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Geochemical features of topsoils in the Gaza Strip: Natural occurrence and anthropogenic inputs ☆

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Abstract

The aims of this study were to establish the current contents of trace metals and major elements in agricultural soils of the Gaza Strip and to identify the main anthropogenic inputs affecting trace metal contents. An extensive soil survey was conducted in agricultural and nonagricultural areas. One hundred and seventy sites that represent a broad range of soil types and locations were selected. The results revealed that soils in the Gaza Strip fall within the range of uncontaminated to slightly contaminated. Up to 90% of the tested soils had trace metal contents equal to the international background values. Ten percent showed slight contamination, primarily by Zn, Cu, As, and Pb, due to anthropogenic inputs, and the mean concentrations of these elements were 180, 45, 13, and 190 mg/kg, respectively. The trace metal contents varied, with the highest contents detected in the southern regions (where one finds clay soil and low precipitation) and the lowest in the northern areas (where are sandy soil and high precipitation). The soil geochemistry is dependent on soil type and location and to a lesser extent on crop pattern and fertilizer and fungicide application. Anthropogenic inputs lead to the enrichment of Zn, Pb, Cu, and Cd in the agricultural soils. The pollution of several investigated sites was found to be most severe for Zn, Pb, Cu, Cd, and, to a somewhat lesser extent, for As, whereas anthropogenic input of Hg, Ni, and Co seemed to be less important. The application of Cd-containing phosphate fertilizers coupled with Cu-containing fungicides may be an important source of Cd and Cu in several soils. High Zn levels (1000 ppm) in several soils may be caused by sewage sludge, which has an average Zn content of 2000 ppm. Saline-sodic soils were found in the central and southern regions, where the soils are characterized by high contents of Na and salty groundwater. Elevated Cl, Na, Zn, and Pb contents in some areas need further investigation to determine their ecological and health implications.

Keywords: Anthropogenic inputs; Gaza Strip; Soil pollution; Trace elements

1. Introduction

Owing to the scarcity of land and rapid urbanization in the Gaza Strip, most agricultural areas are located near industrial areas and the environmental hotspots of wastewater treatment plants and solid waste dumping sites. The soils of these agricultural areas are subject to potential pollution from various sources (Abrahams, 2002). Soils are prone to contamination from atmospheric and hydrological sources, but direct waste disposal causes a major impact on this natural resource, posing serious environmental concern (Navas and Machin, 2002). At the current rates of atmospheric deposition, concentrations of potentially toxic trace metals in soils of several countries worldwide may already be close to exceeding their critical capacity for pollution (Nriagu, 1990). Most trace metal contamination in the surface environment is associated with a cocktail of contaminants rather than one metal (Jung, 2001). It has been noted that roadside soils near heavy traffic and urban soils are polluted by Cd, Cu, Pb, Zn, and other metals (Li et al., 2001). In the polluted soil,

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the trace metal concentrations in crop plants have been found to vary between plant species (Lee et al., 2001). Balances between removed and supplied quantities of trace elements indicate slow depletion of the micronutrients Zn, Cu, and Mn in farming based on cash crops and conventional fertilization. The soil levels of Cd, Hg, and Pb are slowly increasing due to additions of commercial fertilizers (Andersson, 1992; Bowen, 1979).

Soil salinity and sodicity can have a major effect on the structure of soils. Soil structure, or the arrangement of soil particles, is critical in affecting permeability and infiltration (Sparks, 1995). Saline irrigation water, low soil permeability, inadequate drainage, low rainfall, high potential evapotranspiration, and poor irrigation management all have caused salts to accumulate in several soils of Gaza, which deleteriously affects crop growth and yields (Sparks, 1995).

In the Gaza Strip, there is not enough water to leach soluble salts from soil. Consequently, the soluble salts accumulate, resulting in salt-affected soils. The major cations of concern in saline soils and waters are Na^{+}, Ca^{2+}, Mg^{2+}, and K^{+} and the primary anions are Cl^{-}, SO_4^{2-}, HCO_3^{-}, CO_3^{2-}, and NO_3^{-}. Carbonate ions are normally found only at $pH \geqslant 9.5$.

Crop rotation and fertilization vary between different regions depending on climate and soil conditions, and, similarly, there is a variation in the rate of precipitation from south (250 mm/acre) to north (400 mm/acre) over the Gaza Strip.

The main goal of this study was to establish the topsoil geochemistry in the Gaza Strip. A secondary objective was to identify the major anthropogenic inputs affecting soil geochemistry.

2. Materials and methods

2.1. Soil types

The Gaza Strip is 360 km^2 and has several major soil types (Fig. 1). Arenosolic, Calcaric, Rhegosolic, and Calcaric Fluvisolic soils are examples of these soils (Table 1). Arenosolic (sandy) soils of dune accumulations are Regosols without a marked profile. The soils are moderately calcareous (5–8% $CaCO_3$), with low organic matter, and are physically suitable for intensive horticulture.

