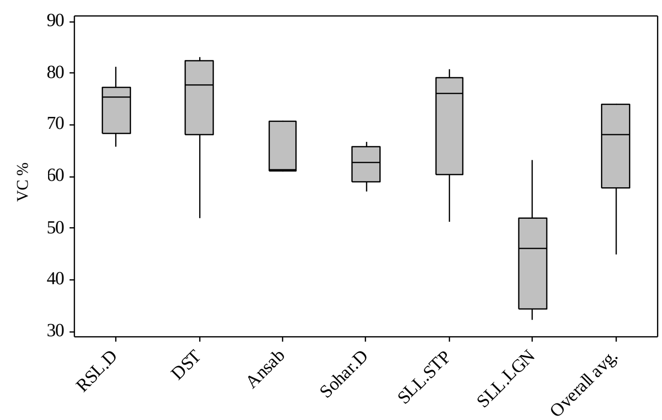

Fig. 7: Obtained VC of WAS

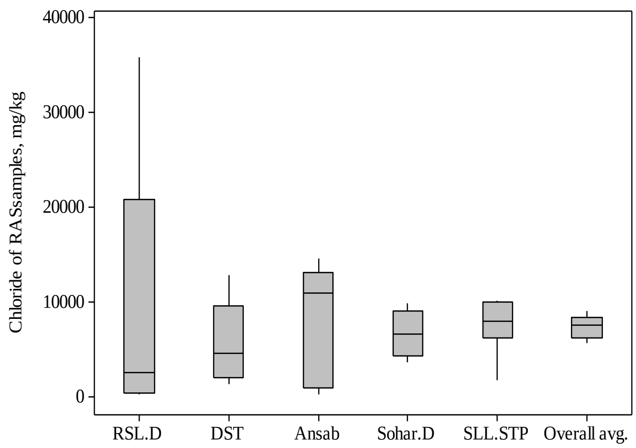

Fig. 8: Chloride values of RAS

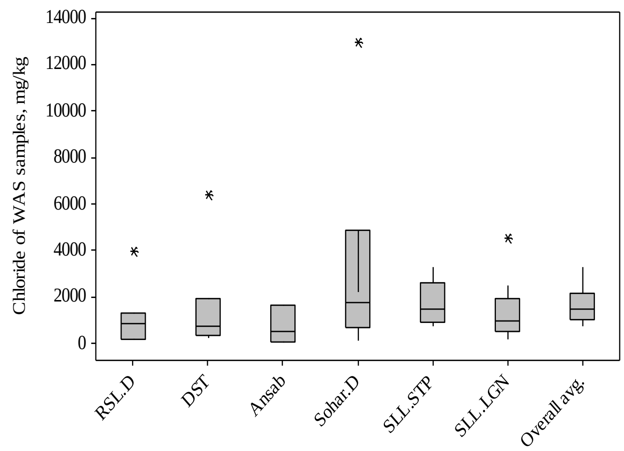

Fig. 9: Chloride values of WAS (* denote extreme value/outlier)

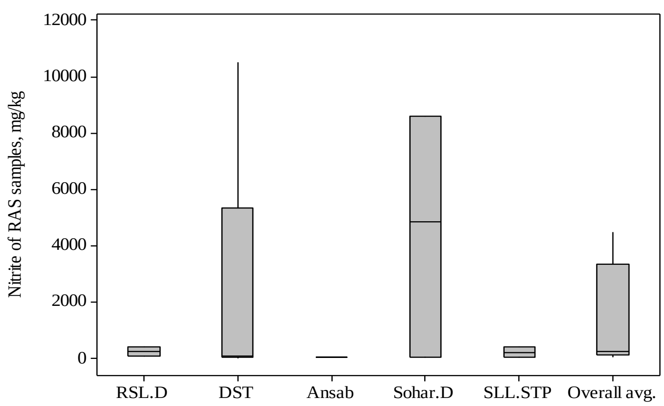

Fig. 10: Nitrite values of RAS

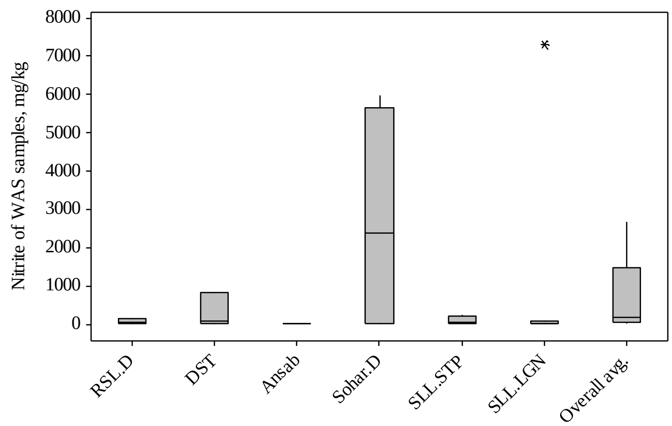

Fig. 11: Nitrite values of WAS (* denote extreme value/outlier)

