Original paper

Clean Techn Environ Policy 6 (2004) 128–137
DOI 10.1007/s10098-003-0228-5

Potential use of treated wastewater and sludge in the agricultural sector of the Gaza Strip

B. H. Shomar, G. Müller, A. Yahya

Abstract Twelve elements (Ag, Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) were analyzed in 120 composite samples of influent and effluent wastewater; the results revealed that domestic wastewater influent contains considerable amounts of heavy metals and the partially functional treatment plants of Gaza are able to remove 40–70% of most metals during the treatment process. Heavy metals in 31 industrial wastewater effluents are within the ranges of international standards. All industries of Gaza are light; although they have no treatment facilities, their effluents are being discharged to municipal sewerage system and the existing treatment plants are capable of absorbing the industrial effluents with no significant impact on treatment bioprocesses.

Thirty parameters were determined in 35 sludge samples: P, AOX, C, S, $CaCO_3$, Mg, Ca, Na, K, Li, Cu, Zn, Ni, Pb, Mn, Fe, Cr, Co, Cd, As, Hg, Ti, Se, Br, Rb, Th, Sr, Y, U, and Zr. Although there are no treatment facilities for sludge within the treatment plants, the results indicated that sludge in general is clean of heavy metals. Only Zinc and AOX showed anomalous concentrations; more than 85% of sludge samples showed that averages of zinc and AOX are 2,000 mg/kg and 550 mg Cl/kg, respectively, which exceed the standards of all industrial countries for sludge to be used in land application.

Introduction

The arid and semi-arid nature of the region renders it a water scarce region. Population growth, and agricultural and industrial development have put more pressure on the existing scarce resources. They are currently being exploited to their maximum capacity to meet the desired development. As a result, a lot of environmental problems have started to arise at all places and levels. Such problems will be more acute in the near future if the current resource utilization patterns continue. Therefore there is an essential need to start looking at the different options and mechanisms that will help overcome these escalating environmental problems.

Lack of wastewater management has a direct impact on problems related to public health, marine and coastal pollution, deterioration of nature and biodiversity, as well as landscape and aesthetic distortion in the Gaza Strip (Ministry of Environmental Affairs 2000) Currently, about 60–80% of the domestic wastewater is discharged into the environment without treatment, either directly at the source, after collection from cesspits, or through the effluent of the sewer system or the overloaded treatment plants (Ministry of Environmental Affairs 2000). Assuming that 60% of the water used for domestic usage comes back as wastewater, Gaza produces about 13 MCM annually (Coastal Aquifer Management Program 2000). About 40% (50,000 m^3/day) of the wastewater that is generated in Gaza is currently discharged into the sea; a minor part infiltrates into the soil and contaminates the groundwater.

Compared to the neighboring countries, the industrial sector in Palestine is presently rather underdeveloped. Most industries are concentrated in the city of Gaza and in the northern areas, grouped in two main industrial estates, Gaza Industrial Estate (GIE) and smaller Beit Hanoun Industrial Estate (BIE). Several industries are scattered among residential areas. The industries of greatest concern are the food industry, chemical industry, tanning industry, textile industry, and the electroplating and metal finishing industry. Industries in Gaza are light and each has 5 to 100 individuals (Shomar 1999). Heavy metals may inhibit the activities of microorganisms within the treatment process. Regulated metals include barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, zinc and arsenic (Edwards 1995). Industrial wastewater requires onsite pretreatment before it can be disposed of into the municipal sewage network to guarantee the stability of domestic wastewater treatment plants (Safi 1999). Because heavy metals cannot be degraded in the wastewater treatment plant, either they end up in the treatment plant sludge or they pass through the plant and leave with the effluent.

Up to now there has been very little production of sludge as all existing wastewater treatment plants are deficient and operating with old technologies. The construction of new wastewater treatment plants or the

Received: 16 December 2002 / Accepted: 14 May 2003
Published online: 15 July 2003

B. H. Shomar (✉), G. Müller, A. Yahya
Institute of Environmental Geochemistry, University of Heidelberg, Im Neuenheimer Feld 236, 69120 Heidelberg, Germany
E-mail: bshomar@ugc.uni-heidelberg.de
Tel.: + 49 6221 546031
Fax: + 49 6221 545228

This research was funded by Bundesministerium für Bildung und Forschung-BMBF, Germany through a project called Monitoring of Groundwater and soil pollution levels in Gaza Strip. The authors would like to acknowledge Prof. Dr. W. Shotyk for his critical reading and comments on the manuscript.

rehabilitation of the existing ones in Gaza will produce a regular daily volume of sludge that will need to be disposed of in landfill sites, incinerated, ocean dumped, composted or applied to agricultural lands (Palestinian Environmental Protection Authority 1994). Sludge treatment facilities are almost absent and the sludge produced is removed from the ponds and left to be dried, partially depending on the season and the available area close to the treatment plant (Palestinian Water Authority 1999). Sludge production is a function of the biological oxygen demand (BOD_5) removal rate (EPA 1999). It is assumed that the minimum sludge production should correspond to a BOD removal rate of 95% (effluent at 30 mg O_2/l) for some treatment plants in Gaza. Next to the available data of the PWA, the field visits confirmed that the amount of sludge that Gaza wastewater treatment plants produce is low. The solids content is within the range of 16 and 22% which categorize the Gaza sludge as a dewatered sludge, although dewatered sludges have as much as 40% solids.

To guarantee and safeguard hygienic standards and have no adverse effects on human health, environmental quality must be given the highest priority. Although opponents of sludge use have many reservations, one of their main concerns is the long-term buildup of heavy metals in the soil (Zufiaurre et al. 1998). Over time, metals such as cadmium, zinc, and copper could build up to levels high enough to damage agricultural soils (EPA 1999). Although the use of sludge on agricultural land is largely dictated by nutrient content (N and P), the accumulation of potentially toxic elements in sewage sludge is an important aspect of sludge quality, which should be considered in terms of long-term sustainable use of sludge on land (Burica et al. 1996). The most important nutrients in the sludge are nitrogen, phosphorus, and potassium. Other nutrients that may be present include calcium, magnesium, sulfur and they add copper even though it is considered as a heavy metal (Alloway and Jackson 1991). According to the American standards of sludge used in agriculture, the average concentration of N and P in dry weight is 2% and <1% respectively; while the total solids are 3.4% (EPA 2002). Although sludge is a valuable source of plant nutrients, the nutrient concentrations are significantly lower than most commercial fertilizers (Sterritt and Lester 1980). It has been suggested that determination of adsorbable organic halogens (AOX) be used as an indicator for these priority substances. Moreover, AOX determination is a relatively easy technique to use. Because AOX is an analytical parameter and represents a wide range of substances, differing not only in their chemical structure but also in their toxicological profile, a description of relevant toxicological endpoints cannot be given (Planquart et al. 1999).