Calcaric Arenosols (loessy sandy soils) can be found some 5 km inland in the central and southern part of the Strip, in a zone along Khan Yunis toward Rafah, parallel to the coast. This belt forms a transitional zone between the Arenosolic soils and the Calcaric (loess) soils. Typical Calcaric soils are found in the area between the city of Gaza and the Wadi Gaza and contain 8–12% $CaCO_3$. Arenosolic Calcaric (sandy loess) soils are transitional soils, characterized by a lighter texture. These soils can be found in the depression between the Calcareous (Kurkar) ridges of Deir El Balah. Apparently, windblown sands have been mixed with Calcareous deposits. Deposition of these two types of windblown materials originating from different sources has occurred over time and more or less simultaneously. These soils have a rather uniform texture. Another transitional form is the Arenosols over Calcaric soils. These are loess or loessial soils (sandy clay loam) that have been covered by a layer (0.20–0.50 m) of dune sand. These soils can be found east of Rafah and Khan Yunis.

Fluvisols (alluvial) and Vertisols (grumosolic), which are dominated by loamy clay textures, are found on the slopes of the northern depressions between Beit Hanoun and Wadi Gaza. Borings east of El Montar ridge have revealed that alluvial deposits of about 25 m in thickness occur. At some depth, calcareous concentrations are present. The $CaCO_3$ content can be approximately 15–20%. Some of the soils have been strongly eroded, and the reddish-brown subsoils may be exposed on the tops of ridges and along slopes. The alluvial sediments are underlain by a calcareous layer.

2.2. Sampling and sample preparation

The soil-sampling campaigns were conducted according to the European soil-sampling guidelines (Theocharopoulos et al., 2001). The criteria for the sampling area, specific site, and point selection were based mainly on pedology, land use, and geology. The depth of sampling varied between 0 and 10 cm for the open and grass soils, 20 cm for the vegetable soils, and up to 30 cm for the ploughed soils.

One hundred and seventy soil samples were collected in October/November 2001, April/May 2002, and January/February 2003: 35 samples from the green houses (vegetables) of three different geographic areas, 25 from fruit farms (olive, peach, guava), 25 from citrus farms of northern and southern areas, 20 from open vegetable farms, 15 from strawberry farms, 20 from the vegetable farms near wastewater treatment plants, 20 from the vegetable farms near solid waste dumping sites, and 10 from non-agricultural, isolated areas representing local reference sites.

At each sampling station, a circle of 2–5 m in diameter was identified and 10 subsamples were collected within the perimeter and mixed to form a composite sample. Samples (0.5 kg) were collected and placed into polyethylene cups and stored at 4 °C. The soils were dried in an oven at 45 °C until of a constant weight. They were then shipped to Germany in plastic sample bags.

