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Characterization of sewage sludge of wastewater treament plants in Alexandria

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Abstract: Provision of two primary sewage treatment plants in Alexandria has resulted in production of substantial quantities of sludge [46,000 tds/y]. This will increase to 112,000 tds/y by 2010. Alexandria sewerage system is a combined system which receives both industrial and domestic wastewater. Industrial contributions to wastewater influent streams can significantly increase industrial contaminants. In evaluating sludge use/disposal alternatives, municipality should first determine the sludge amount and characteristics. Therefore, the present study aims at characterization of the sludge produced at both wastewater treatment plants and after dewatering at the Mechanical Dewatering Facility [MDF]. The study extended over one year. The collected samples have been subjected to physical and chemical analyses, and microbiological examination. The pH values of East Treatment Plant [ETP] liquid sludge and the short sedimentation time indicated that there was no chance for the bioconversion processes. The slightly lower pH value of the West Treatment Plant [WTP] liquid sludge could be due to bioconversion during the storing in the equalization tanks for a long time. There were no observable differences for most of the measured parameters of ETP and WTP liquid sludges. The significant differences of VS, C%, and C/N between both sludges were due to sludge from co-settling of ETP with the suspended solids of WTP influent and to the effect of industrial wastewater discharges to WTP. The heavy metals contents of ETP, WTP, and MDF sludges were in agreement with the standards of Egyptian regulation for sludge re-use [Decree 222/2002], and USEPA and EC directives. However, the mean lead value was very close to the limit mentioned in the Egyptian decree. The Most Probable Number [MPN] of Total coliform [TC] and Faecal coliform [FC], and different eggs; larvae; and worms of parasitic species for sludge from both plants were unsafe for the sludge re-use. The MPN of TC and FC of the MDF sludge were almost similar to their corresponding values in the feed sludge. However, parasites showed big reduction. The study ended by some recommendations which can be made to improve the quality of the produced sludge.

INTRODUCTION

The provision of two primary sewage treatment plants in Alexandria [East Treatment Plant [ETP] and West Treatment Plant [WTP] has resulted in production of substantial quantities of sludge [46,000 tds [tons dry solids/y]. This will increase to 112,000 tds/y by 2010, according to the current wastewater treatment development plans. The sludge from the two proposed

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wastewater treatment plants to serve western Alexandria will produce at least an additional 60,000 tds/y at full capacity.

Sludge is a by-product of municipal wastewater treatment. The characteristics of sludge depend on both the initial wastewater composition, and the subsequent wastewater and sludge treatment processes used. Wastewater sludge has beneficial plant nutrients and soil conditioning properties. However, it may also contain potentially toxic elements,[2] synthetic organic chemicals, pathogenic bacteria, viruses, parasites, and other microorganisms which present potential risks to the environment, agricultural production, and human health, unless the sludge is treated to appropriate standards and its use is controlled.[3,4]

Alexandria sewerage system is a combined system which receives both industrial and domestic wastewater. Industrial contributions to wastewater influent streams can significantly increase industrial contaminants.[5] At the beginning, the generated sludge was disposed off by incorporation into the soil at the Dedicated Land Disposal [DLD] of site 9N [the sludge disposal facility of Alexandria General Organization for Sanitary Drainage [AGOSD]. As the capacity of Alexandria sludge disposal site is limited by current operation system and sludge should be regarded as valuable resource for soil fertilization, the process was changed from sludge spreading to composting.

Effective sludge management is an essential component of environmental pollution control. The composition of a sludge can limit a municipality's choice of sludge use/disposal options.[6] Thus, when evaluating sludge use/disposal alternatives, the municipality should first determine the sludge amount and characteristics.[7] Therefore, the present study aims at characterization of the sludge produced at both treatment plants and after dewatering at the Mechanical Dewatering Facility [MDF] to assist the decision makers in controlling the current sludge disposal/reuse method. It will also recommend the modifications which can be made to protect public health and environment.

MATERIAL AND METHODS

Liquid sludge samples from both treatment plants were taken in order to characterise contributions from each plant.

MDF dewatering sludge samples were also taken. The samples were generally collected weekly over the period from September 2000-September 2001. The collected samples were subjected to the physical and chemical analyses in accordance with the methods outlined in WHO manual of sludge, solid waste, and compost analysis.[8] They were analyzed microbiologically according to the Standard Methods for the Examination of Water and Wastewater.[9] Samples were examined for parasitic cysts, eggs, and larvae using a modification of the centrifugal flotation technique.[10]

RESULTS AND DISCUSSION

1. East and West Treatment Plants liquid sludge characteristics

The results of physico-chemical and heavy metals characteristics of the liquid sludge samples collected from ETP [41 samples] and WTP [42 samples] are presented in tables [1 and 2].