The main objective of this study is to introduce the concentration of trace metals and some major parameters in domestic, industrial wastewater and sludge for the first time. Moreover, it tries to highlight the various options that aim to reuse the treated wastewater and sludge in the Gaza Strip in a manner that will ensure agriculturally sustainable development.

Materials and methods

The study area

There are, at the present time, four wastewater treatment plants that are either being planned, under construction or in operation. The two main operating treatment plants are: the Beit Lahia Wastewater Treatment Plant in the northern area of Gaza and the Gaza Wastewater Treatment Plant in the region of Gaza City (Fig. 1), but none is working properly. The monitoring program on wastewater of the two treatment plants is conducted by the Palestinian Water Authority (PWA) and only a few parameters (pH, solids, BOD, and COD) are recorded in a regular basis.

Beit Lahia (Northern) wastewater treatment plant

The Beit Lahia Wastewater Treatment Plant, located some 1.5 km east of the town of Beit Lahia in the northern part of the Gaza Strip, was erected in stages, commencing in 1976. It serves the town of Jabalia, as well as the nearby refugee camp and the communities of Beit Lahia and Beit Hanoun. The population in the area amounts to about 150,000 people today. But, depending on an exceptionally high natural rate of growth, the population could rise to 260,000 in the year 2010 and reach over 350,000 people in the year 2020, according to the official forecasts. That means a doubling of the population in a period of 20 years (Palestinian Central Bureau of Statistics 2000). The existing plant consists of several ponds disposed in two lines, the first two ponds of each line being aerated, and with possibilities of interconnection. The plant has no pretreatment facilities and it is designed for a peak flow of 2,600 m^3/h. The plant is located in a depression without natural outlet to the sea, although it does not lie so far (4.5 km) from it. The effluent merely overflows from the last pond of the works, spreading in a large sand dune area in the immediate vicinity of the plant, where it infiltrates to groundwater. The plant faces major operation problems, such as: no preliminary treatment; presence of sand; BOD of over 600 mg O_2/l; an overflow of used water; and the pumping station is out of operation.

The average sludge production at the Beit Lahia WWTP can be estimated to be on average 8.5 tons total solids per day in the year 2010, i.e. approximately 28 m^3/day.

Gaza Wastewater Treatment Plant

This plant was originally constructed in 1977 as a two-pond treatment system. In 1986, it was expanded to a capacity of 12,000 m^3/day with the construction of two additional ponds. A project in 1994 rehabilitated the plant without capacity increase. In 1999, with USAID funding, the plant was expanded to a capacity of 32,000 m^3/day and consisted of anaerobic ponds, an aerated pond, biotowers, an effluent polishing pond, disinfection, effluent pump station/force main and sludge drying beds. The current flow to the plant is about 42,000 m^3/day from Gaza City and parts of Jabalia. The sludge produced in this plant is exposed to the sun and then accumulated and transferred to dumping sites. The plant is close to less urbanized areas