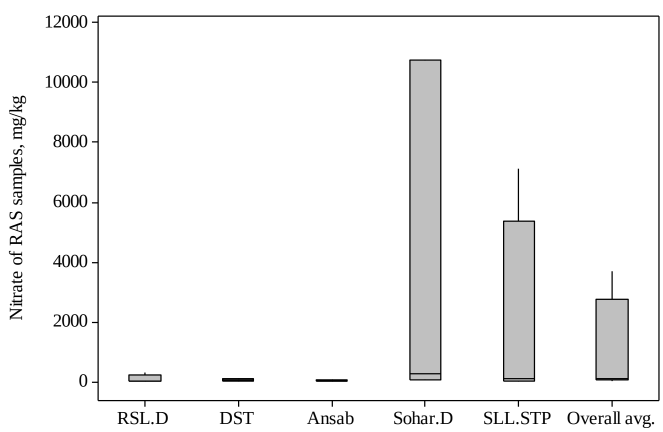

Fig. 12: Nitrate values of RAS

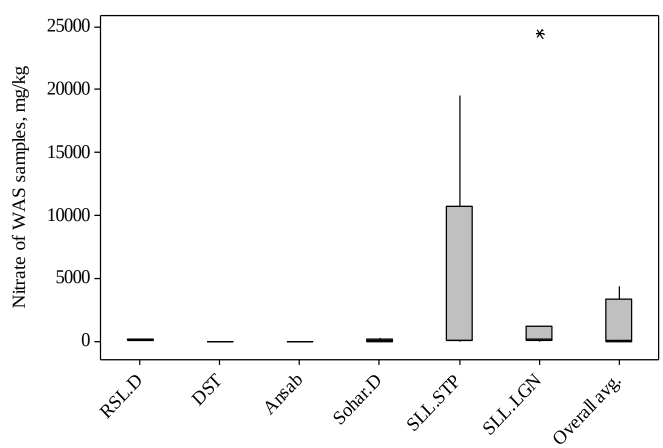

Fig. 13: Nitrate values of WAS (* denote extreme value/outlier)

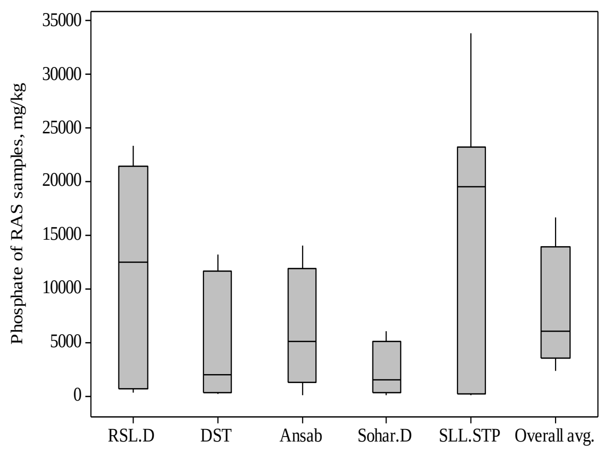

Fig. 14: Phosphate values of RAS

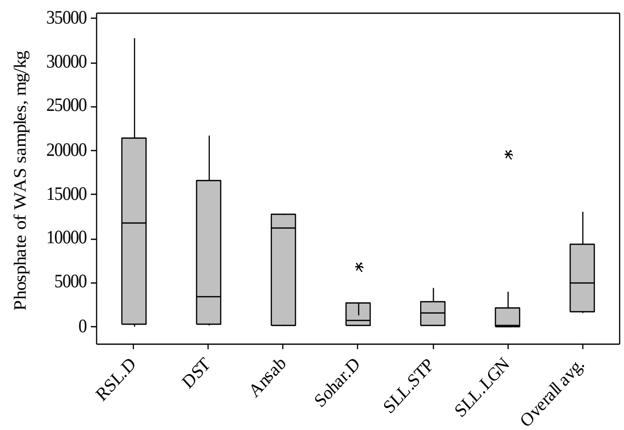

Fig. 15: Phosphate values of WAS (* denote extreme value/outlier)

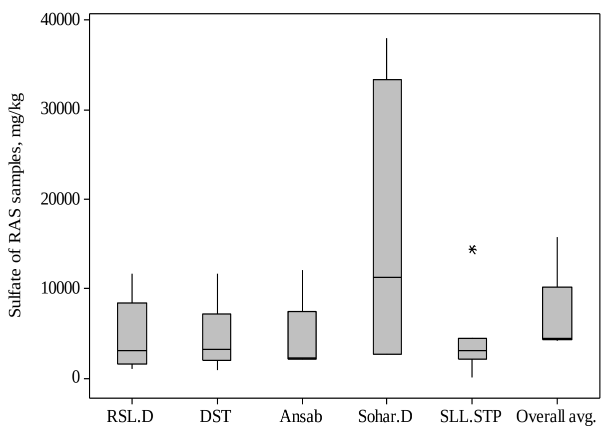

Fig. 16: Sulfate values of RAS (* denote extreme value/outlier).

