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Municipal sewage sludge characteristics and waste water treatment plant effectiveness under warm climate conditions

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ABSTRACT

The present paper deals with the characterization of the municipal sewage sludge (MSS) and the effectiveness of the waste water treatment plant (WWTP) under warm climate condition. The WWTP effectiveness is more than 98.5% for the BOD_5, 90% for COD, 95% for SS, 70% for TN, 99% for NH_4, while the TP efficiency rang from 15.17% to 99.12%. The total $kWh/kgBOD_5/month$ is from 1.97 to 3.13, while the total kWh/m^3 of wastewater influent range from 0.62 to 1.36. The yearly chemical consumption (chlorine, polymer, lime) depends at the end from the season. The sludge does not present significant concentration of metals and the evaluation with sequential extraction showed that the metals are associated with inert forms while the application of the, Generalized acid neutralization capacity (GANC) test indicated that by increasing the leach ate pH, the heavy metal concentration decreases.

Keywords: Wastewater treatment plant; Sludge characteristics; Metals extraction; Metals partitioning; BOD and COD removal; MLVSS; SVI

1. Introduction

Increasing urbanization and industrialization has culminated in a dramatic growth in the volume of municipal wastewater produced worldwide. This wastewater contains all the substances that enter in human metabolism, such as food, beverages, pharmaceuticals, a great variety of household chemicals and the substances discharged from trade and industry to the sewer system [1]. Moreover, rain water and its contact materials also contribute to this composition. As a result, the constituents of the municipal wastewater discharged into the sewer system are a mirror of our civilization and of human and urban metabolism.

Sewage sludge is the concentrated bioactive residue of mostly organic clay-sized particles derived from wastewater treatment processes. The consolidation and hydraulic characteristics of the dewatered sludge material are of major importance with regard to its long-term behavior in landfills (sludge mono-fills, municipal landfills or sludge lagoons), currently the principal means of disposal in the European Community. In many countries, there is an almost complete reliance on landfilling since the spreading of sewage

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sludge material on land is banned and incineration may not be an option. The sludge landfill and its engineered capping system are subject to considerable settlement that must be assessed at the design stage. In practice, sewage sludge shows unpredictable consolidation behavior that can be attributed to a number of causes [2,3]. Firstly, the engineering processes for treating and dewatering the raw wastewater generally involve the addition of flocculating agents that affect the final structure of the sludge material. Secondly, ongoing or reactivated biodegradation of the volatile organic solids occurs, especially if the material is disturbed, warmed or aerated. Thirdly, the composition and viscosity of the pore fluid (more akin to a soft gel than water) is likely to change with time. The consolidation properties of sewage sludge materials, including dewatered sludge material direct from a treatment plant [3,4]; material in a sludge lagoon [2,3,5] and dried compacted sludge materials [3,4] have been studied using the standard odometer apparatus, the Rowe hydraulic consolidation cell and the flexible wall permeameter.

The sludge is classified as difficult solid waste that requires special treatment before the disposal because of the noxious properties. The sludge contains salts, organic pollutants and mainly heavy metals. Knowledge of heavy metal content and its form distribution in the sludge are the most important factors in selecting the disposal alternatives [6–11].

1.1. Legislation on waste water treatment plants

The Council Directive 91/271/EEC of 21 May 1991 [12] concerning urban waste-water treatment (also known as The European Water Act) establishes restrictive threshold concentrations in the wastewater emissions and its implementation is leading to a rapid multiplication of wastewater treatment plants (abbreviated WWTPs) across Europe. This activity causes an enhanced environmental quality of the wastewaters; however, it also implies such side effects as material and energy consumption as well as generation of waste, [13].

The directive concerns:

- the collection, treatment and discharge of urban waste water from agglomerations; and
- the treatment and discharge of biodegradable waste water from certain industrial sectors.

Its objective is to protect the environment from the adverse effects of such waste water discharges. Member States must ensure that urban waste water is collected and treated prior to discharge according to specific standards and deadlines. In terms of the treatment objectives, secondary (i.e., biological) treatment is the general rule, with additional nutrient removal in so-called sensitive areas (tertiary treatment); for certain marine areas primary treatment might be sufficient. The deadlines for implementing the directive vary according to the size of the agglomeration and the characteristics of the receiving waters.

The description of the current status on the discharge and treatment of urban and industrial wastewater is based on information from the inventory of urban WWTP and the sewage network prepared for implementation of the EU Directive 91/271/EEC [12] concerning urban wastewater treatment. Directive 91/271/EEC [12] sets a series of requirements with respect to the systems for collection, treatment and disposal of wastewater, and the related legal aspects and terms for implementation. For the needs of the implementation, an assessment of the current status was necessary. The assessment was conducted in the steps listed below:

1. Legislation reflecting the requirements of the Directive 91/271/EC.
2. Competent bodies and responsibilities.
3. Procedure for issuing permits for discharging wastewater from the urban collection system.
4. Discharge and treatment of urban and industrial wastewater according to the Directive (Art. 13).
5. Status of the national system for monitoring of surface and wastewaters.
6. Identification of ‘‘sensitive areas’’ according to Annex 2 of the Directive.
7. Existing situation concerning the treatment of WWTP sludge.
8. The procedure for issuing permits for discharging wastewater from the urban collection system was adopted along with the Water Law in 1999 and the Regulation on Emission Standards in 2000.

1.2. Description of the area

Cyprus is situated in the north-eastern part of the Mediterranean Sea, 338 east's and 358 north of the Equator. It is situated 75 km south of Turkey, 105 km west of Syria, 380 km north of Egypt, and 380 km east of Rhodes (Greece). The third largest Mediterranean island after Sicily and Sardinia, with a total population up to 1,000,000 citizens, it has an area of 9,251 km^2, of which 1,733 are forested. Cyprus has a record of successful economic performance, reflected in rapid growth, full employment conditions and external and internal stability, almost throughout the post-Independence period. The underdeveloped economy, inherited from colonial rule until 1960, has been transformed into a viable economy with dynamic services, industrial and agricultural sectors and advanced physical and social infrastructure. In terms of per capita income, is currently estimated at US $13,000 during 2000 and at US $20,000 during 2008, it is classified as the highest income country of all the entering new EU members [14]. In the greater eastern area of Cyprus are the Municipality of Paralimni and Ayia Napa. Those municipalities with permanency population almost 22,000 citizens (19,000 and 3,000, respectively) consists the main economical lung of the island due to the fact that in this area there are the largest hotel resorts. During the winter the population is estimated at 22,000 citizens but from the begging of April since October are estimated at 75,000 with the tourist per day. Cyprus the island of Venus consist the major Tourist destination in the eastern Mediterranean. With almost 2,000,000 tourists per year who visit Cyprus, from all around the world, and especially the European Union, the two Municipalities has the ability to quest almost the 35–40% per year of the total tourist that they visit the Island [15].