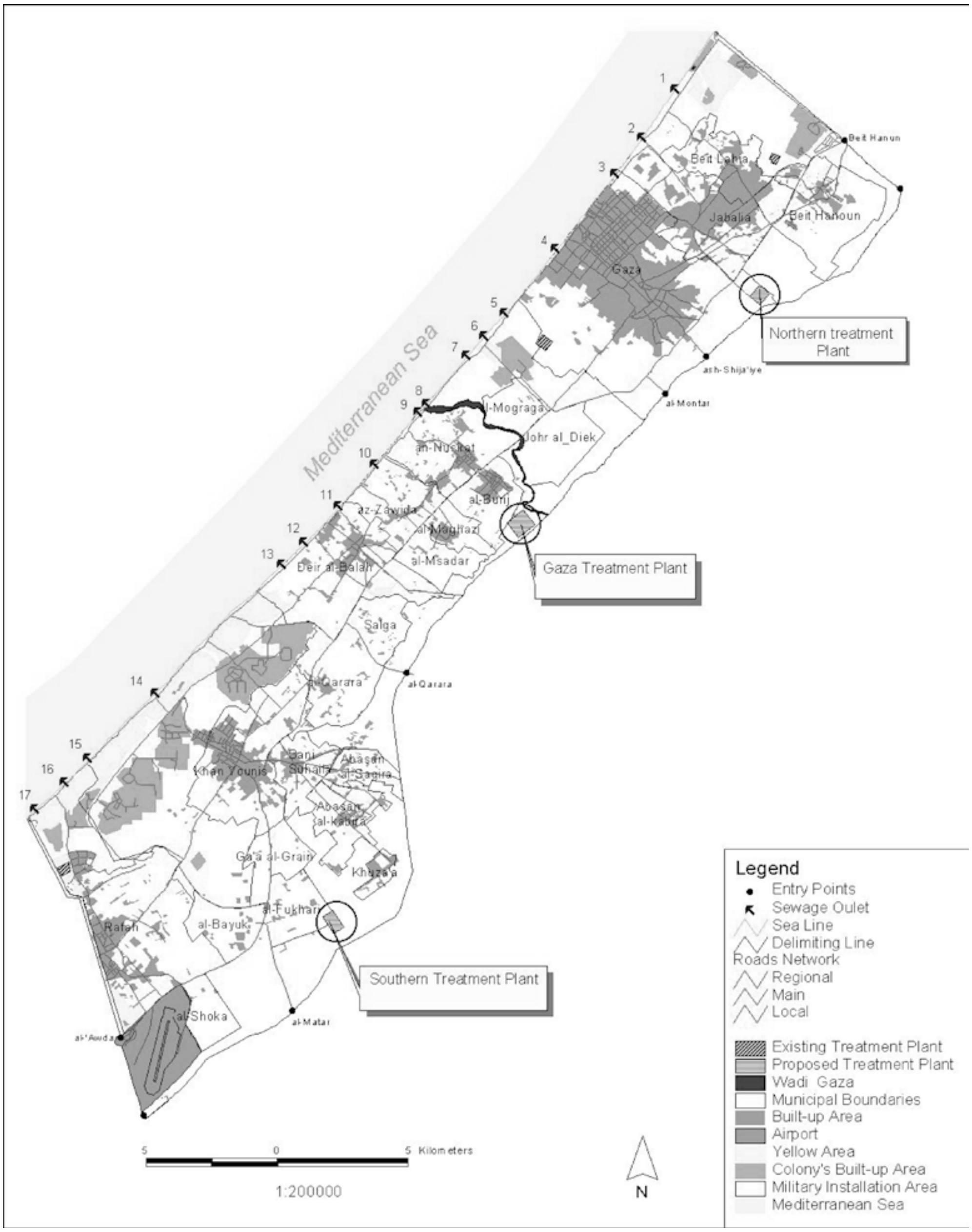

Fig. 1. Existing and proposed wastewater treatment plants and sewage outlets to the sea in the Gaza Strip

and closer to agricultural areas to facilitate the distribution of reused water to farmers.

Industries

The major industries were selected to represent all industrial activities in the Gaza Strip (Tables 4, 5 and 6). Among 31 industries, 20 are located in the two major industrial estates, Gaza and Beit Hanoun. The other 11 industries are scattered among residential areas especially in Gaza, Jabalia and few in Khan Yunis.

The sampling and analysis

Domestic wastewater

The continuous presence of a trained guard in each wastewater treatment plant made the sampling campaigns easier, especially because his mandates are to protect the plant and to collect samples for the routine monitoring program of the PWA. Three sampling campaigns have been conducted in 3 years (20 influent and 20 effluent samples each year) in the periods 20 November–12 December 2000, 26 June–17 July 2001 and 25 April–17 May 2002.

A series of grab samples (8–10) were taken over 1 day (1 l per 2 h), starting from 6:00 am, and combined in a container to form a composite sample. Finally, 1 l of the mixture was taken in an acid-washed bottle and transferred to the laboratory, and was then filtered in an acid-washed filter holder and through a 0.45-μm Sartorius filter. The first few milliliters were used for rinsing, then they were discarded, and the filtrate was transferred to clean acid-washed polyethylene bottles and acidified with concentrated nitric acid (Ultrapur, Merck, v/v), and stored at

4°C until analyses by the ICP/MS (Perkin Elmer-Sciex, Elan 6000) were performed; the other part of wastewater was filtered with no additives and stored at 4 °C for anion analyses by ion chromatography (IC DIONEX DX-120). Several parameters were measured during the fieldwork: temperature, electrical conductivity and pH, other parameters (SS, TSS, TDS, COD and BOD_5) were measured a few hours later according to the American standard methods (APHA 1995).

Industrial wastewater

The samples were taken from the effluent wastewater of the existing operating industries in Gaza, and they were collected in the same periods as the domestic wastewater. Although the situation in Gaza was very difficult, the sampling program went smoothly, and all but three of the industries that were initially selected were sampled, as listed in Tables 4, 5 and 6. In coordination with the staff of monitoring and inspection of the Palestinian Ministry of Environment, 31 composite samples were collected (10 in the first year, 21 in the following two years). They had the same treatment and analysis as the domestic wastewater samples.

Sludge

Thirty-five sewage sludge samples were collected during the campaigns, 5, 20 and 10 in the 3 years. Samples of sludge were collected in polyethylene containers from the different drying lagoons of the two treatment plants and from the accumulated piles in the surrounding areas. After collection, samples were freeze-dried until complete dryness; then they were ground and homogenized in an agate mortar and sieved through a mesh of 63-mm pore size.

About 0.5 to 1.0 g of the homogenized sample were dissolved in 10.5 ml of concentrated hydrochloric acid (37% p.a.) and 3.5 ml of concentrated nitric acid (65% p.a.) in 50 ml retorts. The samples were allowed to degas (12 h). Then all samples were heated to 160 °C on a sand bath until a complete extraction had taken place (3 h). After cooling, the solutions were diluted with distilled water in 50-ml volumetric flasks and kept in 100-ml polyethylene bottles for analysis. Heavy metals were analyzed by two different techniques: flame atomic absorption spectrometry (AAS vario 6- analytikjena) was used for determination of Mg, Li, Ca, K, Na, Cu, Zn, Ni, Pb, Mn, Fe, Cr, Co, Cd and As; an energy-dispersive miniprobe multielement analyzer (EMMA) for direct analysis was used for K, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Y, Zr, Pb, Th and U (Cheburkin and Shotyk 1996). The distribution of total phosphorus represented as (PO_4) was measured for all sampling stations (APHA 1995). Mercury concentrations were determined using atomic absorption spectroscopy after thermal combustion of the freeze dried samples (50–100 mg) and Hg pre-concentration on a single gold trap by means of an advanced mercury analyzer (AMA) 254 solid phase Hg-Analyzer (LECO). The total carbon and sulfur contents were determined directly in dried samples by using a carbon–sulfur determinator (Leco CS-225). Carbonates were measured directly via a carbonate bomb (Müller and Gastner 1971). The TOC can be calculated by the subtraction of inorganic carbon from total carbon. AOX was determined using a Euroglas Organic Halogen Analyzery—Netherlands according to the DIN 38414 S18 Deutsche Einheitsverfahren zur Wasser, Abwasser und Schlammuntersuchung, Sludge and Sediment (Group S) Determination of AOX (DIN 1989).