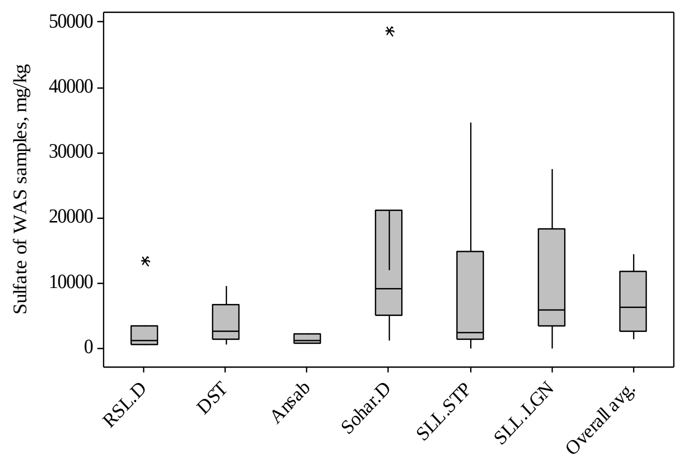

Fig. 17: Sulfate values of WAS (* denote extreme value/outlier)

Discussion

Observed wide range of pH for DST, fermentative microorganisms are recommended to be used for treating this sludge in an aerobic digestion (12). According to the statistical analysis, there were outlier points for WAS samples in SLL.STP and SLL.LGN which show a possible mistake throughout the sampling or measurement phases. The wider EC range observed in the RAS sample for Ansab STP while the range in the overall average is narrow, similar results have been reported from the Cyprus on EC values of domestic sludge (15).

The volatile content (VC) ranges in RAS and WAS are broader than the range of secondary sludge which is 50 to 70% according to a previous study of wastewater sludge (13). Chloride values for WAS, in Figure 9, four outlier points were located which may indicate that there are some errors happening while taking those readings. The general STD for all STPs, chloride values of RAS, WAS, and primary sludge was relatively high which might be due to the effect of seasonal change.

It can be seen from Fig. 10 that the range of nitrite concentration in DST and Sohar.D is much wider than the other STPs for RAS samples which is rather strange because the values of nitrite in aeration and settling tank were found low. An outlier point was found for nitrite in WAS samples of SLL.LGN which is mostly because of experimental error. The seasonal effect on nitrate values appeared clearly in WAS, RAS and primary sludge because the value of STD was found very high. Higher bromide values of waste activated sludge (WAS) are similar to the results observed by (Zorpha et al,) in the study of composting domestic sewage sludge with zeolities (16). Further, bromide in RAS, WAS and primary sludge, the value of STDs were very high which signify that the seasonal change effected the readings.

The average obtained values of the cations in both RAS and WAS samples were within the Omani Standard for the re-use of sludge in agriculture except for Zn in WAS samples of Sohar.D (Table 2 and 3). The value of cations in RAS samples in Sohar.D noted as NA because it was not available due to missing of those samples. The effect of seasonal change emerged at Cu, Pb, Ni and Zn results because STD was found relatively high. Similar results have been reported from Taiwan and analysis of sludge showed exceeding concentrations of Cu, Zn, Ni and Cd with maximum levels legally allowed in Taiwan farmland soil (14).

Table 3: Average obtained value of cations (dry weight mg/kg) for WAS samples

Sample	Cd	Cr	Cu	Pb	Mo	Ni	Zn
RSL.D	0.20	1.53	246.70	288.90	11.65	42.64	380.30
DST	0.20	0.99	376.24	43.32	6.07	83.88	844.65
Ansab	0.20	8.60	250.10	55.60	6.00	100.60	768.10
Sohar.D	NA	NA	784.60	109.40	5.60	547.80	3170.00
SLL.STP	0.20	1.30	323.48	60.36	17.10	33.52	1083.72
SLL.LGN	0.20	1.00	244.08	197.44	16.10	25.44	1269.52
Overall average	0.20	2.68	370.87	125.84	10.42	138.98	1252.71
EPA Standard	85	Not available	4300	840	75	420	7500
Omani Standards	20	1000	1000	1000	20	300	3000

Conclusion

The main aim of this study was to characterize domestic wastewater sludge in Oman from three different regions (Muscat, Sohar and Salalah) and to suggest alternate ways to reuse this sludge. The study showed very high concentration of phosphate in all the samples. Hence, it might be worth to further investigate on the sources of phosphate. Cations in both domestic RAS and WAS samples were low and suggest that the domestic sludge can be reused in agriculture. The study recommends that a regular maintenance should be performed to prevent any accumulation of some harmful substances which may affect the sludge quality and the sludge drying beds should be large enough to handle the produced sludge for better management. The study also suggests composting the produced sludge instead of dumping from the domestic STPs to landfill because the small levels of heavy metals. Furthermore, a pilot study has to be conducted to make sure that there will be no harmful effects to the environment if this sludge is used as fertilizer and fermentative microorganisms are recommended for treating the sludge in aerobic digestion due to the suitable pH range observed for such process.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

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