There is no major water consuming industry in the project area, and according to the available development plants the situation will remain the same in the future. In the nearby area there are mainly tourist activities like Hotels, restaurants, bars, pubs, knight clubs, and water parks. 115 Hotels and apartment in Municipality of Paralimni and 185 Hotels and apartments in the Municipality of Ayia Napa, according to the Cyprus Tourist Organization, [16] are presented, almost 6,000 houses, one water park (100,000 m^2 approximately), 8 petrol stations and 12 cars cleaning services, approximately 15 machinist's craftsmanship, small industries like bakeries, confectioneries, car wash, food suppliers, supermarkets, schools, 6 clinical laboratories, 2 private clinics and 1 public hospital, football fields and athletic activities, 2 chicken farms (approximately 30,000 chicken/y), 2 big laundries, 1 concrete plant and some small industrial activities which they do not produced liquid waste consist the main activities of the area.

1.3. WWTP process description

The total population served is 120,000 including residents, tourist and labour force in tourism. The number of tourist beds used as the dimensioning basis is 44,000 in Paralimni and 36,000 in Ayia Napa [16]. The estimated total wastewater flow is about 28,000 $m^3\ d^{-1}$ during the peak season and about 18,000 $m^3\ d^{-1}$ during the low season. The average flow (yearly average) is estimated to be about 20,000 $m^3\ d^{-1}$.

Due to the fact that, the treated effluent will be used for irrigation the treatments shall consist of primary pretreatment, secondary and tertiary stages and disinfection. The disinfected tertiary effluent will be led into the daily balancing reservoir and the surplus secondary treated effluent stored without disinfections into the separate storage reservoirs of each municipality, volumes 200,000 m^3 (Paralimni) and 150,000 m^3 (Ayia Napa). The tertiary stage and chlorination occur after the reservoirs before discharging the water to irrigation. The treatment plant also receives septage sludge. For emergency situations there will be two spill ponds, total volume 50,000 m^3, in connection with the mechanical pretreatment stage. The wastewater from Paralimni and Ayia Napa pumped in a separate force mains to the treatment plant, while each influent is measured. The proposed wastewater treatment process consists of pre-treatment for wastewater and septage, secondary-biological treatment based on activated sludge method (extended aeration) and a tertiary treatment stage after reservoirs. Finally, the water will be disinfected and conveyed in the tourist areas for irrigation use. The secondary treated water stored in reservoirs to be used for irrigation while surplus water, which cannot be stored, will be led to forest areas for irrigation. During low flows and at the beginning of the operation of the treatment plant (coverage of sewers connected into the system <50%) two or three of the four lines of the aeration stage shall be closed down. Also, the secondary clarifiers and the tertiary units shall be operated to 50% or 75% capacity during low flow, [17]. The influence enters the plant via screening. There is one mechanically operated coarse screen and two parallel lines for mechanically operated fine screens. Hand raked screen also is located in the bypass channel. Normally, influent flows to the mechanical screens, each of which can be bypassed to the hand raked screen. Timers and level sensors control the operation. Also, the water level difference on the channel starts the function of the cleaning system. Screenings are removed from the screens to a screening compactors system directly. Screenings are then transferred with trucks for disposal by landfill. The wastewater then flows gravitationally into two aerated grit removal basins. Pre-aeration also reduces odor emissions. Air is supplied to the bottom of the basin and the airflow remains constant. Sand-water mixture flows into a tank and is conveyed into the screenings bin. Overflow from the sand tank is led back to sand removal basins. Influent flows to the circulation basin and mixed with the returned sludge while lime is possible added to the influent at this point. Then the mixture liquid flows into aeration (aeration process is extended and during aeration oxidation of ammonia to nitrate takes place). Nitrification consumes alkalinity from the water; consequently pH must be adjusted by added lime. Aeration takes places with submerged aerators (air-diffusers). When bottom aeration is applied, air is fed from blowers. Concentration of oxygen is kept at the required level by controlling with valves the airflow entering the process. The flow of air from blowers is controlled automatically by oxygen meters which are applied in activation lines. Air pressure in the main pipes from the blowers is kept constant [17]. Mixed liquor flows by gravitation from aeration into four parallel secondary clarifiers. Clarified effluent by gravity flows to tertiary units of the process. There are two tertiary units one for each municipality.

Most of the sludge sediment on the bottom of clarifiers returns by pumping at the beginning of the process. Excess sludge produced in the biological process is pumped to the aerated buffer tank and from there by pumping sludge flows to the dewatering unit (two mechanical thickeners and two centrifuges). Secondary treated effluent, shared between the two tertiary units according to the influent flow proportion. Tertiary stage is separated for Paralimni and Ayia Napa. It comprises chemical coagulation and up/down flow sand filtration. When chemical precipitation is included coagulant is mixed in wastewater in rapid mix chamber. Wastewater then flows into flocculation basins where it is stirred with slow speed stirrers to allow coagulation and forming of flocs. Coagulant aid is added with demand. Chemical flocs and residual solids (organic and solids) are removed in flotation sand filtration stage.

The secondary treated effluent from the biological stage flows to sand filters for removal of residual solids. The tertiary treated water after chlorination flows by gravity into a daily balancing basin. Filter beds are washed with filtered effluent and pressurized air. Backwash water flows into a dirty water basin and recycled to mechanical pretreatment unit. Filtered effluent flows to disinfections with chorine. Chlorination takes place with gaseous chlorine. Chlorine dosing is flow controlled. Occasionally sand filters are washed with chlorinated water pumped from this basin. From chlorinated water basins water flows by gravity to daily balancing tank. Treated effluent will be used for irrigation. The spill pond will be equipped with diffuser aerators and propeller mixers. From the pond wastewater is pumped to the process (to screening).

1.4. Sludge Management (current situation) from WWTP

Sludge is separated from wastewater in secondary clarifiers. Secondary sludge (excess sludge from biological process) is pumped from the return sludge stream into primary clarifiers. Excess sludge is taken from two of the four basins. Back wash water from sand filters is pumped to primary clarifiers. Sludge sediment in primary clarifiers is pumped into two gravity thickeners. Pumping is controlled with timers. The thickeners are equipped with torque measurement. Thickened sludge is pumped with two pumps to belt filter presses to be dewater. Pumps are controlled from the level of the wet zone of belt filter presses. Polymer is dosed prior to dewatering. Each of the two sludge lines controls a respective polymer pump. Preparation and dosing of polymer solution takes place automatically. Effluent after sand filters is used for polymer dissolving and diluting as well as for washing of belt filter presses with showers. Dewatered sludge falls from the presses on a conveyor screw at the end of each equipment. Dewatered sludge is stabilized now with lime (CaO). Lime is dosed from lime silo with dry feeder. Mixing of sludge and lime occurs in a conveyor screw. Stabilized sludge is transferred by means of a belt conveyor to the landfill site using trucks. Over flows from the thickeners and filtrates (rejects) from sludge dewatering are collected into a well and pumped back to the wastewater process (to sand removal).

Land filling is the main disposal practice until now in Cyprus. No other practices like incineration, composting, or other treatment methods are applied.

The present paper (as there is a very limited work on the subject) deals with the characterization of the municipal sewage sludge (MSS) and the effectiveness of the WWTP of the Municipality of Paralimni – Agia Napa in the eastern of Cyprus, under warm climate conditions.