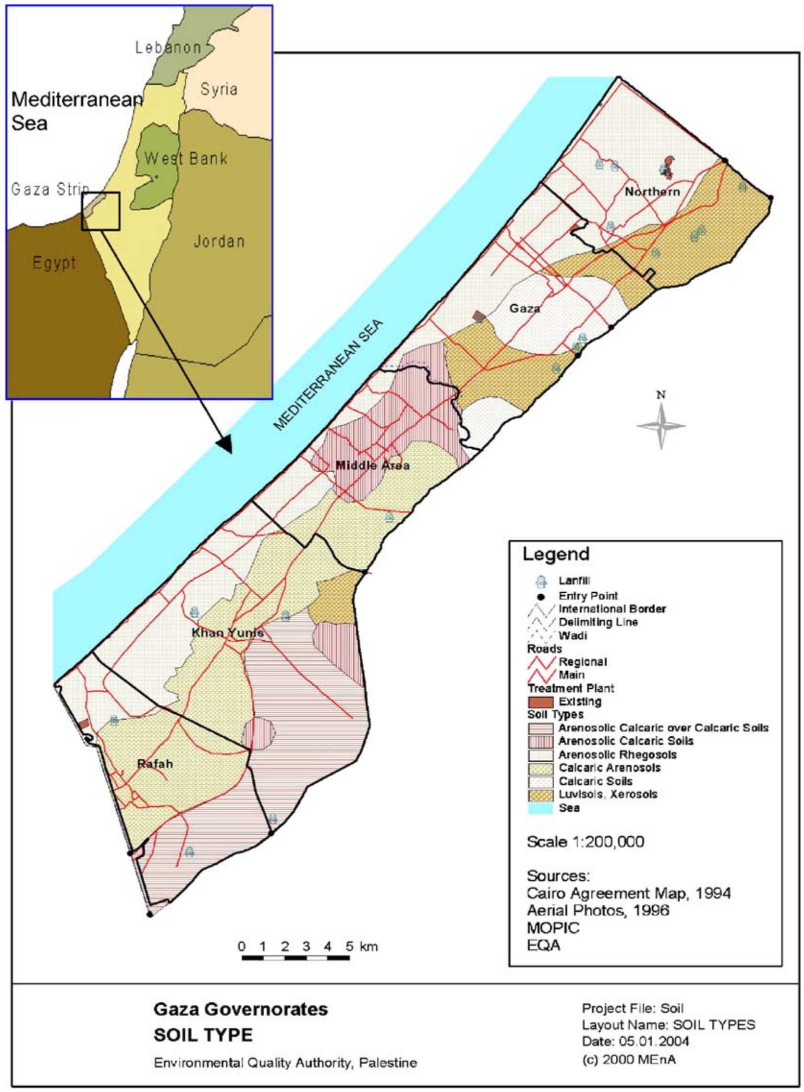

Fig. 1. Location of the Gaza Strip and soil type distribution.

Table 1
Soil types, land form, and dominant land use of the Gaza Strip

Soil type	Land form	Dominant land use
Arenosolic Rhegosols	Active steep dunes Undulating stabilized dunes Calcareous ridges	Irrigated horticulture in greenhouses Irrigated horticulture in tunnels and open fields El Mawasy rain-fed vegetables/fruit Rainfed grapes
Calcaric Arenosols	Flat/rolling interdune areas	Open horticulture, tunnels
Arenosolic Calcaric Soils	Flat/rolling plains or depressions	Dates Citrus plantation Some irrigated vegetables, field crops
Calcaric Soils	Rolling plains	Citrus plantations
Arenosolic Calcaric over Calcaric Soils	Gently rolling plains	Rain-fed fieldcrops Almonds, olives Some irrigated vegetables
Luvisols, Xerosols	Ancient alluvial valleys	Citrus orchards
	Depressions and slopes	Rain-fed field crops Non-rain-fed vegetables

2.3. Analyses

Samples were freeze-dried until complete dryness and then sieved through a 2-mm sieve and ground to a powder by using a ring mill (FRITSCH-Labor Planeten Mühle, Pulverisette 5). Approximately, 0.5–1.0 g of each homogenized sample was dissolved in 10.5 ml of concentrated HCl (37% p.a.) and 3.5 ml of concentrated HNO_3 (65% p.a.) in 50-ml retorts. The samples were degassed (12 h) and then 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. Samples were analyzed by ICP/OES (VISTA-MPX, VARIAN) for the alkali and alkaline-earth elements Mg, Li, Ca, K, and Na, the trace metals Cu, Zn, Ni, Pb, Mn, Fe, Cr, Co, and Cd, and the metalloid As. Energy-dispersive miniprobe multielement analyzer-X-ray fluorescence (EMMA-XRF) 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 P represented as PO_4 was measured according to APHA et al. (1995). Mercury concentrations were determined using atomic absorption spectroscopy after thermal combustion of the freeze-dried samples (50–100 mg) by an advanced mercury analyzer 254 solid-phase Hg-analyzer (LECO). The total C and S contents were determined in dried samples by using a carbon–sulfur determinator (LECO CS-225). Carbonates were measured via a carbonate bomb (Müller and Gastner, 1971). The TOC was calculated by the subtraction of inorganic C from total C. The adsorbable organic halogens (AOX) were determined using a euroglas organic halogen analyzer. Analytical procedure DIN 38414 S18 followed that in the "Deutsche Einheitsverfahren zur Wasser, Abwasser und Schlammuntersuchung, Sludge and Sediment (Group S) Determination of AOX" (DIN, 1989). The AOX in soil was analyzed according to Asplund et al. (1994). A 10- to 50-mg milled soil sample was added to an acidic nitrate solution (20 ml, 0.2 M KNO_3, 0.02 M HNO_3) and shaken on a rotary shaker (200 rpm) for at least 1 h. The suspension was filtered through a 0.45-m polycarbonate filter. The filter with the filter cake was then combusted under a stream of O_2 at 1000 °C in a Euroglas AOX analyzer (Model 1200) in which the formed hydrogen halides were determined by micro-coulometric titration with Ag ions. Each sample was analyzed in duplicate. Blanks were analyzed according to the same procedure but without the addition of soil.