It has been found that there were significant differences between the two treatment plants regarding pH, VS, C, C/N, and Zn, table [1]. The accumulation of septic solids at the two equalization tanks slightly lowered the pH values of WTP liquid sludge [5.2-7.6] as compared with ETP liquid sludge pH [5.4-8.9]. The difference in VS% for ETP [53.9%] and WTP [69.3%] could be due to that ETP liquid sludge was being pumped to the WTP through the west zone collector and added to the sludge at WTP. This reason explains also the difference between the carbon values [28% and 36.1%, respectively] and consequently the C/N ratio [20.2 and 24.7, respectively]. However, the significant difference in Zn may be due to that industrial wastewater discharged into the ETP may contain more Zn concentration than that of west zone.

The mean value of moisture content of ETP liquid sludge [97.7%] almost agreed with the results of Chauhan[11] [97.5-98.5%], standard range [97-99%] according to the standard procedures of the primary treatment operation, and EPA [93-97%].[12] The mean value of moisture content of WTP liquid sludge [95.3%] agreed with the results of liquid sludge from wastewater treatment plant of Doyle and Haight study [94.7 - 95%].[13]

The pH values of ETP sludge ranged between 5.4 and 8.9. This range was not in agreement with the results of Han *et al.*, study[14] [5.0-6.5]. However, they were almost in compliance with the normal values of

Table 1: Physico-chemical characteristics of sludge samples collected from wastewater treatment plants in Alexandria in comparison with USEPA, EC, and Egyptian regulations, 2000-2001

Source	ETP		WTP		Significance	MDF		USEPA	EC Directive	Egyptian Decree
Parameter	Mean	Range	Mean	Range	of T-test	Mean	Range	part 503	86/278/EEC	222/2002[20]
Moisture %	97.7	90.2-99.7	95.3	93.9-99.2		71.2	59.1-76.6			
pH		5.4-8.9		5.2-7.6	xxx		5-6.4			
V.S.%	53.9	42.9-75.4	69.4	51.9-84.7	xxx	72.5	60.7-77.4			
Carbon %	28	13.9-39.21	36.1	27-44	xxx	37.7	31.6-40.2			
TKN %	1.43	0.9-2.19	1.51	1.06-2.6		1.6	1.2-2.02			
NH3 [mgg-1]	0.15	0.06-0.54	0.18	0.04-1.2		0.16	0.08-0.65			
NO3 [mgg-1]	0.06	0.02-0.3	0.05	0.02-0.1		0.05	0.02-0.14			
P [mgg-1]	4.9	2.1-8.4	5	2.6-10.4		4.8	2.5-7.7			
C/N	20.2	12.9-29.2	24.7	15-35.4	xx	23.7	19.6-30.3			
Cd [mgkg-1]	1.9	0.1-4.9	1.8	0.2-5.3		1.4	0.3-3.9	39-85	20-40	39
Cr [mgkg-1]	33.8	9.3-59.4	36.1	18.7-76.8		38.2	6.7-74.3	1200-3000		1200
Cu [mgkg-1]	198	79-520	181.2	103-282		179.2	34-261	1500-4300	1000-1750	1500
Pb [mgkg-1]	296.9	19-796	276.6	141-680		268.6	112-406	300-840	750-1200	300
Ni [mgkg-1]	49.8	14.8-231.5	40.8	11.4-138.8		30.5	9.5-69.8	420	300-400	420
Zn [mgkg-1]	501.4	190-938	453	251-733	x	410	185-551	2800-7500	2500-4000	2800

N.B. ETP= East Treatment Plant   WTP= West Treatment Plant   MDF= Mechanical Dewatering Facility

xxx= $p<0.001$ xx=$p<0.01$ x=$p<0.05$

Results based on dry weight

Table 2: Heavy metals concentrations of liquid sludge samples collected from wastewater treatment plants in Alexandria in comparison with some European countries, 2000- 2001, mg/kg.

Source	ETP	WTP	Germany	France	Netherlands	Portugal	Luxembourg
Metal	Liquid Sludge	Liquid Sludge					
Cd	1.9	1.8	1.8-4	0.4-49	0.38-17.8	0.98-15	1.5-6.9
Cr	33.8	36.1	34.242	10-927	10-297	27-920	29-305
Cu	198	181.2	216-849	31-2942	110-906	125-555	124-405
Pb	296.9	276.6	75-237	18-832	24-704	68-195	90-234
Ni	49.8	40.8	26-60	7-311	4.5-137	29-69	13-149
Zn	501.4	453	850-1600	205-9714	60-1712	608-980	1007-2096

N.B. Data other that of Alexandria are reported by reference No. 29
Results based on dry weight

Table 3: Comparison of sludge heavy metals concentrations at wastewater treatment plants in Alexandria with the Greater Cairo sludge at different wastewater treatment plants, 2000-2001, mg/kg.