2. Materials and methods

A sufficient amount of the sludge samples were collected 2 time per month (26 samples per year) and are analyzed in a numerous of parameters. Sludge is analyzed for pH, EC, Salinity, Alkalinity, Total Phosphorus (TP), Organic Matter (OM), Ash, Total Organic Carbon (TOC) content, Total Kjeldahl Nitrogen (TKN), C/N ratio, ammonia content, Total Humic substances (THS, Humic and Fulviv Acid), E4/E6 ratio, Lignin and Cellulose, Germination Index (GI), Grow Index (G), VSS, moisture, Chlorine Ions (Cl^-), Fats and Oils, N-NO_2^+. N-NO_3^+. Every 6 month (twice per year) sludge, were analyzed for heavy metals such as Cd, Cu, Cr, Ni, Pb, Zn, Mn, Co, Hg, As, Fe, Na, K, Ca, Mg, CN, B. For the determination of those parameters were used several methods which has been describe elsewhere, [11,18–22].

The sample from influent is collected electronically by using an automatic collector who has the ability to collect a homogenized sample of a total volume of

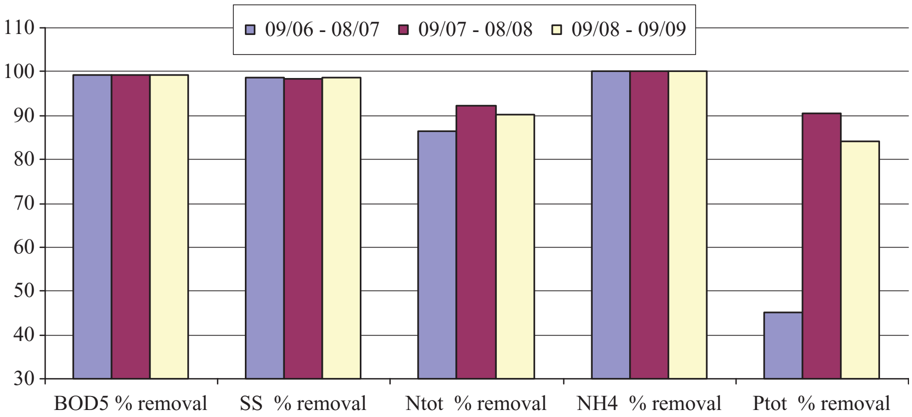

Fig. 1. WWTP efficiency from 2006 to 2009.

3 L in a total time of 24 h. The other sample from the effluent and the tertiary of Paralimni and tertiary of Ayia Napa are collected manually before the analyzing.

The liquid samples daily are analyzed for the last years in the following parameters (in order to estimate the effectiveness of the WWTP): Suspended Solids (SS), $BOD_{5,}$ COD, Total Phosphorus (TP), and Total Nitrogen (TN). Mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), settled sludge volume, sludge volume index (SVI), Volatile Suspended Solid (VSS) also were determined. All the parameters are determined according to Standards Methods [18,19].

In order to study the forms of metals in the sludge samples, a sequential chemical extraction procedure was used for the partitioning of these metals into five fractions as described elsewhere [10,23,24]. According to this scheme, heavy metals are associated with five fractions: exchangeable (extracted by 1 M CH_3COONa for 1 h at room temperature and at pH 8.2), bound to carbonates (extracted by 1 M CH_3COONa for 5 h at room temperature and at pH 5.0), bound to iron and manganese oxides (extracted by 0.04 M $NH_2OH.HCl$ in 25% v/v CH_3COOH for 6 h at 96°C), bound to organic matter (extracted by 0.02 M HNO_3 and 30% w/v H_2O_2 for 2 h at 85°C and pH 2.0, followed by the addition of 3.2 M CH_3COONH_4 in 20% w/v HNO_3 with 30% w/v H_2O_2 for 3 h at 85°C, diluted with distilled water and let for 30 min at room temperature) and residual (extracted by 40% w/v HF, c.HNO_3 and 0.2 M NH_4NO_3 at pH 3.0, for 1 h and at room temperature).

The GANG test procedure was used for the estimation of the leachability of metals from the sludge samples [25,26]. This test is a single batch procedure that utilizes a series of sludge samples extracted with increasingly acidic leachant. A known quantity (1 g) of sludge sample is placed in a series of 100 ml polyethylene bottles. 20 ml of liquid is added to each bottle. A declining amount of distilled water is added to each bottle followed by an increasing amount of 2N acetic acid. This process produces a series of bottles containing increasing equivalents of acid per kilogram of samples but the same total liquid volume (20 ml). The mixtures were tumbled in rotating extractors for 48 h and then were let to stand for 15 min. Following, in the supernatant the pH was measured and the metal concentrations were determined by AAS. Leachants strength starts out at the 0 equivalents of acetic acid and is increased until pH is below 5 for three consecutive equivalents.

Statistical analysis was performed using Microsoft Excel 2010.

3. Results and discussion

3.1. WWTP effectiveness

The WWTP presented with a great effectiveness (Fig. 1) which is up to 99.35% for the BOD5, 98.58% for the SS, 86.56–92.29% for the N, 99.99% for the NH_4, 45.12–90.60% for the P. The removal efficiency from several WWTPs in India [27] for the BOD_5 range from 70.61–99.43% while the TKN varies from 21.08% to 94.58%.

Usually the efficiency on anaerobic waste water treatment plant confirm with the reduction of COD. Settled sewage with initial COD 135–218 ppm (conditions: T = 5–20°C and with hydraulic retention time (HRT) from 1 to 10 h) the efficiency of the anaerobic expanded bed reactor range from 35% to 77% [28,29]. The anaerobic sequencing batch reactor has efficiency on COD removal from 62% to 95% for a non-fat dairy milk as substrate and with initial COD 600 ppm (conditions: T = 5–20°C and HRT = 6–24 h) according to some researchers [30,31]. Settled sewage as substrate

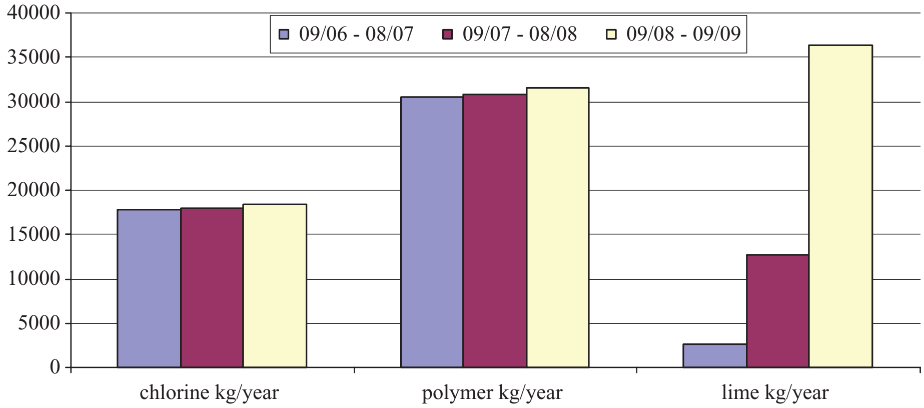

Fig. 2. Chemical consumption the last 3 years from Sep 06 to Sep 09.

with initial COD up to 186 ppm in 20°C and HRT from 1 to 5 h has 70–80% reduction in anaerobic attached-film expanded bed according to Jewell et al. [32] and Zakkour et al. [29]. Kobayashi et al. [33] mention that the efficiency of the anaerobic filter for the treatment of settled sewage with initial COD 288 ppm is 73% (T = 7.5–18°C, HRT = 24 h). Up flow anaerobic sludge bed efficiency on COD removal for raw sewage varies from 65% to 89% with initial value on COD from 322 to 948 ppm (T = 7.5–18°C, HRT = 8–24 h) according to Zakour et al. [29]. Finally the efficiency of the expanded granular sludge bed on settled sewage with initial COD up to 391 ppm on 13–19°C with HRT to be from 1 to 3.5 h is up to 16–34% [29,34].