Quality control

For quality control, analytical blanks and two samples with known concentrations of heavy metals were prepared and analyzed using the same procedures and reagents. For wastewater analysis, Standard Reference Material 1643c was used for determination of trace elements (NIST 1991). For sludge samples, the accuracy was evaluated by two Sewage Sludge Standard Reference Materials (DIN 1997). As an independent check on the trace element measurements of the sludge, these were also measured in solid samples using the energy-dispersive miniprobe multielement analyzer EMMA-XRF (REF). As a boundary and a reference of the expected results, about nine international standards of heavy metals in domestic wastewater, industrial wastewater and sludge were chosen (Table 1).

Results and discussion

Domestic Wastewater

In a 2-week monitoring of general parameters, the performance of the two plants was recorded (Table 2), while the performance of the plants with respect to the heavy metals in 3 years is shown in Table 3. The general parameters indicated that the two plants under the existing treatment facilities were working well and they were able to remove >92%, >88%, >60% of BOD_5, COD and both total P and total N, respectively.

The heavy metal removal was not constant due to the many factors affecting the treatment process. A good example was the shortage in aerator performance, and this affected the oxygen contents in the aeration lagoons and the latter affected the form of the metals and their solubility; this could explain the maximum and minimum variations of some parameters sensitive to dissolved oxygen such as Fe, Mn and As. The results indicated that the concentrations of major anions (Cl, F, NO_3 and SO_4) and major cations (Na, Ca, Mg and K) in wastewater were similar to their values in the groundwater of the area of each treatment plant. Many metals have a high affinity to react with anions and this affects their mobility within the treatment process and their final contents in effluent and sludge. Anomalous results of some elements indicated that their concentrations in the effluent were higher than those in the influent; despite the fact that there is no clear explanation, it is assumed that the accumulation of these elements in water has occurred in the final sedimentation lagoons of each plant. There was no steady state behavior of each element in the 3 years of monitoring; the same phenomenon appeared independently for each treatment plant. On the other hand; major indicating parameters (BOD_5, COD and TSS) were removed to the maximum and all tested heavy metals in the effluent complied with different standards.

All tested elements showed similar concentrations in the influent in the 3 years monitored and no significant

Table 1. Standards of heavy metals in wastewater and sludge

Element	Domestic wastewater[a] (mg/l)			Industrial wastewater[b] (mg/l)		Sewage sludge[c] (mg/kg)		
	EPA[d]	China[e]	Ayers and Westcot[f]	WHO[g]	Jordan[h]	USA[i]	Germany[j]	France[k]
Ag				0.03	1			
Al			5					
As	0.05	0.05	0.1		0.05	41		
Cd	20	0.005	0.01		0.01	39	1.5	2
Co	2		0.05					
Cr	5	0.1	0.1	5	0.05	1200	100	150
Cu	0.2	1	0.2	1	1	1500	60	100
Fe			5					
Mn	10		0.2		1			
Ni	0.2		0.2	1	0.1	420	50	50
Pb	0.05	0.1	5	0.1	0.1	300	100	100
Zn	2	2	2	5	15	2800	200	300
Hg		0.001			0.001	17	1	1

[a]Standards for reuse
[b]Standards for discharging into municipal sewerage system and to the environment
[c]Limit values for heavy metals in sludge for use in agriculture
[d]EPA (1999)
[e]China National Regulations for Agricultural Irrigation (1992)
[f]Ayres and Westcot (1985)
[g]WHO (1986)
[h]Ministry of Municipal and Rural Affairs and the Environment, Jordan (1991)
[i]EPA (2002)
[j]ICON (2001) and McGrath (1995)
[k]McGrath (1995)

Table 2. Performance of wastewater treatment plants in the Gaza Strip (4–19 July 2001)

Parameter[a]	German standards	Beit Lahia WWTP[b] influent	Beit Lahia WWTP effluent	Removal (%)	Gaza WWTP influent	Gaza WWTP effluent	Removal (%)
pH		7.04	7.43	−6	7.5	7.7	−3
Temperature (°C)		22.3	22.3	0	25.5	26	−2
Settleable solids SS (Ml/l)		6	0.1	98	9	0.1	99
Total dissolved solids (TDS) mg/l		895	1007	−13	1470	1536	−4
Total suspended solids (TSS) mg/l		1288	1024	20	440	20	95
Chloride (mg/l)		270	250		555	480	
Fluoride (mg/l)		0.6	0.6		1.2	1.4	
Sulfate (mg/l)		242	250		314	320	
Total P (mg/l)	2	15	6	60	23	9	61
Total N (mg/l)	18	17	6	65	19	7	63
NO_2 (mg/l)		63	16	75	71	20	72
NH_4-N (mg/l)	10	64.4	61.4	5	62	60	3
COD (mg O_2/l)	110	884	108	88	940	89	91
BOD_5 (mg O_2/l)	25	420	35	92	520	25	95

[a]Average value of each parameter
[b]WWTP: wastewater treatment plant

difference was observed between the values of both treatment plants; the effluents showed a similar situation; only Ag showed anomalous results in the influent of 2000 and 2002 for the Beit Lahia treatment plant. The wastewater effluent had good characteristics close to the guidelines and standards of many developed countries (Table 1), and in general the results revealed that there was no significant difference between the performances of the two treatment plants in terms of heavy metal removal (Fig. 2). Moreover, the wastewater effluent of the two treatment plants was suitable for all purposes and applications such as agriculture and industry. Generally the results showed that heavy metals in the effluent are low and they comply with the standards of reused wastewater in agriculture.