Source	ETP	WTP	Abu Rawash	Helwan	Berka
Metal	Liquid Sludge	Liquid Sludge			
Cd	1.9	1.8	26	124	3.2
Cr	33.8	36.1			
Cu	198	181.2	243	342	634
Pb	296.9	276.6	269	68	552
Ni	49.8	40.8	99	97	68
Zn	501.4	453	1726	2488	3680

N.B. Data other that of Alexandria are reported by reference No. 21
Results based on dry weight

Table 4: Microbiological examination of sludge samples collected from wastewater treatment plants in Alexandria, 2000-2001

Source	ETP		WTP		Significance	MDF	
Parameter	Mean	Range	Mean	Range	of T-test	Mean	Range
Bacteria [MPN/100ml]							
Total Coliform	$28x10^9$	$36x10^2$-$24x10^{10}$	$14x10^{10}$	$24x10^4$-$24x10^{11}$	x	$28x10^9$	$43x10^2$-$24x10^{10}$
Faecal Coliform	$22x10^9$	$36x10^2$-$11x10^{10}$	$13x10^{10}$	$23x10^3$-$24x10^{11}$		$19x10^9$	$3x10^2$-$24x10^{10}$
Parasites [Count/100 ml]							
Ascaris	1294	0-16478	1290	0-13240		55	0-3800
Toxocara	1714	0-56538	918	0-8296		34	0-2550
Fasciola	609	0-22720	2846	0-1940		1	0-28
Enterobius	0	0	3	0-126		0	0-3
Amoeba	1377	0-21846	764	0-17490		6	0-128
Giardia	100	0-3120	402	0-12224		2	0-111
Strogyloides	2875	0-43692	1011	0-15048		39	0-2600
Trichuris	0	0	27	0-1136		15	0-1090
Heterophyse	6	0-254	15	0-618		0	0
Taenia	12	0-284	0	0		0	0
Hymenolepis	22	0-884	0	0		0	0

N.B. ETP= East Treatment Plant WTP= West Treatment Plant MDF= Mechanical Dewatering Facility

x=$p<0.05$

MPN= Most Probable Number

For MDF, bacteria and parasite count/g

sludge from the primary sedimentation clarifiers [5.0-8.0 with a typical value of 6.0].[15] This may be related to that the sludge of Han's study was generally highly putrescible. In general, these values represented the typical range of primary sludge, and they reflected the plain sedimentation operation with the short sedimentation time [1.59 hours average], where there was no chance for the bioconversion processes .

The pH values of WTP sludge ranged between 5.2 and 7.6. This range was in compliance with the results of pH values of liquid sludge from wastewater treatment plant of Malina study[15] [6.5-7.0]. The significant lower pH value of the WTP liquid sludge than that of ETP could be due to the formation of organic acids resulting from sludge bioconversion during the storing of liquid sludge in the equalization tanks for 16 hours. However, the pH values did not severely decrease because the sludge equalization tanks are equipped with air diffusers, which keep the sludge mixed and reduce septicity.

The mean values of volatile solids at ETP and WTP sludges were significantly different [53.9% and 69.4%, respectively]. The V.S. of ETP disagreed with that of Malina[15] [60 to 80% with a typical value of 65%]. This discrepancy between both results was due to that Alexandria sewerage system received domestic waste, industrial wastes, and street runoff containing dirt, oil, sweepings,.....,etc. All of these materials lowered the organic content of the primary sludge at ETP. On the other hand, the results of V.S. in WTP sludge agreed with that of Malina.[15]

The mean values of nitrogen and phosphorus of the ETP liquid sludge were 1.43% and 0.49%, respectively. These values were lower than those of Malina results[16] [ranged between 1.5 and 4% with a typical value of 2.5% for nitrogen and 0.8 to 2.8% with a typical value of 1.6% for phosphorus]. The high values of phosphorus and nitrogen in Malina study may be due to the more use of detergents.

The mean value of nitrogen [1.51%] in WTP sludge was lower than that of liquid sludge of Hall[17] study [3.5%]. This may be attributed to the high dilution effect and the poor nitrogen sources of industrial effluents discharged to the west zone. On the other hand, the mean value of phosphorus [5.0 mg/g] was higher than that of the results of Hal,[18] study [2.8 mg/g]. The higher phosphorus content of WTP sludge was due to the phosphate detergents production industries in the west zone.