3.2. WWTP chemical consumption

The chemical consumption of the WWTP is presented in Fig. 2. During the low tourist season in the area (November to March) the consumption of the chemicals, the consumption of electricity in kWh/month, the Flow rate (m^3), the sludge production (Table 1) are to low. February and December usually are the months with the minimum consumption every year while the months with the maximum demand in chemicals and electrical consumption are June, July and August where there is a pick in the tourist activities (foreign and locals) in the area. Comparing the three last Augusts (2007, 2008 and 2009) we observed that the total flow range from 369,599 to 382,153 m^3. During August Cypriot are make their holidays in Paralimni (with Protaras and Fig tree location) and Agia Napa are the most famous and popular place in the Island. During August the kWh/kgBOD$_5$ range from 2.06 to 2.84 presenting an increasing of 37.86% from 2007 to 2009. At the same time the demand in kWh/m^3 of Flow is 0.62–0.89 and the production of sludge is up to 800 m^3.

3.3. MSS production

Influent flow and BOD$_5$ variation and sludge production in relation with the monthly flow from 2006 to 2009 presented in Fig. 3. As it is observed from Fig. 3 the period from December to April the sludge production range from 65 to 285 m^3 month^{-1}. This period all the tourist activities are closed in the area and the people equivalence is approximately up to 22,000 max and for the two Municipalities.

VSS is at 72%, SVI varies from 104.23 to 131.06, the MLVSS from 3.65 to 3.92 mg/l and the MLSS range from 432.11 to 476.11 g/l (Table 2). A minimum of 14 d was required for optimum MLSS and MLVSS reductions. The longer the retention time, the higher the reductions achieved. For domestic (municipal) sludge's, a high reduction in settled sludge volume was observed between 14 and 21 d. Therefore, the best retention time appears to be about 17 d, just after the improvement in settle ability; at this time the filterability was still reasonable. The SVI may be monitored each day, and the supernatant removed as soon as the sludge settle ability reaches optimum. However, the retention time should not be longer than 21 d because of the risk of foam production and the decrease in filterability [35].

Sludge's resulting from wastewater treatment constitutes a valuable source of essential nutrients fro agricultural cultivation [36]. In addition, organic matter from sludge's improves some physical and chemical properties of soil, leading to better plant growth. Along with this, sludge application to soils is considered a useful method for their final disposition [36,37]. However, sludge's may contain high amounts of potentially toxic trace elements which may exceed soil natural concentration by two or more order of magnitude [36,38,39].

Table 1
Electrical consumption in relation with the monthly flow rate and sludge production

	Flow (m^3)	Sludge (m^3)	$kgBOD_5$/month	kWh/month	kWh/$kgBOD_5$
Sep-06	287,745	180	109,343	238828	2.18
Oct-06	261,249	185	85,428	201162	2.35
Nov-06	115,611	285	36,649	136421	3.72
Dec-06	88,625	275	29,867	120530	4.04
Jan-07	91,529	140	27,093	108004	3.99
Feb-07	127,576	80	37,762	96958	2.57
Mar-07	118,781	110	4,286	125908	2.98
Apr-07	160,829	175	63.45	138313	2.19
May-07	257,534	350	104,559	206027	1.97
Jun-07	295,374	505	109,879	230392	2.10
Jul-07	358,999	710	116,316	283609	2.44
Aug-07	382,153	730	115,028	236935	2.06
Total	254,6005	3,725	877,255	2123087	
Sep-07	321,263	470	88,347	237735	2.69
Oct-07	283,007	320	97,637	249046	2.55
Nov-07	125,249	570	3,749	147794	3.95
Dec-07	116,114	220	37,273	98697	2.65
Jan-08	111,568	130	35,479	92601	2.61
Feb-08	104,795	205	32,591	90124	2.77
Mar-08	117,089	150	35,127	99526	2.83
Apr-08	137,765	150	54,142	147409	2.72
May-08	243,804	245	82,406	241366	2.93
Jun-08	292,808	465	103,068	281096	2.73
Jul-08	340,078	850	110,525	258459	2.34
Aug-08	369,599	345	120,859	269807	2.23
Total	256,3139	4,120	834,903	2213659	
Sep-08	301,647	375	103,767	241318	2.33
Oct-08	273,656	315	84,286	216188	2.56
Nov-08	133,831	380	44,432	139184	3.13
Dec-08	111,979	65	40,648	104140	2.56
Jan-09	133,555	170	42,738	117528	2.75
Feb-09	111,585	130	33,810	97079	2.87
Mar-09	127,644	130	39,187	104668	2.67
Apr-09	164,812	184	57,355	130201	2.27
May-09	244,322	304	82,825	197901	2.39
Jun-09	305,829	664	99,394	266071	2.68
Jul-09	345,898	728	108,958	307849	2.83
Aug-09	373,075	816	116,772	332037	2.84
Total	2,627,833	4,261	854,172	2254165	

3.4. MSS characteristics

Table 3 presents the physicochemical characteristics of sludge from 2004 until the end of 2009 while Table 4 presents the metals concentration in sludge. The water content was 70.2%. The pH values of dry sludge sample were about 7. The EC were about 3,000 mS/cm. The total phosphorous content was found in high levels due to the fact that the main load of the treated wastes was municipal. The E4/E6 ratio shows the characterization of humic materials. As the E4/E6 ratio is bellow 5, the samples are characterized as Humic Acid (whereas if the ratio is above 5 the sample is characterized as Fulvic Acid), [20]. The C/N ratio is considered to be very low for the production of high quality final compost. The organic matter is about 50% of the VSS while the TOC is about 30%.