2.4. Quality control

Analytical blanks and two standard reference materials with known concentrations of trace metals were prepared and analyzed using the same procedures and reagents (Avila-Perez et al., 1999). Precision for the results of soil samples was estimated using the reproducibility between the duplicates, and a coefficient of variation of less than 5% was found. The accuracy was evaluated using 20 aliquots of two River Sediment Standard Reference Materials-RS1 and RS3-Deutsche Industrie Norm (DIN, 1989, 1997). Geochemical reference materials were also analyzed by EMMA techniques. A deviation of less than 5% from the certified values was found. The coefficient of variation for triplicates (two samples and one standard) was less than 2% for all parameters except for Cd, which had a coefficient of variation higher than 6%. The difference between the standard reference materials (RS1 and RS3) supplied by DIN was used to estimate the accuracy of the analytical method (ICP/OES), and the data accuracy rates were within the following standards: $CaCO_3$, 0.9%; Mg, 0.44%; Ca, 1.05%; Cu, 0.7%; Zn, 0.72%; Ni, 0.77%; Pb, 0.65%; Mn, 0.73%; Fe, 0.67%; Cr, 1.26%; Cd, 6.7%; and As, 0.66%. The accuracy rates with EMMA were Cu, 1.1%; Zn, Ni, Pb, Mn, and Cd, 1%; and As, Fe, and Cr, 0.9%.

2.5. Fertilizers and fungicides

Samples of commonly used fertilizers and fungicides were collected from private stores in Gaza. They were freeze-dried and ground to powder. Fertilizer and fungicide samples were measured using EMMA-XRF for K, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Br, Rb, Sr, and Pb. The analyzer used monochromatic excitation with energy of 19.6 keV. The software includes a possibility to normalize the peak area of each element by the intensity of incoherent scattering radiation. This feature allows the elimination of the matrix effect for samples with a different matrix. However, with an extremely wide range of matrices for fungicide samples, even such normalizing does not work well. Several fungicide samples had a very heavy matrix due to the presence of high concentration of Mn, Cu, Zn, and Br.

The EMMA-XRF analyzer was calibrated using different standard reference materials. The analytical data for trace elements in the fungicides are semiquantitative and may have a relative error of up to 30%. As the results of the EMMA-XRF were semiquantitative, a quantitative determination was carried out after a full digestion procedure by using the ICP/OES (VISTA-MPX, Varian) instrument for analyzing Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sc, Sr, and Zn. The detection limit of the ICP/OES was estimated as 10% less than the lowest measurable standard used for calibration.

3. Results

Owing to the large data set obtained from the analysis of 170 soil samples, each having 20 parameters, this section will cover mostly elements that are environmentally significant in Gaza. Mercury was detected in 56 samples, while Sb was detected only in 8 of them. The levels of Ti, Br, Rb, Sr, Y, and Zr were low to very low, and consequently data from these elements are not presented in Table 2. The statistical median of similar soils was considered and 11 soil categories were used to represent all samples (Table 2).

Among a total of 27 elements analyzed, only a few trace elements showed environmental relevance in Gaza: As, Cd, Cr, Hg, and, to a lesser extent, Pb. The trace metal accumulations in the soils affected by sludge were characterized by a large spatial variability, with some "hot spots" of Cu and Zn with concentrations of up to 1220 and 1500 mg/kg, respectively (Shomar et al., 2004).

A nonparametric Spearman correlation coefficient was calculated for the raw data of 170 soil samples and the results are presented in Table 3.

Fertilizers are expected to be a source of trace elements apart from natural occurrence. Table 4 shows the contents of some trace metals in selected commercial fertilizers commonly used in the Gaza Strip. The levels of Ni, As, Se, Rb, Y, and Zr were below the detection limit of the analytical procedure, and consequently they are not included in Table 4. Table 5 shows examples of the fungicides used in Gaza and their content of trace metals.

3.1. Adsorbable organic halogens

The AOX in the soils of Gaza was very low and ranged between the detection limit (0.5) and 20 mg Cl/kg. A few sites showed high AOX values of 250 mg Cl/kg due to their location near the sludge disposal areas and solid waste dumping sites.

3.2. Phosphorus, carbon, and sulfur

The total P concentration in the topsoil varies between about 0.4 and 1.2 g P/kg, which is suitable for agricultural purposes.

Total C in soils of the Gaza Strip was between 0.5% and 3%. The lowest percentage of S in the soils of the Gaza Strip was 0.016%, while the highest was 0.07%. It is important to mention that the irrigation water in the southern areas of the Gaza Strip has high contents of SO_4 (380 mg/L) and that this leads to greater soil acidity (Shomar et al., 2005).

3.3. $CaCO_3$, Ca, Mg, Na, and K

The results showed great variation (1.6–19%) of $CaCO_3$ contents in the soils of Gaza. Calcium in the tested soils was between 0.7% and 5.4%. Several of the residual soils in Gaza were relatively low in Mg (0.03%). Sodium contents in soils were 110–825 mg/kg. The high Na content of household products for laundry, kitchen, bath, and cleaning are a primary source of Na in soil. Addition of water softener wastes or the Na content in the local water supply also contributes to the problem. Soils showed suitable amounts of K with respect to agricultural requirements. The lowest and the highest K averages were 330 and 4500 mg/kg, respectively.