The low mean value of ammonia [0.15 mg/g] in ETP sludge could be attributed to that the time of sedimentation was too short to allow bioconversion. This agreed almost with Bailey and Schiemann study[19] which stated that short time of sedimentation did not allow organic nitrogen mineralization.

The results of heavy metal analysis of liquid sludge samples are presented in table [2]. The mean values of Cd, Cr, Cu, Pb, Ni, and Zn metals in ETP sludge were 1.9, 33.8, 198.0, 296.9, 49.8, and 501.4 mg/kg, respectively. All of the above mentioned results were below the results of Bailey and Schiemann study[19] except for Ni [range of 14.8–231.5 mg/g] in the present study which was similar to the said study [range of 15.6-243 mg/g]. As shown in the table, the highest metal concentration was that of zinc [501.4 mg/kg]. However, it is in the safe range for sludge reuse, as a soil conditioner, according to the Egyptian Standards [2800 mg/kg].[20] In general, they indicated that the concentrations were generally well below the European and American limits, and were also within Egyptian sludge regulations [Decree 222/2002] as shown in table [2]. It could be said here that the large domestic contribution in the east zone of Alexandria, which represents the main wastewater source for ETP, could mask significant inputs of metals from industrial sources that would be reduced to improve sludge quality.

There were wide variations in WTP sludge heavy metals individual data, as may be anticipated from industrial discharges, table [2]. The table presented that all WTP liquid sludge metal concentrations are, more or less, within the range for heavy metals concentrations found in German sludge except for lead. This was related to the uncontrolled industrial discharges at the west industrial complex areas which include Moharram Bey, EL-Kabbary, and El Mahmoudia industrial complexes. In general, the concentrations of potentially toxic elements in WTP sludge are somewhat lower than those found in European countries and US, except for lead in some individual samples. The average lead content was 276.6 mg/kg and the Egyptian limit concentration is 300 mg/kg, but a large number of individual lead values were above this limit, reaching a maximum of 680 mg/kg.

In particular, lead concentrations in some ETP and WTP sludge samples were significantly above those found in Egyptian regulations.[20] This was due to the industrial wastewater from battery manufacturers within the east and west zones catchments. Also the high pH values in the sludge may cause corrosion problems of sewerage metal pipelines containing lead.

The values of potentially toxic elements in ETP and WTP liquid sludge were somewhat lower than those found in the Greater Cairo wastewater treatment plants as reported in table [3]. This can be attributed to many reasons. Most of the Greater Cairo wastewater treatment plants receive significant amounts of industrial effluents and, consequently, the quality of the sludge may be expected to be poor.[21] In addition, Cairo has a large number of fabricated metals industries compared with that of Alexandria [184 in the area covered by both plants] and the rainfall and the domestic discharges in Alexandria assist in diluting the industrial effluent.

The results of microbiological examination of the liquid sludge samples collected from ETP and WTP are presented in table [4]. The average MPN/100ml of total coliform [TC] and faecal coliform [FC] of both ETP and WTP liquid sludges were $28x10^9$ and $14x10^{10}$ for TC and $22x10^9$ and $13x10^{10}$ for FC, respectively. The results of TC and FC of the present study for both plants were slightly higher than obtained by Golueke[22] [$1.2x10^8$ and $2x10^7$, respectively] and Pahren[23] [$2.8x10^9$ and $2.4x10^8$]. According to the Egyptian decree No. 222/2002 [the MPN of faecal coliform in the treated sludge should be less than 1000 cells/1g dry solids] and USEPA regulation [pathogens in sewage sludge should be reduced to levels which would not affect human health or environment before sludge or sludge products are beneficially used[24]], the sludge of both ETP and WTP was considered unsafe to use unless subjected to a treatment that can inactivate the pathogenic microorganisms.

It is also clear from table [4] that most of the eggs, worms, and larvae had been detected in both sludges. *Strongyloides* larvae with a mean value of 2875 larvae/100 ml recorded the maximum value in ETP sludge while *Heterophys* eggs with a mean value of 6/100 ml recorded the lowest. *Trichuris* and *Enterobius* had not been detected. For WTP sludge, *Fasciola* had recorded the maximum with a mean value of 2846/100 ml while *Enterobius* recorded the minimum [3/100 ml]. *Taenia* and *Hymenolepis* had not been detected. The recorded results of parasites prohibit the use of the sludge before treatment according to the Egyptian decree No. 222/2002 which states that sludge should be treated and the treated sludge should contain no more than one helminthes egg/kg and the eggs present should not exceed 3 genera of helminthes eggs.