3.5. MSS metals, SCE, GANG test

Comparing the results with other studies [20,25] the concentrations of the examined metals in sludge (Table 4) are to low due to the fact that the WWTP does

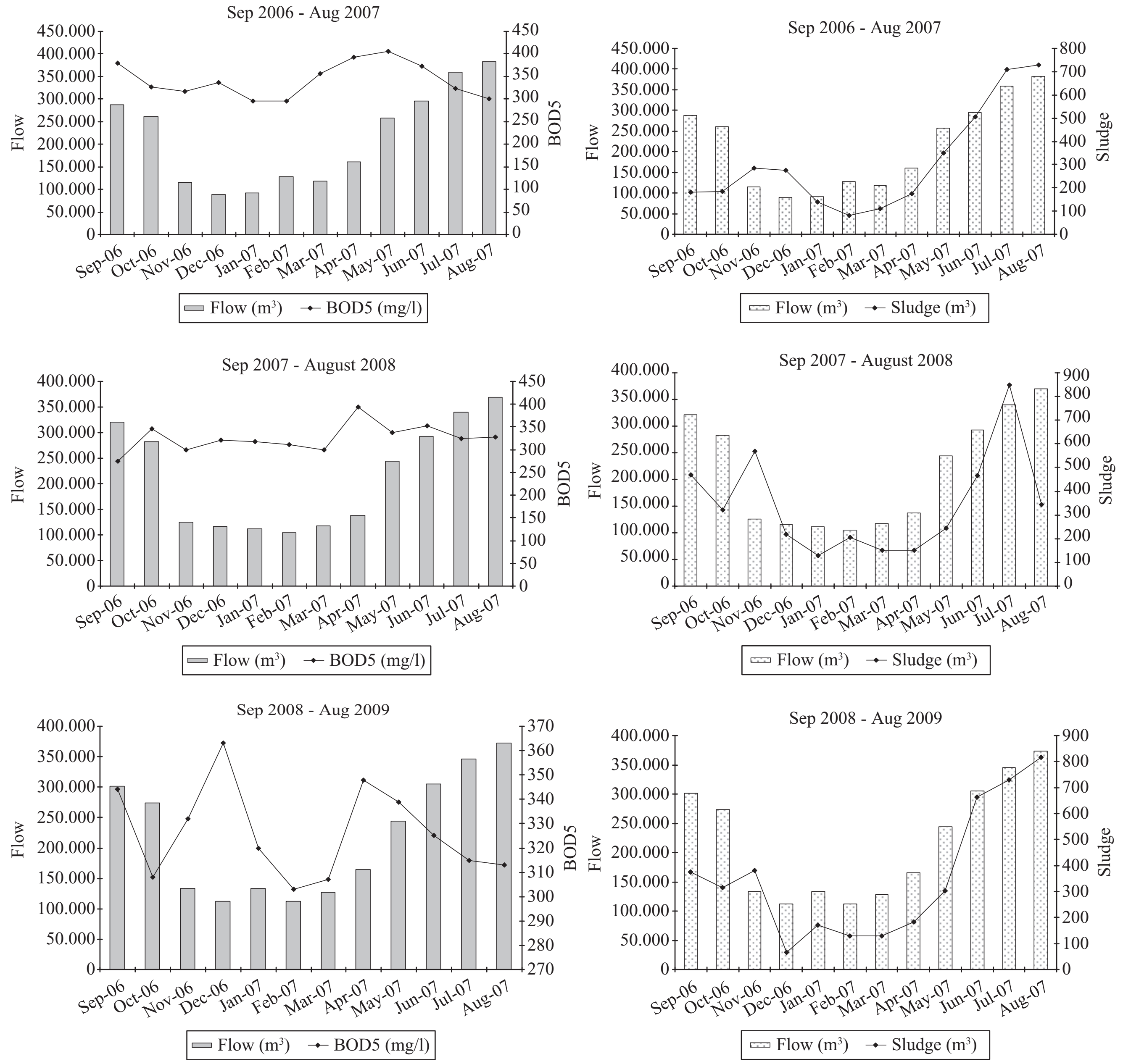

Fig. 3. Flow and BOD_5 variation and Sludge production in relation with the monthly flow from 2006to– 2009.

Table 2
MLSS, MLVSS, SVI and VSS variation

Month–Year	MLSS (ppm)	MLVSS (ppm)	SVI	VSS (%)	Monthly flow (m^3)
Sep-06–Aug-07 (Average)	457.34	3.76	120.12	71.68	212,167
Sep-06–Aug-07 (Standard Deviation)	92.12	0.64	17.16	4.12	106689.4
Sep-07–Aug-08 (Average)	432.11	3.92	104.23	73.01	213594.92
Sep-07–Aug-08 (Standard Deviation)	159.56	0.79	21.22	4.63	103814.09
Sep-08–Aug-09 (Average)	476.54	3.65	131.06	72.45	218986.08
Sep-08–Aug-09 (Standard Deviation)	71.79	0.33	14.87	5.25	98474.192

Table 3
Characteristics of MSS

Parameters	2005	2006	2007	2008	2009
Moisture (%)	85.91 ± 3.01	81.12 ± 4.25	77.32 ± 2.45	83.10 ± 2.13	78.12 ± 3.12
pH	7.23 ± 0.37	7.55 ± 0.25	7.22 ± 0.35	7.14 ± 0.21	7.19 ± 0.28
EC mS/cm (25°C)	3058 ± 138	2779 ± 201	3004 ± 176	3423 ± 198	2790 ± 166
Total phosphorous (mg/g)	55.12 ± 28.91	62.09 ± 19.25	58.96 ± 24.62	71.05 ± 34.51	67.25 ± 21.12
Organic matter % (VSS)	55.12 ± 5.12	49.63 ± 4.33	50.12 ± 6.18	49.63 ± 4.66	52.39 ± 6.09
Total organic carbon (%)	30.31 ± 3.16	27.29 ± 2.81	27.56 ± 5.42	27.30 ± 4.02	28.81 ± 3.19
Ash (%)	23.16 ± 6.41	24.79 ± 7.52	28.32 ± 5.97	26.99 ± 4.08	27.55 ± 5.08
Total Kjeldahl nitrogen (%)	6.40 ± 3.42	7.45 ± 2.06	7.25 ± 2.51	6.24 ± 1.11	6.42 ± 1.69
Humic substances (%)	2.67 ± 0.77	3.55 ± 0.55	3.98 ± 0.57	4.07 ± 0.33	4.65 ± 0.23
Humic acid (mg/g)	0.78 ± 0.13	0.81 ± 0.11	1.01 ± 0.12	1.15 ± 0.74	0.89 ± 0.26
Fulvic acid (mg/g)	15.23 ± 5.12	22.52 ± 12.31	13.69 ± 9.95	14.56 ± 4.89	17.66 ± 7.52
E4/E6	1.89 ± 0.08	1.41 ± 0.07	1.66 ± 0.09	1.59 ± 0.06	1.49 ± 0.07
Lignin (mg/g)	0.25 ± 0.06	0.36 ± 0.09	0.22 ± 0.05	0.31 ± 0.04	0.42 ± 0.09
Cellulose (mg/g)	9.58 ± 1.23	12.69 ± 3.42	11.55 ± 2.69	13.33 ± 3.11	10.59 ± 2.55
Germination index	24 ± 7	44 ± 8	39 ± 5	37 ± 11	41 ± 9
Grow index (%)	32 ± 5	39 ± 9	42 ± 5	25 ± 10	36 ± 8
Cl− (mg/g)	2.87 ± 0.58	3.14 ± 0.95	3.55 ± 0.63	2.99 ± 0.88	3.79 ± 0.46
Alkalinity ppm $CaCO_3$	0.312 ± 0.091	0.295 ± 0.101	0.284 ± 0.082	0.230 ± 0.049	0.205 ± 0.057
Salinity ppm $CaCO_3$	0.875 ± 0.214	0.524 ± 0.158	0.625 ± 0.126	0.714 ± 0.099	0.598 ± 0.129
N-NH_4^+ mg/g d.w	0.125 ± 0.008	0.203 ± 0.012	0.195 ± 0.022	0.236 ± 0.033	0.158 ± 0.055
N-NO_3^+ mg/g d.w	0.356 ± 0.089	0.402 ± 0.108	0.360 ± 0.127	0.286 ± 0.106	0.358 ± 0.149
C/N	5.06 ± 2.31	7.21 ± 3.29	5.91 ± 1.87	8.12 ± 2.87	9.21 ± 4.45
Fats and oils (mg/g)	2230 ± 324	2015 ± 295	1560 ± 198	1720 ± 223	1340 ± 125

All value in dry matter except moisture. n.d : not detected.