Industrial wastewater

From the field surveys, it was found that the industrial wastewater was disposed of to the municipal sewage system when the latter was present, or to septic tanks constructed for each industry, or directly to the surrounding areas, which are in some cases wadies. Treatment processes were almost absent, and in the best case they were very simple, represented by sediment tanks. There was no periodic inspection, and if present there were no scientific rules regarding the discharge standards or quality control. Tables 4, 5, and 6 show the heavy metals in the effluent of 31 industries. The tables confirm important conclusions: unlike the domestic wastewaters, it is very difficult to generalize about the industrial wastewaters; the characteristics of the industrial wastes vary not only with the type

Table 3. Average concentrations of heavy metals in influent and effluent wastewater

	LD[a]	Inf 2000	Eff 2000	Inf 2001	Eff 2001	Inf 2002	Eff 2002
Beit Lahia wastewater treatment plant							
Ag (µg/l)	0.5	0.7	0.6	NM[b]	NM	7.3	1.3
Al (µg/l)	25	73	39	NM	NM	138	44
As (µg/l)	5	5.6	5.1	0.7	0.6	5.5	5.4
Cd (µg/l)	0.5	<0.5	0.8	0.1	<0.5	<0.5	1.3
Co (µg/l)	0.3	0.3	0.8	NM	NM	0.6	0.8
Cr (µg/l)	2.5	38.9	7.6	25.3	2.9	25.2	8.4
Cu (µg/l)	1	6.0	6.7	2.5	2.7	8.5	5.1
Fe (µg/l)	15	373	114	344	76	356	347
Mn (µg/l)	1	120	96	116	47	142	139
Ni (µg/l)	0.5	21.9	11.8	NM	NM	13.1	12.1
Pb (µg/l)	2.5	2.6	<2.5	2.9	<2.5	2.7	<2.5
Zn (µg/l)	10	120	35	105	29	87	59
Gaza wastewater treatment plant							
Ag (µg/l)	0.5	0.8	0.8	NM	NM	0.7	1.0
Al (µg/l)	25	71	61	NM	NM	89	278
As (µg/l)	5	6.6	7.0	0.4	1.1	7.8	8.4
Cd (µg/l)	0.5	0.5	<0.5	0.1	0.1	0.5	<0.5
Co (µg/l)	0.3	0.4	0.7	NM	NM	0.5	0.9
Cr (µg/l)	2.5	11.3	4.8	7.0	2.6	11.3	5.9
Cu (µg/l)	1	7.0	7.0	4.3	3.2	6.9	7.5
Fe (µg/l)	15	137	132	163	121	198	202
Mn (µg/l)	1	76	68	303	103	70	52
Ni (µg/l)	0.5	5.5	6.8	NM	NM	5.4	7.1
Pb (µg/l)	2.5	2.6	2.6	2.5	<2.5	3.3	<2.5
Zn (µg/l)	10	75	54	61	41	92	56

[a]Limit of detection
[b]NM: not measured

of industry, but also from plant to plant, due to differences in manufacturing processes and, to a lesser degree, the quality of the original raw water used. Under the worst-case scenario of the industrial wastewater production in terms of quality and quantity, the treatment plants are able to absorb all amounts of pollutants and the final effluent is considered clean for agriculture and other reuse applications.

Sludge

Table 7 summarizes the statistical analysis of sludge quality and the average value is considered to represent each parameter, bearing in mind that the median value is very close to the average.

Heavy metals

According to the results of the wastewater, the majority of metals transfer to sewage sludge, although 20% may be lost in the treated effluent, depending on the solubility and this may be as high as 40%–60% for the most soluble metal, Ni. It is important to mention that the quality of the wastewater effluent has a direct relationship with the quality of the sludge produced from the same plant. This means that when the total solids in the effluent are high the sludge has low solid contents and the treatment process is not efficient and vice versa.

In addition to the common metals analyzed (Table 7) in sludge samples in many parts of the world, an extra nine elements were determined (Table 8) and, although these elements are of lesser importance, seven of them have low concentrations and only titanium (Ti) and strontium (Sr) as an alkaline earth metal showed considerable amounts in the tested samples.

The results for Zn in more than 90% of sludge samples revealed that this metal is present in high amounts and this is a very serious fact. Zinc in sludge of Gaza exceeds that of all standards of developed and industrial countries (Table 1). This raises the question about the main sources of Zn in sludge. Based on the field surveys, the Zn sources are expected to be domestic and commercial in origin. Domestic sources of Zn are corrosion and leaching of plumbing, water-proofing products, anti-pest products, wood preservatives, deodorants and cosmetics, medicines and ointments, paints and pigments, printing inks and coloring agents. The commercial sources are galvanization processes, brass and bronze alloy production, tires, batteries, paints, plastics, rubber, fungicides, paper, textiles, taxidermy, building materials, special cements, and also cosmetics and pharmaceuticals.

As mentioned above, the effluent wastewater showed low contents of Zn and the average of Zn removal in the treatment process was 55%; this ratio finds its way to the sludge and this may explain the high contents of Zn in sludge. For further quality assurance, the same samples were analyzed by the EMMA, and the Zn average was 1,400 mg/kg which is the same as the American standard. Under the best-case scenario of Zn contents in sludge and taking the EMMA reading, it is recommended not to apply this sludge on agricultural land before detailed investigations.

A brief comparison between the sludge of the two plants revealed that Mg, Ca, Li, Cu, Zn, Fe, Cr, Co and As have similar concentrations and no significant changes occurred during the 3 years of monitoring; however the results for As and Zn were 2–3 times higher in the years 2001 and 2002, respectively. Nickel was 2–3 times higher in Beit Lahia WWTP while Mn and Pb were 2 times higher in the sludge of Gaza WWTP; the reason is expected to be the fluctuation of industrial activities and the irregular production load of these elements in the