3.4. Fe and Mn

The contents of Fe in the soils of Gaza ranging between 0.2% and 2% were less than the value listed by Turekian and Wedepohl (1961) of 4.72% in the upper crust. The highest Fe levels were found in the middle area and Khan Yunis. Manganese showed a similar trend to Fe. Generally, Mn levels were low, the range being between 37 and 542 mg/kg. The correlations between Fe and Mn for the same soil types showed that both had the same source and behavior ($r = 0.9$).

3.5. Cu, Zn, Cd, Ni, Pb, Cr, Co, As, and Hg

The median of Cu in soils of the Gaza Strip was 10 mg/kg. The highest (45 mg/kg) was found in the greenhouses and the lowest (2 mg/kg) in the open sandy farms. Zinc seems to be distributed uniformly. The lowest Zn (2 mg/kg) was found in the local reference samples, with the highest (1800 mg/kg) being found in the soils exposed directly to domestic sludge. The Cd unit in μg/kg reflects its low level in soils. More than 75% of the soil samples showed results below the detection limit (10 μg/kg). Several greenhouses had 430 μg/kg of Cd in their soils. One site beside the wastewater treatment plant showed a level of 1500 μg Cd/kg. The correlation coefficient between Zn and Cd in the different soils was 0.85 for the soils of the greenhouses of the southern regions, while it was only 0.53 for the northern regions.

Nickel was low, with an average of 28 mg/kg, and no significant difference was found in the Ni levels of each area. Only one guava farm showed a high level of Pb (145 mg/kg), while the rest of the soils showed an average of 30 mg/kg. The correlation between Pb and organic C was good ($r = 0.8$). This could explain the behavior of Pb in the clay soils, as it attaches to the organic matter. An anomalous result for Cr (472 mg/kg) was found in the area of Beit Hanoun. The site was 10 m from the industrial estate. The same soil from Beit Hanoun showed Co to be 29 mg/kg, while the average

Table 2
Concentrations of trace metals and other elements in selected soils of the Gaza Strip

Soil taken from	C (%)	AOX (mg/kg)	P (g/kg)	Mg (mg/kg)	Ca (%)	Na (mg/kg)	Fe (%)	Mn (mg/kg)	Cr (mg/kg)	Cd (μg/kg)	Pb (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Co (mg/kg)	Hg (μg/kg)	As (mg/kg)
DL[a]	0.05	0.5	0.001	0.01	0.01	0.01	0.01	0.01	1	10	10	2	5	1	2	2	1
Reference areas ($n = 10$)																	
Minimum	0.2	<0.5	0.1	260	0.3	89	0.2	30	2.0	<10	<10	<2	<5	3.2	<2	<5	<1
Maximum	0.4	<0.5	0.2	560	2.0	115	0.7	44	5.4	15	<10	4.1	11.3	8.8	3.4	<5	<1
Mean	0.3	<0.5	0.2	346	0.9	107	0.3	37	2.8	<10	<10	2.3	5.0	5.3	1.9	<5	<1
Median	0.2	<0.5	0.1	330	0.7	110	0.2	37	2.4	<10	<10	<2	<5	5.0	<2	<5	<1
SD	0.1	0.0	0.0	82	0.5	9	0.1	5	1.0	6	0.3	1.0	3.4	1.9	0.9	0.0	0.4
Citrus farms (1) ($n = 12$)																	
Minimum	0.9	7.0	0.4	699	1.6	360	0.3	96	17	<10	<10	2	15	3.0	2.0	3.2	1.2
Maximum	2.9	10.0	1.3	11,093	7.1	792	2.0	420	130	105	23.0	23	50	67.4	16.9	10.3	4.1
Mean	2.0	8.2	0.8	2273	3.0	524	1.4	319	85	43	18.8	7	35	39.1	7.5	6.4	3.0
Median	2.0	8.0	0.9	1530	2.9	497	1.3	349	97	43	19.5	6	40	40.0	6.3	6.1	3.0
SD	0.6	1.1	0.3	2601	1.4	110	0.6	88	32	23	3.4	5	10	14.5	4.6	2.0	0.7
Citrus farms (2) ($n = 13$)																	
Minimum	0.7	6.0	0.2	1100	1.2	105	0.5	74	12	<10	<10	3	5	18	3.3	<5	<1
Maximum	2.2	11.0	1.2	3128	3.1	473	2.0	393	130	220	22	23	28	72	16.9	10.3	3.9
Mean	1.4	7.7	0.7	1679	2.3	260	1.0	189	66	83	14	11	16	44	7.5	7.2	2.1
Median	1.3	7.0	0.6	1760	2.5	240	0.9	188	65	70	14	7	19	46	5.0	7.0	2.4
SD	0.5	1.5	0.3	634	0.6	133	0.5	94	46	73	4	6	7	17	5.1	1.9	1.3
Greenhouses (1) ($n = 12$)																	
Minimum	2.2	4.0	0.1	677	1.9	119	0.4	165	10	<10	<10	<2	5	7	<2	<5	<1
Maximum	2.5	8.0	2.0	3903	4.4	765	1.3	289	110	432	20	12	25	76	9.4	21	12
Mean	2.4	5.3	0.8	2204	2.9	321	0.9	238	54	119	14	6	17	29	5.2	7	4
Median	2.4	5.0	0.5	2030	3.0	206	1	256	65	49	17	5	19	19	5.7	8	5
SD	0.1	1.2	0.7	1126	0.6	244	0.3	44	29	146	6	3	6	25	3.4	5	4
Greenhouses (2) ($n = 13$)																	
Minimum	1.7	5.0	0.3	324	2.4	222	0.3	132	12	<10	11	6	8	11	<2	8	5
Maximum	2.4	14.0	2.9	4562	4.6	765	1.5	198	72	187	20	12	17	78	9.4	14	12
Mean	2.2	10.8	1.2	1848	3.0	394	0.9	162	49	53	15	9	12	43	3.9	10	8
Median	2.3	12.0	0.8	1800	2.7	366	1.0	160	60	46	15	9	13	47	3.0	10	8
SD	0.2	2.4	0.8	1150	0.6	169	0.4	22	23	52	3	2	2	22	2.4	2	2
Greenhouses (3) ($n = 10$)																	
Minimum	1.7	5.0	0.5	422	2.2	156	0.6	309	32	<10	<10	5	8	4	3	4	<1
Maximum	2.9	13.0	2.1	13,958	7.0	888	2.9	598	130	227	57	81	23	90	11	12	9