Table 4
Metals concentration in sludge

Metals (mg/kg dry base)	July 2003	July 2004	July 2005	July 2006	March 2007	April 2008	August 2008	August 2009	86/278/EOK for land disposal or in agricultural
Cupper (Cu)	190.2	193.7	149.0	151.1	125.1	179.4	136.5	141.9	
Iron (Fe)	8,890	7,031	6,900	7,210	4,829	4,241	6,039	7,900	1,000–1,750
Manganese (Mn)	195.9	178.4	183.7	167.3	204.7	102.1	144.9	177.3	
Zing (Zn)	345.1	355.7	390.2	384.1	407.5	356.3	309.4	287.6	
Nickel (Ni)	17.91	15.39	20.82	17.91	16.79	16.96	14.05	15.55	2,500–4,000
Boron (B)	91.6	88.4	75.5	90.4	77.98	63.6	67.9	88.9	
Cobalt (Co)	0.071	0.060	0.052	0.092	0.065	0.018	0.068	0.043	
Lead (Pb)	115.5	93.1	98.7	87.5	80.4	65.5	74.6	82.0	
Chromium (Cr)	13.01	11.32	15.92	17.01	20.71	17.81	16.08	11.01	750–1,200
Cadmium (Cd)	0.712	0.991	0.690	0.796	0.882	1.019	0.908	0.775	100–500
Calcium (Ca)	19,234	20,018	23,434	26,100	21,948	24,141	27,201	26,987	20–40
Sodium (Na)	3,020	3,315	2,688	3,001	2,698	2,734	2,996	3,030	
Potassium (K)	12,001	8,789	10,345	11,007	10,493	12,759	10,870	9,982	
Magnesium (Mg)	9,991	10,234	8,903	11,212	10,873	11,864	9,825	10,034	
Arsenic (As)	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	
Mercury (Hg)	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	
Cyanides (CN)	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	

Significant different at $p < 0.05$, n.d : not detected.

not receive any heavy wastes and the examine metals are in the limits of the specific directive for the safe discharge of the sludge.

Total concentration of heavy metals in sewage sludge indicate the decree of contamination, but give little insight into the forms in which the metals are presented, or their potential for mobility and bioavailability after dispersal in the environment [40–42]. An experimental approach commonly used for studying the mobility, transport and bioavailability of metals in sludge's is the use of sequential chemical extraction (SCE) procedures. Such techniques comprise the utilization of a series of chemical extract ants in a sequence of reagents of increasing harshness. The GANG test results, presented in Figs. 4 and 5, showed that by increasing the leach ate pH, the heavy metals concentration in leachates were decreased. It was observed that at pH greater than 5 the metal amount in leachate was decreased. This phenomenon can be explained by the fact that the metal load was not bound to the exchangeable and carbonate fractions (Fig. 6). The bioavailability and eco-toxicity of metals mainly depends on their speciation in sludge (Fig. 6). Heavy metals that are distributed in exchangeable and carbonate fraction (most mobile forms) and reducible fraction are readily to be absorbed in plants or in water system causing pollution [43]. So, these fractions should be identified as direct effect fraction. As it is observed the metal extraction from those fraction are to limited and no significant problems can be recognized. The heavy metal bound to residual and organic fraction is often considered ''un-reactive'' [43], and not affected by environment changes, is identified as stable fraction.

4. Discussion

Wastewater treatment systems have been designed to minimize the environmental impacts of discharging untreated wastewater. Different options for wastewater treatment have different performance characteristics and also different direct impacts on the environment. Some systems have high energy usage, some use materials that have a high embodied energy (e.g., plastics) others occupy a lot of land [44]. The objective of sewage treatment is to produce a disposable effluent without causing harm or trouble to the communities and prevent pollution. Biosolids, the treated form of sewage sludge, have been in use in UK and European agriculture for more than 80 years, though there is increasing pressure to stop the practice of land application. In the 1990s there was pressure in some European countries to ban the use of sewage sludge as a fertilizer. Switzerland, Sweden, Austria, and others introduced a ban. Since the 1960s there has been cooperative activity with industry to reduce the inputs of persistent substances from factories. This has been very successful and, for example, the content of cadmium in sewage sludge in major European cities is now only 1% of what it was in 1970. European legislation on dangerous substances has eliminated the production and marketing of some substances that have been of historic concern such as persistent organic micro pollutants. The European Commission has said repeatedly that the ''Directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture'' (86/278/EEC) [45] has been very successful in that there have been no cases of adverse effect where it has been applied. The EC encourages the use of sewage sludge in agriculture because it conserves organic matter and completes nutrient cycles. Recycling of phosphate is regarded as especially important because the phosphate industry predicts that at the current rate of extraction the economic reserves will be exhausted in 100 or at most 250 years. The problems dealing with sewage sludge are complex because it is largely constituted of those substances responsible for the offensive character of untreated wastewater [46]. Besides the potentially hazardous materials, however, sludge also contains valuable materials. To identify potential alternatives for a sustainable treatment, it is useful to evaluate the composition of the sludge. This composition can be roughly characterized by five groups of components, which are present in the sludge:

- Non-toxic organic carbon compounds, Kjeldahl-N, phosphorus containing components;
- Toxic pollutants:
  - Heavy metals, such as Zn, Pb, Cu, Cr, Ni, Cd, Hg, As (varying from more than 1,000 ppm to less than 1 ppm);
  - PCBs, PAHs, dioxins, pesticides, endocrine disrupters, linearalkyl-sulfonates, nonyl-phenols.
- Pathogens and other microbiological pollutants;
- Inorganic compounds such as silicates, aluminates, calcium and magnesium containing compounds;
- Water, varying from a few percent to more than ninety five percent.

Nitrogen, phosphorus, and organic carbon containing compounds can be considered as valuable compounds, as well as some inorganic compounds. A sustainable treatment includes the recovery and useful reuse of the valuable products and the minimization of the possible adverse environmental and human impact of sewage sludge. The management of the solids and concentrated contaminants present in the sludge is still one of the most difficult and expensive problems in the field of wastewater engineering.