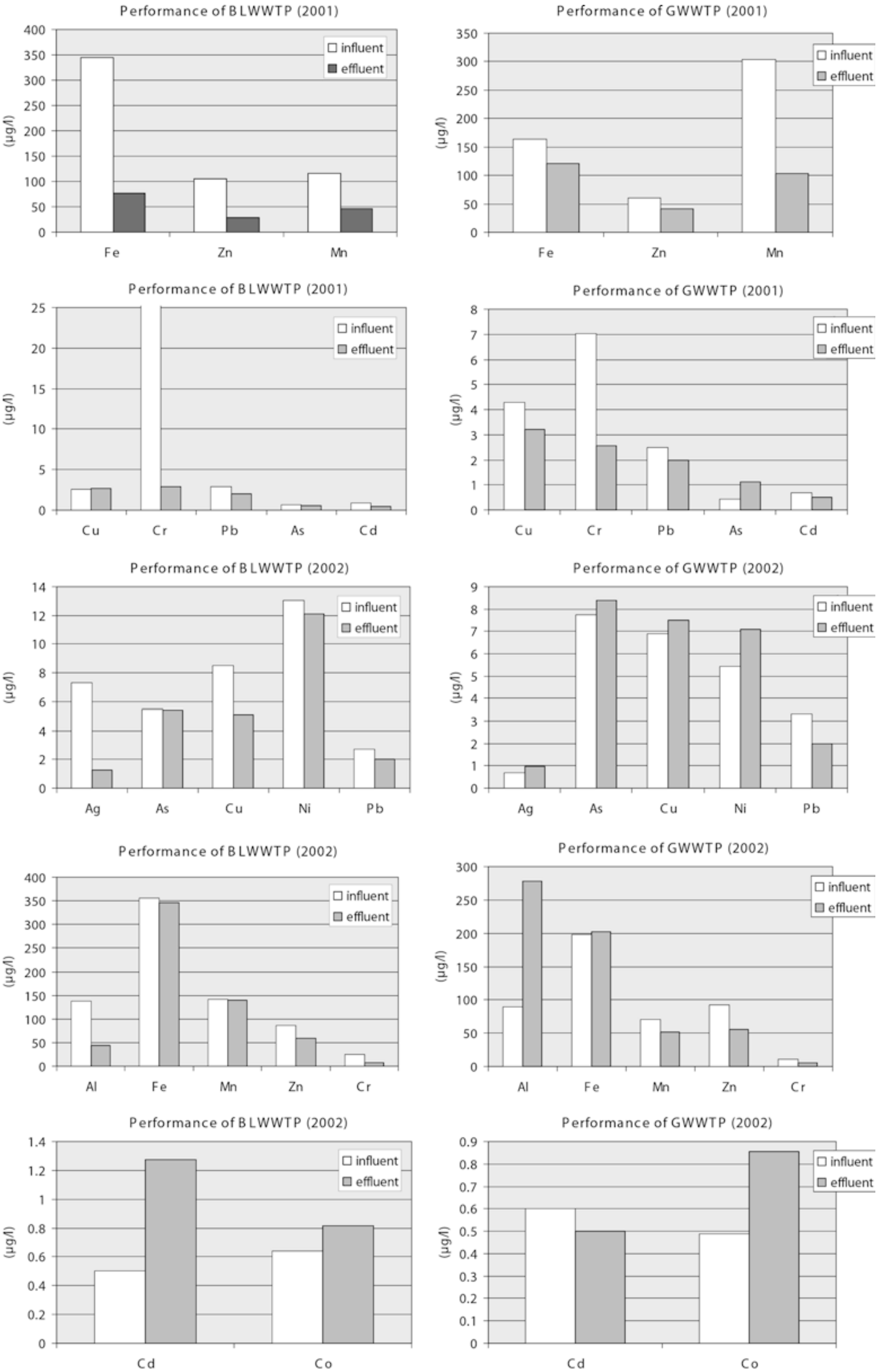

Fig. 2. Performance of Beit Lahia wastewater treatment plant (BLWWTP) and Gaza wastewater treatment plant (GWWTP), heavy metals in influent and effluent wastewater

industrial wastewater. The high concentrations of Na in the sludge of Gaza (2–3 times) may be connected to the same ratio of Na in groundwater and wastewater for the two areas.

Nutrients (N and P)

The averages of calculated total organic carbon TOC (total carbon–inorganic carbon) for sludge are 17–22% for Beit Lahai and Gaza, respectively, while the results of nitrogen for the two plants showed averages that are less than 2% (the American standards); nitrogen in Beit Lahia WWTP was 1.35% while it was 1.6 in Gaza WWTP. This range puts the sludge of Gaza in an acceptable ranking for land application.

The average of phosphorus in the sludge of Gaza plant was 0.7% while it was only 0.4% in the sludge of the Beit

Table 4. Heavy metals in the effluents of ten industries in the Gaza Strip (μg/l), year 2000

Industry	Fe	Zn	Cu	Mn	As	Pb	Cr	Cd
Pharmaceutical industry	97	259	2.68	40	0.92	<2.5	<2.5	<0.5
Cosmetics industry	127	109	4.262	45	0.36	4.1	5.52	<0.5
Jeans washing	775	1369	500	124	1.2	6.61	16.43	<0.5
Electroplating factory	5450	29500	4000	219	3.58	102	15859	70.15
Galvanic factory	2900	3096	14.95	26	2.36	10.3	797	9.40
Detergent factory	1619	1730	1	71	7.77	110	1073	8.65
Cloth washing factory	277	503	500	57	1.9	6.52	50.65	<0.5
Ice cream factory	222	251	100	26	1.44	<2.5	50.95	0.86
Soft drinks factory	825	143	400	64	1.34	4.25	22.32	<0.5
Car washing machine	1308	212	100	75	2.12	27.3	23.13	<0.5

Table 5. Heavy metals in the effluents of ten industries in the Gaza Strip (μg/l), year 2001

Industry	Fe	Zn	Cu	Mn	As	Pb	Cr	Cd
Pharmaceutical industry	97	259	2.68	40	0.92	<2.5	1.89	0.06
Cosmetics industry	127	109	4.26	45	0.36	4.10	5.52	0.09
Jeans washing	775	1369	500	124	1.20	6.61	16.43	0.03
Electroplating factory	5,450	29,500	4,000	219	3.58	102	15,859	70.15
Galvanic factory	2,900	3,096	14.95	26	2.36	10.3	797	9.40
Detergent factory	1,619	1,730	0.67	71	7.77	110	1,073	8.65
Cloth washing factory	277	503	500	57	1.9	6.52	50.65	0.28
Ice cream factory	222	251	100	26	1.44	<2.5	50.95	0.86
Soft drinks factory	825	143	400	64	1.34	4.25	22.32	0.19
Car washing machine	1,308	212	100	75	2.12	27.30	23.13	0.44

Table 6. Heavy metals in the effluents of 11 industries in the Gaza Strip (μg/l), year 2002