2. Mechanical Dewatering Facility [MDF] evaluation

East treatment plant sludge, pumped to the WTP, is co-settled with the wastewater from the west zone. The combined or mixed primary sludge is dewatered, after conditioning with the addition of polymer, at the MDF using belt filter presses. The physico-chemical results of dewatered sludge samples collected from the MDF [75 samples] are presented in table [1].

The moisture content with a mean value of 71.2% almost agreed with the results of Doyle and Haight[13] [60%-83%] and with the range of designed dewatered sludge contents[25] [70-75%].

The range of pH values [5.0-6.4] agreed with the lower range of the results of Malina[26] [5-8] and with the typical designed range of dewatered sludge [5-6].[27] The pH of the feed sludge was 6.0 and was reduced to 5.2 during sludge conditioning operation as a result of sludge septicity.

Volatile solids with a mean value of 72.5% agreed with that of the results of Malina [60-80%].[16] The mean volatile solids content of the dewatered sludge [72.5%] was higher than that of the liquid sludge [68.9%]. This may be due to the addition of organic polymer needed for thickening of liquid sludge at MDF.

The nitrogen values with a mean value of 1.6% were almost in the typical range for dewatered sludge of the WRC[28] study [1.70%].

The results of phosphorus with a mean value of 4.8 mg/g disagreed with the results reported by Hall[28] [2.8 mg/g] and Kelly[29] [0.19-0.28 mg/g]. This may be attributed to the increase use of detergents nowadays and to the concentration effect in the MDF. There was no observed difference between the phosphorus value of the liquid [5.0 mg/kg] and dewatered sludge [4.8 mg/kg] which may be attributed to the adsorption of phosphorous compounds on the dewatered sludge.

The mean values of Cd, Cu, and Zn [1.4, 179.2, and 410 mg/kg] were lower than that of the mean values of Campbell[30] [6, 366, and 737 mg/kg, respectively]. On the other hand, the MDF dewatered sludge heavy metals concentrations were well within the standards required for agricultural use according to the Egyptian decree for the safe use of sludge.[20] However, some lead values in MDF sludge were beyond the limit [300 mg/kg] mentioned in the Egyptian decree. Therefore, it is important to ensure that the lead concentrations were kept below the limit value for sludge reuse. In general, there was also no observable difference between the values of heavy metals in the liquid and dewatered sludge.

The results of microbiological examination of the MDF dewatered sludge are presented in table [4]. The average MPN/100ml of TC and FC with mean values of $28x10^9$ and $19x10^9$ were almost similar to their corresponding values in ETP and WTP liquid sludges. This means that the processing of the liquid sludge at MDF has no effect on the bacterial population. Also, this sludge still requires a treatment before re-use according to the Egyptain and USEPA regulations.

On the other hand, parasites have shown more reduction than their corresponding values in the ETP and WTP sludges where three genera were absent [*Heterophys*, *Taenia*, and *Hymenolepis*]. *Enterobius* has recorded values less than 10. The remaining 7 genera have also been reduced. However, sludge should be treated to be safe for use.

CONCLUSION AND RECOMMENDATION

It can be concluded that:

1- There were no significant differences for most of the measured parameters between ETP and WTP liquid sludges. The differences of VS, C%, and C/N between the both sludges were due to co-settling of ETP sludge with the suspended solids of WTP influent and to the effect of industrial wastewater discharges along the west zone collector.

2- The pH of the MDF sludge was less than those corresponding values in the feed sludge.

3- The heavy metals contents of ETP, WTP, and MDF sludges were in agreement with the standards of Egyptian regulations for sludge re-use [Decree No. 222/2002], and USEPA and EC directives. However, some lead values were more than the limit mentioned in the Egyptian decree.

4- The number of TC, FC, and different eggs; larvae; and worms of parasitic species for both plants were unsafe for the sludge to be used.

5- The MPN of the MDF sludge were almost similat to their corresponding values in the feed sludge. However, parasites showed great reduction.

Therefore, the following recommendations should be considered in order to improve the quality of the produced sludge:

1. Progressive reduction of industrial contaminants entering the sewerage system should remain as an objective of regulatory authorities in Alexandria by engorcing industries to comply with regulations concerning the discharge of industrial wastes into sewerage system so that the sludge could be used safely for agricultural purposes.
2. Continuous aeration of the sludge at the equalization tanks of MDF to keep the sludge mixed and reduce septicity.
3. Continuous monitoring of the quality of sludge for both organics and metals contaminants under quality assured conditions.
4. MDF sludhe must be stabilized by treatment either by digestion of composting to produce safe sludge to be used for agriculture.

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