The domestic wastewater from the Beer Sheva, Israel, presents according to the Kaplan et al. [47] the following concentration of the examined metals; 224.2 μg/l of Zn, 2 μg/l of Cd, 53 μg/l of Pb and 34.3 μg/l of Cu. Primary-treated wastewater produced by the two plants was in Alexandria, Egypt (Egypt has

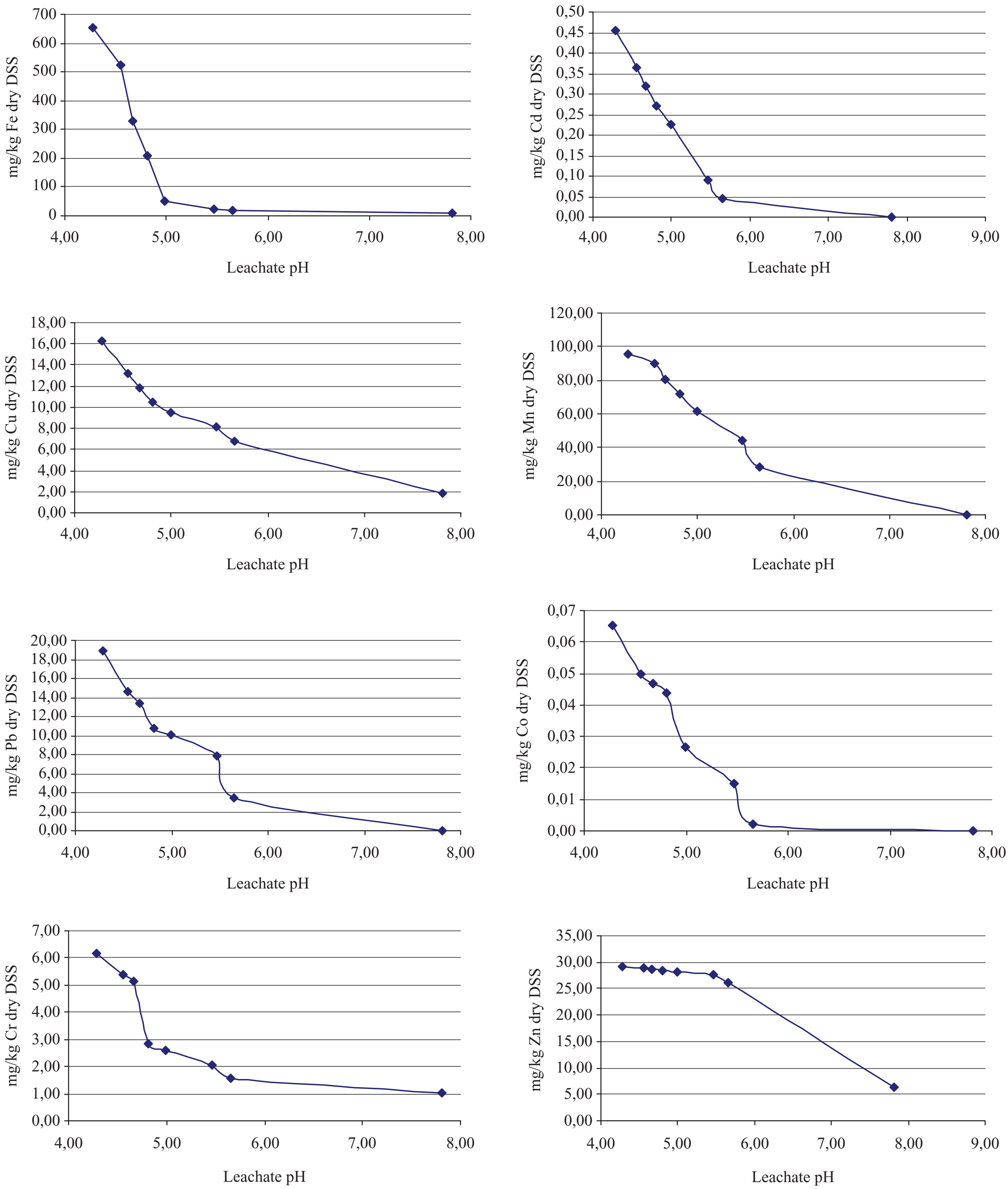

Fig. 4. GANG heavy metals releases to leachates from MSS as a function of pH of leach ate.

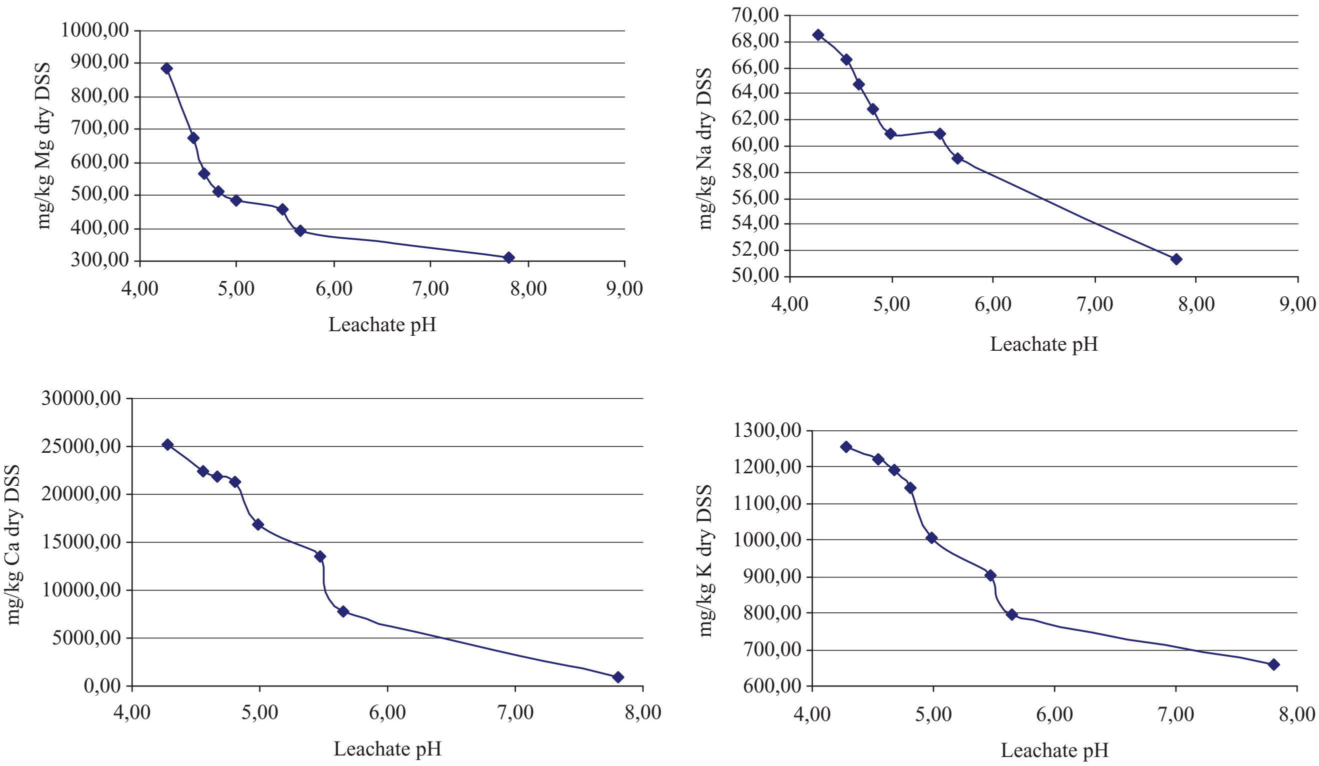

Fig. 5. GANG trace elements releases to leachates from MSS as a function of pH of leach ate.