Industry	Ag	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Industry of detergents (1)	2.79	925	31	0.7	2.2	103.5	174	645	12	27	10.7	269
Industry of detergents (2)	35.05	1010	29	2.3	2.3	281.0	48	375	16	5	7.9	174
Metal coating—galvanization	21.55	104	8	<0.5	3.4	71.5	385	565	3	5	<2.5	10200
Jeans–washing industry	8.9	59	5	0.6	0.8	7.6	39	380	111	5	<2.5	940
Pharmaceuticals	1	313	14	0.8	3.5	102.5	54	3,200	221	22	53.0	605
Cosmetics and perfumes	0.5	33	8	<0.5	0.5	11.4	11	379	42	5	<2.5	426
Jeans-washing industry	1.755	38	10	<0.5	0.5	34.1	25	281	32	13	<2.5	102
Paintings	<0.5	1440	15	0.5	2.2	8.7	51	585	45	6	453.0	173
Soft drinks	2.05	466	14	0.8	1.0	27.3	32	1,330	21	14	84.5	63
Industry for plastics	<0.5	920	5	<0.5	0.3	6.9	10	395	22	2	17.2	53
Metal electroplating	0.94	143	<5	0.7	3.6	48,050	1585	1,270	80	74	7.0	1085

Table 7. Averages of trace metals and major parameters in sludge of 3 years

Parameter	Gaza WWTP 2000 Mean	BLWWTP 2001 Mean	Gaza WWTP 2001 Mean	BLWWTP 2002 Mean	Gaza WWTP 2002 Mean
PO_4(g/kg)	10	10	21	13	25
AOX (mg/kg)	490	467	523	480	495
C (%)	15	31	31	34	24
S (%)	0.5	2.0	2.0	3.8	2.6
$CaCO_3$ (%)	23	17	23	17	22
Mg (%)	0.9	1.2	1.3	1.0	1.0
Ca (%)	7	4	4	8	11
Na (mg/kg)	2,230	1,257	3,076	4,145	7,095
K (mg/kg)	2,425	1,158	1,447	1,890	1,746
Li mg/kg	3.3	3	3	3.1	2.9
Cu (mg/kg)	110	200	251	257	276
Zn (mg/kg)	897	1,646	1,909	2,000	2,281
Ni (mg/kg)	24	60	25	46	25
Pb (mg/kg)	49	77	121	92	140
Mn (mg/kg)	206	148	235	158	244
Fe (%)	1.1	1.7	1.2	1.4	1.4
Cr (mg/kg)	50	120	82	98	93
Co (mg/kg)	4.1	6.5	5.3	2.8	2.5
Cd (mg/kg)	0.9	2.4	1.3	2.0	1.8
As (mg/kg)	18.2	35.0	21.2	6.4	4.1
Hg (mg/kg)	3.1	2.0	2.6	2.4	3.3

Table 8. Other elements in sludge produced from Gaza (mg/kg), by using EMMA

Parameter	LD[a]	Sludge quality of Beit Lahia WWTP, April 2002					Sludge quality of Gaza WWTP, April 2002				
		max	min	mean	median	σ	max	min	mean	median	σ
Ti		3,336	2,457	2,835	2,846	328	3,213	2,276	2,719	2,854	416
Se	0.6	2	1	1.2	1.0	0.5	5	3	3	3	1.0
Br	0.7	20	18	19.2	19	0.7	27	17	23	23	3.9
Rb	0.7	13	8	10.5	11	2.1	12	8	10	10	1
Sr	0.8	363	335	349	352	11.5	984	540	709	651	168
Y	1.0	9	6	8.0	9	1.2	8	6	7	7	1.0
Zr	0.5	86	59	71.0	69	10.5	185	96	129	103	42
Zn	1.0	1,597	1,383	1,495	1,472	98	1,642	1,107	1,341	1,261	239
Th	2.5	9	5	7	7	1.8	3	0	2	2	1.4
U	2.5	5	3	4	4.3	0.8	11	6	9	9	2.0

[a]Limit of detection

Lahia plant. Both results are less than the standards of the U.S.A. (1%) and other developed countries. All other values of K, Ca, Mg etc. are shown in Table 7 and they are all within the international standards.

Adsorbable organic halogens (AOX)

In this survey of contamination levels of sludge of Gaza, it was found that concentration of AOX is in the range of 200–600 mg Cl/kg, while the German and EU standard is 500 mg Cl/kg. AOX is not a measure of toxicity, and according to the site visits the main sources are expected to be the paper pulp industry. Even though the wastewater effluent of the paper industries was not examined, it is proposed that the main source of AOX in sludge was the 26 paper industries distributed in Gaza and the northern area. These industries were using old technologies and they represented the largest consumer of chlorine and the greatest source of toxic organochlorine discharges directly into waterways. Large quantities of toxic organochlorine byproducts, including dioxin and thousands of other substances, were being discharged into the municipal sewage system. Many organochlorines resist natural breakdown processes, so they build up over time in the sludge, and this explains the high AOX ratio in the sludge of Gaza. Based on the results of the heavy metals and of the other major parameters obtained in this study, the application of sludge should comply with the soil physical, chemical and biological characteristics. Protection of soil organisms and microbially mediated soil processes is important. Regular monitoring systems for sludge and soil should be implemented and risk assessment programs should be adopted prior to and after sludge application.

Variation of heavy metal contents in wastewater and sludge

The fluctuation of heavy metal contents in wastewater and sludge could be explained as follows: firstly, the majority of industries in Gaza are connected to the treatment plants and they represent a major source of heavy metals in wastewater; these industries work neither to a regular time schedule nor in a steady state of wastewater production; secondly, around 35% of population and industries in Gaza are not connected to the wastewater collection network and they use septic tanks for wastewater disposal, these septic tanks have different sizes and they used to be emptied into the treatment plants by special tankers, the quantity and the quality of the transported wastewater is not stable; and thirdly, Gaza is located in a semi-arid zone where the rainy season is very short (4–5 months) and the seasonal variation plays an important role in the variation of wastewater characteristics. The three sampling campaigns were conducted in three different seasons; the weather and the rain intensity were varying even from day to day and this affects the concentration of heavy metals in both influent and effluent wastewater. Moreover, the wastewater treatment plants are open lagoons and they directly receive rain water on the rainy days and this affects the quality of wastewater and sludge.