Table 2 (*continued*)

Soil taken from	C (%)	AOX (mg/kg)	P (g/kg)	Mg (mg/kg)	Ca (%)	Na (mg/kg)	Fe (%)	Mn (mg/kg)	Cr (mg/kg)	Cd (μg/kg)	Pb (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Co (mg/kg)	Hg (μg/kg)	As (mg/kg)
DL[a]	0.05	0.5	0.001	0.01	0.01	0.01	0.01	0.01	1	10	10	2	5	1	2	2	1
Mean	2.3	8.3	1.1	3434	4.0	580	1.5	474	86	80	25	22	16	50	5	8	3
Median	2.4	9.0	1.1	2211	3.7	588	1.3	518	80	58	21	12	17	52	5	9	3
SD	0.4	2.7	0.5	3271	1.7	204	0.7	90	29	73	14	24	3	27	2	2	3
Strawberry farm ($n = 15$)																	
Minimum	0.5	15	0.3	795	0.1	50	0.2	42	5	<10	<10	2	6	4	<2	6	<1
Maximum	4.0	350	0.9	6771	5.5	351	1.0	210	274	67	200	33	59	60	10	33	14
Mean	2.4	115	0.6	3287	3.8	194	0.6	126	133	26	61	14	25	30	3	15	5
Median	2.3	23	0.6	3225	4.3	189	0.4	106	120	16	14	7	18	18	3	10	4
SD	0.95	126	0.19	2085	1.6	75	0.29	59	102	29	82	12	18	22	3	10	4
Open farms ($n = 20$)																	
Minimum	0.7	4.0	0.3	1633	1.3	156	0.5	140	5	<10	<10	4	5	14	2	5	<1
Maximum	2.9	7.0	1.3	13,958	7.0	887	2.9	531	130	177	57	88	23	71	11	14	4
Mean	1.8	5.6	0.9	3118	3.9	404	2.2	430	83	52	30	57	12	50	4	9	1
Median	1.8	5.5	1.1	2075	3.2	347	2.6	505	120	57	29	80	13	60	3	10	1
SD	0.7	0.8	0.3	2710	1.8	225	0.8	136	54	43	17	31	3	17	2	2	1
Fruit farms ($n = 25$)																	
Minimum	0.8	12	0.2	213	0.8	119	0.3	110	5	<10	<10	<2	<5	4	<2	<2	<1
Maximum	21.0	21	1.2	8389	920	920	410	410	472	472	170	170	187	187	28	28	18
Mean	1.9	15	0.6	4470	4.0	537	1.5	307	61	256	82	70	10	111	8	17	10
Median	2.01	15	0.6	5789	3.8	564	1.7	301	84	360	130	16	11	165	10	21	12
SD	0.5	2	0.2	2693	2.1	190	0.6	70	46	212	62	65	5	75	3	9	6
Nearby WWTP ($n = 20$)																	
Minimum	0.2	33	0.1	212	0.1	50	0.2	26	5	<10	<10	<2	5	10	<2	<2	<1
Maximum	4.0	410	1.5	4913	3.4	765	1.7	239	278	1495	210	40	59	300	13	42	15
Mean	2.3	225	0.6	2318	2.0	370	0.7	117	193	236	110	25	36	70	7	24	8
Median	3.0	250	0.6	2108	2.7	350	0.4	106	260	33	114	30	40	31	9	30	11
SD	1.1	110	0.4	1363	1.3	225	0.5	65	112	465	84	11	13	89	3	13	5
Nearby SWDS ($n = 20$)																	
Minimum	0.3	33	0.6	213	0.8	50	0.1	26	2	22	146	<2	<5	28	2	27	<1
Maximum	3.2	356	8.0	6914	3.5	765	1.7	239	280	66	210	35	50	190	11	36	19
Mean	2.3	175	1.2	2910	2.7	341	0.5	83	168	41	185	21	38	149	7	31	10
Median	3.0	178	0.9	2395	3.1	372	0.2	41	244	41	186	26	44	172	8	32	12
SD	0.9	105	1.6	1636	0.8	207	0.6	68	119	8	17	9	13	44	2	2	4