two primary treatment plants, the eastern and the western wastewater treatment plants – EWTP and WWTP – that receive mixed domestic – industrial influents) presented the following characteristics : BOD5, COD, TSS, TDS, FOG, Zn, and Cu recorded averages of 155, 380, 184, 1250, 22, 0.1779 and 0.0577 mg/l, respectively, in the primary-treated wastewater of the EWTP. Significantly higher levels for almost all the tested parameters were detected in the WWTP effluent especially organic content, solids and oil and grease where 280, 519, 435, 1,609, 32 mg/l were recorded as average levels for BOD_5, COD, TSS, TDS and FOG, respectively. This is mainly attributed to the fact that WWTP serves wider sectors of Alexandria and overloaded with much more quantities of industrial effluents from Alexandria West where more than 80% of industrial activities centralized. However, Zn recorded much lower average in the WWTP effluent (0.0564 mg/l) compared to that of the EWTP (0.1779 mg/l) while no significant differences were recorded in the Cu levels among the two plants (0.0528 and 0.0577 mg/l in the WWTP and EWTP effluents) [48].

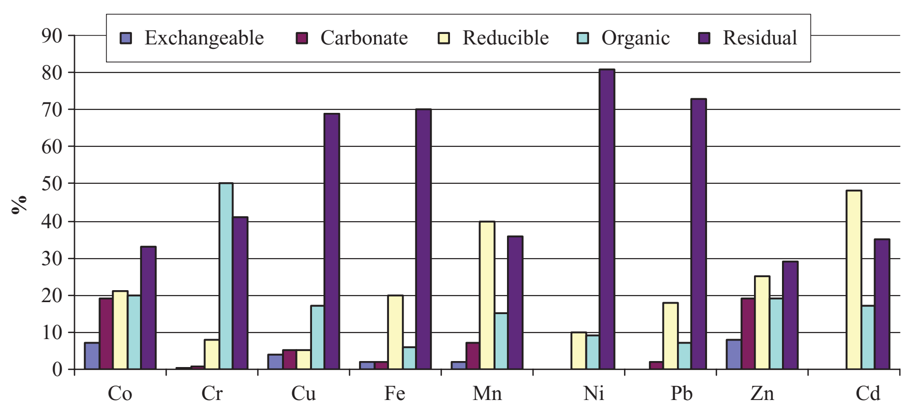

Fig. 6. Metals partitioning in MSS

Psittalias waste water treatment plant (municipal and industrial waste) which is the biggest in the greater area of Athens (Greece) the heavy metals concentration on sludge [11,21] is (in mg/g dry bases): 0.002 for Cd, 0.563 for Co, 0.552 for Cr, 0.258 for Cu, 5.089 for Fe, 0.150 for Mn, 0.041 for Ni, 0.326 for Pb, 1.739 for Zn. Zorpas et al. [31] mention that the concentration of metals in mg/g dry base from Komotinis WWTP (Greece, mainly municipal waste) was 0.044 for Cr, 0.040 for Cu, 7.760 for Fe, 0.218 for Mn, 0.750 for Mg, 0.864 for Zn, 0.050 for Ni, 0.139 for Pb, 14.50 for Ca, 2.36 for K, 1.16 for Na. Also the same researcher [31] mention that the metal concentration in mg/g dry base in sewage sludge from the Metorphosis WWTP in Athens (Greece mainly municipal waste) is 0.210 for Cr, 0.282 for Cu, 11.048 for Fe, 0.141 for Ni, 0.275 for Pb and 1.193 for Zn. During 1993 Savvides [24] mention that the sewage sludge from the WWTP of Limasol (Cyprus, treat only municipal waste) in mg/g dry samples was 0.090 for Cr, 0.060 for Cu, 5.56 for Fe, 1.760 for Ni, 0.050 for Pb, 0.40 for Zn. Carmen et al. [49] presents the following concentration from sewage sludge from Spain WWTP, in mg/kg dry mater: K is at 1527.0, Fe at 13.67, Cd at 0.030, Cr at 0.10, Cu at 7.62, Mn at 6.54, Ni at 1.26, Pb at 0.50 and Zn at 26.64. Samples of sewage sludge were taken from Beixiaohe Waste Water Treatment Plant, located at Haidian District of Beijing City, where activated sludge process is used to treat sewage. The raw sludge is characterized by metal contents of 154; 1280; 88.0; 61.4; 15.6; 469 mg kg^{-1} (dry matter) respectively for Cu, Zn, Pb, Ni, Cd and Cr according to Liu et al. [9]. Land application of sewage sludge (biosolids) has been a worldwide agricultural practice for many years [50]. Land application of sewage sludge has been extensively used as an effective dispersive method throughout Canada, the United States and Europe for more than 40 years. Many studies have demonstrated the positive effect of land application of sewage sludge or sludge compost on corn and forage yields and soils [6,11,51–54]. It effectively disposes of a 'waste' product while recycling valuable nutrients into the soil-plant ecosystem; however, too often the dispersal has created environmental problems that force government agencies to restrict the amount and type of sewage sludge which can be land applied.

5. Conclusions

Urban wastewater systems, having sewer system, wastewater treatment plant and receiving water as their main elements, can be found throughout the world. The present paper (as there is a very limited work on the subject) deals with the operation description and characterization of the MSS and the efficiency of the WWTP of the Municipality of Paralimni - Agia Napa in the eastern of Cyprus. The area presented with a long period of warm and high temperature conditions (>27°C, and during summer >32°C). The average monthly flow of Influent varies from 88,625 to 382,153 m^3.

The sludge almost 4,200 t/y does not present with significant consecration of heavy metals. However, the sewage sludge contains high concentration of organics and phosphorus and with father treatment like composting may be used in agriculture purposes. MSS presented with no significant ($p < 0.05$) concentration of heavy metals but presented with low concentration of humics, lignin, cellulose, and the Germination Index (G.I) are to low. Comparing the results with others the concentrations of the examined metals in sludge are to low due to the fact that the WWTP does not receive any heavy wastes and the examine metals are in the limits of the specific directive for the safe discharge of the sludge. Although the concentrations of metals are to low the application of the GANG procedure indicated that by increasing the leach ate pH, the heavy metal concentration decreases. The sequential extraction results showed that the metals are associated with inert forms.

The WWTP efficiency is more than 98.5% for the BOD_5, 90% for COD, 95% for SS, 70% for TN, 99% for NH_4, while the TP efficiency rang from 15.17% to 99.12%. The total kWh/kgBOD_5/month is from 1.97 to 3.13, while the total kWh/m^3 of waste range from 0.62 to 1.36. The yearly chemical consumption (chlorine, polymer, lime) depends at the end from the season.

Land filling is the main disposal route for sewage sludge at present in Cyprus. On the other hand, land filling generates potential environmental hazards, including the production of odor and methane gas, as well as contamination of groundwater by leach ate. A possible solution for the treatment of sewage sludge may be the composting due to the fact is clear and there in no any negative elements or may be the incineration to produced energy (a waste to energy concept).

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