Conclusions

1. The existing wastewater treatment plants in Gaza show a similar performance, and although they are partially functional, the heavy metal contents of the effluent are less than that of the standards of neighboring countries, and the treated wastewater could be used in agriculture with respect to heavy metals.
2. The industries in Gaza are light and they have no treatment facilities. Some individual industries produce high amounts of heavy metals in their effluents but the wastewater treatment plants have the capability to absorb the industrial effluents with no significant impact on the treatment bioprocesses.
3. The existing plants produce small amounts of sludge with low contents of all tested heavy metals except Zn, which exceeds the standards of all industrial countries. This is additional to the AOX which is found to be more than 500 mg Cl/kg in some sludge samples of the Gaza treatment plant, while more than 85% of the samples have less than 500 mg Cl/kg.
4. In addition to total metal concentrations the determination of specific chemical forms of heavy metals and their mode of binding in soil is very important in order to estimate their mobility, bioavailability and related ecotoxicity. Education, information, and training of farmers also play an important role in promoting sensible reuse practices.
5. Gaza Strip is a good example for similar studies in all neighboring countries which have similar conditions of metrology and climate, environment and natural resources, population growth, water scarcity, wastewater management problems, and finally socio-economic sit-

uations. The findings and conclusions of wastewater reuse and sludge application could be imitated in these similar areas not only in the region but also in many developing countries.

6. By the reuse of treated wastewater, Gaza can not only reduce the pollution load of the Mediterranean Sea with wastewater contaminants but also consider wastewater as a precious source of water which could be used in agriculture.

References

Alloway BJ, Jackson AP (1991) The behaviour of heavy metals in sewage sludge-amended soil. Sci Total Environ 100:151–176

APHA, AWWA and WPCF (eds) (1995) Standard Methods for examination of water and wastewater. APHA Publishing, Washington, D.C.

Ayres RS, Westcot DW (1985) Water quality for agriculture. Irrigation and Drainage Paper No. 29, Rev.1. Food and Agriculture Organization, Rome

Burica O, Strazar M, Mahne I (1996) Nitrogen removal wastewater in a pilot plant operated in the recirculation anoxic-oxic activated sludge mode. Water Sci Technol 33:255–258

Cheburkin AK, Shotyk W (1996) An energy-dispersive miniprobe multielement analyzer (EMMA) for direct analysis of Pb and other trace elements in peats, Fresenius J Anal Chem 354:688–691

China National Regulations for Agricultural Irrigation (1992) Characteristics of wastewater reuse, GB 5084–92, www.chinaep.net/biaozhun/hjbiaozh/hjbz015.htm

Coastal Aquifer Management Program (CAMP) (2000) Water Quality Baseline Survey—Final Report, Gaza, pp 1–54

DIN (1989) Bestimmung adsorbierbarer organisch gebundener Halogene (AOX) DIN 38414 S18 Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung Schlamm und Sedimente (Gruppe S). Beuth, Berlin

DIN (1997) SRS1 Deutsche Industrie Norm. Beuth, Berlin

Edwards JD (1995) Industrial Wastewater Treatment, a guidebook. CRC Press, Boca Raton, Fla., pp 1–192

EPA (1999) Biosolids generation, use and disposal in the United States. EPA530-R-99-009. Office of Solid Waste and Emergency Response, Washington, D.C.

EPA (2002) Review draft biosolids applied to land: advancing standards and practices. EPA503-R-02–007. Office of Water Sciences, Washington, D.C.

ICON (2001) Pollutants in urban wastewater and sewage sludge—final report, February 2001. IC Consultants Ltd, Office for Official Publications of the European Commission, Luxembourg

McGrath SP (1995) Metal concentrations in sludges and soil from a long-term field trial. J Agr Sci 103:25–35.

Ministry of Environmental Affairs (1999) Palestinian Environmental Strategy—Main Report, October, Gaza, Palestine, pp 1–94

Ministry of Environmental Affairs (2000) Palestinian Environmental Action Plan, October 2000, Gaza, Palestine, pp 63–69

Ministry of Environmental Affairs (2002) Gaza Coastal and Marine Environmental Action Plan, LIFE–Project 2002, Gaza, Palestine, pp 42–51

Ministry of Municipal and Rural Affairs and the Environment (1991) National Environmental Strategy for Jordan, a resource book of information and guidelines for action, August, Amman, Jordan, pp 218–226

Müller G, Gastner M (1971) The carbonate bomb, a simple device for the determination of carbonate content in the sediments, soils and other materials, Neues Jahrb Mineral 466–469

NIST (1991) Standard reference material program, trace elements in water 1643c. National Institute of Standards and Technology, Washington, D.C.

Palestinian Central Bureau of Statistics (2000) Population, Housing and Establishment Census 1997. Palestinian National Authority, Ramallah

Palestinian Environmental Protection Authority (1994) Gaza Environmental Profile, Part One-Inventory of Resources, Gaza, pp 17–21

Palestinian Water Authority (1999) Prefeasibility study for a reused water distribution system in Rafah and a sludge treatment facility for Gaza Governorates, Palestinian National Authority, Gaza

Planquart P, Bonin G, Prone A, Massiani C (1999). Distribution, movement and plant availability of trace metals in soils amended with sewage sludge composts: application to low metal loadings. Sci Total Environ 241:161–179

Safi W (1999) Textile and jeans washing industries in the Gaza Strip. MSc Thesis, DEW75. IHE, Delft, The Netherlands, pp 18–22

Shomar B (1999) Heavy metals in the groundwater of the Gaza Strip. MSc Thesis, DEW 70. IHE, Delft, The Netherlands, pp 37–41

Sterritt RM, Lester JN (1980) The value of sewage sludge to agriculture and effects of agricultural use of sludge contaminated with toxic elements: a review. Sci Total Environ 16:55–90

WHO (1986) Environmental Health 8, Industrial Wastewater in the Mediterranean Area. Regional Office for Europe, Copenhagen

Zufiaurre R, Oliver A, Chamorro P, Nerin C, Callizo A (1998) Speciation of metals in sewage sludge for agriculture uses. Analyst 123:255–259