WWTP, wastewater treatment plant; SWDS, solid waste dumping site.
[a]DL, detection limit

Table 3
The Spearman correlation coefficients, $N = 170$

		C (%)	AOX (mg/kg)	P (g/kg)	Mg (mg/kg)	Ca (%)	Na (mg/kg)	Fe (%)	Mn (mg/kg)	Cr (mg/kg)	Cd (μg/kg)	Pb (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Co (mg/kg)	Hg (μg/kg)	As (mg/kg)
C	Cor. coef.	1.00	0.29	0.31	0.17	0.31	0.23	−0.02	0.05	0.26	0.00	0.41	0.18	0.31	0.14	0.16	0.31	0.29
	Sig. (2-tailed)		0.00	0.00	0.02	0.00	0.00	0.78	0.47	0.00	0.90	0.00	0.01	0.00	0.06	0.03	0.00	0.00
AOX	Cor. coef.	0.29	1.00	0.07	0.30	0.11	0.07	−0.25	−0.33	0.41	−0.00	0.42	0.30	0.41	0.32	0.32	0.56	0.50
	Sig. (2-tailed)	0.00		0.34	0.00	0.13	0.30	0.00	0.00	0.00	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P	Cor. coef.	0.31	0.07	1.00	0.06	0.13	0.27	0.11	0.21	0.14	0.11	0.27	0.23	0.18	0.25	0.09	0.25	0.12
	Sig. (2-tailed)	0.00	0.34		0.40	0.07	0.00	0.13	0.00	0.05	0.14	0.00	0.00	0.01	0.00	0.20	0.00	0.12
Mg	Cor. coef.	0.17	0.30	0.06	1.00	0.33	0.17	0.24	0.18	0.20	0.06	0.17	0.20	0.07	0.18	0.178	0.26	0.13
	Sig. (2-tailed)	0.02	0.00	0.40		0.00	0.02	0.00	0.01	0.00	0.43	0.02	0.00	0.36	0.01	0.02	0.00	0.07
Ca	Cor. coef.	0.31	0.11	0.13	0.33	1.00	0.19	0.18	0.27	0.18	0.05	0.07	0.19	−0.00	0.05	0.04	0.14	0.11
	Sig. (2-tailed)	0.00	0.13	0.07	0.00		0.01	0.01	0.00	0.01	0.46	0.31	0.01	0.97	0.49	0.54	0.05	0.15
Na	Cor. coef.	0.23	0.07	0.27	0.17	0.19	1.00	0.50	0.48	0.14	0.23	0.31	0.29	0.07	0.31	0.33	0.22	0.20
	Sig. (2-tailed)	0.00	0.30	0.00	0.02	0.01		0.00	0.00	0.06	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.00
Fe	Cor. coef.	−0.02	−0.25	0.11	0.24	0.18	0.50	1.00	0.81	0.03	0.22	0.08	0.22	−0.13	0.10	0.20	0.01	−0.11
	Sig. (2-tailed)	0.78	0.00	0.13	0.00	0.01	0.00		0.00	0.69	0.00	0.27	0.00	0.08	0.16	0.00	0.86	0.15
Mn	Cor. coef.	0.05	−0.33	0.21	0.18	0.27	0.48	0.81	1.00	0.01	0.29	−0.01	0.19	−0.15	0.09	0.13	−0.09	−0.14
	Sig. (2-tailed)	0.47	0.00	0.00	0.01	0.00	0.00	0.00		0.82	0.00	0.87	0.01	0.04	0.24	0.07	0.24	0.05
Cr	Cor. coef.	0.26	0.41	0.14	0.20	0.18	0.14	0.03	0.01	1.00	0.11	0.27	0.22	0.32	0.21	0.12	0.26	0.07
	Sig. (2-tailed)	0.00	0.00	0.05	0.00	0.01	0.06	0.69	0.82		0.14	0.00	0.00	0.00	0.00	0.10	0.00	0.35
Cd	Cor. coef.	0.00	0.00	0.11	0.06	0.05	0.23	0.22	0.29	0.11	1.00	0.10	0.26	−0.08	0.74	0.14	0.07	0.19
	Sig. (2-tailed)	0.90	0.91	0.14	0.43	0.46	0.00	0.00	0.00	0.14		0.17	0.00	0.29	0.00	0.06	0.31	0.01
Pb	Cor. coef.	0.41	0.42	0.27	0.17	0.07	0.31	0.08	−0.01	0.27	0.10	1.00	0.42	0.30	0.43	0.37	0.53	0.35
	Sig. (2-tailed)	0.00	0.00	0.00	0.02	0.31	0.00	0.27	0.87	0.00	0.17		0.00	0.00	0.00	0.00	0.00	0.00
Ni	Cor. coef.	0.18	0.30	0.23	0.20	0.19	0.29	0.22	0.19	0.22	0.26	0.42	1.00	0.00	0.50	0.28	0.45	0.28
	Sig. (2-tailed)	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00		0.99	0.00	0.00	0.00	0.00
Cu	Cor. coef.	0.31	0.41	0.18	0.07	0.00	0.07	−0.13	−0.15	0.32	−0.08	0.30	0.00	1.00	0.11	0.16	0.27	0.22
	Sig. (2-tailed)	0.00	0.00	0.01	0.36	0.97	0.35	0.08	0.04	0.00	0.29	0.00	0.99		0.15	0.03	0.00	0.00
Zn	Cor. coef.	0.14	0.32	0.25	0.18	0.05	0.31	0.10	0.09	0.21	0.74	0.43	0.50	0.11	1.00	0.28	0.42	0.40
	Sig. (2-tailed)	0.06	0.00	0.00	0.01	0.49	0.00	0.16	0.24	0.00	0.00	0.00	0.00	0.15		0.00	0.00	0.00
Co	Cor. coef.	0.16	0.32	0.09	0.17	0.04	0.33	0.20	0.13	0.12	0.14	0.37	0.28	0.16	0.28	1.00	0.25	0.28
	Sig. (2-tailed)	0.03	0.00	0.20	0.02	0.54	0.00	0.00	0.07	0.10	0.06	0.00	0.00	0.03	0.00		0.00	0.00
Hg	Cor. coef.	0.31	0.56	0.25	0.26	0.14	0.22	0.01	−0.09	0.26	0.07	0.53	0.45	0.27	0.42	0.25	1.00	0.49
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.05	0.00	0.86	0.24	0.00	0.31	0.00	0.00	0.00	0.00	0.00		0.00
As	Cor. coef.	0.29	0.50	0.12	0.13	0.11	0.20	−0.11	−0.14	0.07	0.19	0.35	0.28	0.22	0.40	0.28	0.49	1.00
	Sig. (2-tailed)	0.00	0.00	0.12	0.07	0.15	0.00	0.15	0.05	0.35	0.01	0.00	0.00	0.00	0.00	0.00	0.00	

Cor. coef., correlation coefficient; sig., significance.

Table 4
Chemistry of selected commercial fertilizers used in the Gaza Strip

	K (%)	Ca (ppm)	Ti (ppm)	Cr (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)	Br (ppm)	Rb (ppm)	Sr (ppm)	Pb (ppm)
DL[a]	0.05	0.05	30	20	10	10	1.5	1	0.7	0.7	0.8	0.6
Gibberellic acid	<0.05	<0.05	<30	<20	13	25	<1.5	11	<0.7	<0.7	<0.8	<0.6
Fe-EDDHA	5	<0.05	<30	<20	<10	58,028	4	24	<0.7	8	2	<0.6
NO_2, Fe, Mn	>10%	<0.05	<30	<20	140	360	27	45	19	19	<0.8	<0.6
Thiabendazole	<0.05	1	1142	<20	45	10,475	<1.5	<1	45	4	5	<0.6
Clindune	4	<0.05	<30	7794	<10	204	<1.5	<1	38	18	4	<0.6
Cu, Fe fertilizer	<0.05	<0.05	<30	<20	19,987	47,890	10,583	4999	11	<0.7	18	9
$N+P_2O_5+KO$	>10%	3	44	<20	387	949	21	16	6	11	2079	<0.6

[a]DL, detection limit.

Table 5
Chemistry of selected commercial fungicides used in the Gaza Strip

Fungicide	K (%)	Ca (%)	Ti (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)	Br (ppm)	Rb (ppm)	Sr (ppm)	Pb (ppm)
Benony	<0.05	<0.05	<30	23	22	7	<1	<0.7	<0.7	<0.8	<0.6
Fosethyl aluminum	<0.05	<0.05	388	<10	642	<1.5	7	<0.7	8	3	5
Chlor thalonil	1.0	<0.05	425	76	1327	<1.5	6	3	37	127	18
Propineb	<0.05	<0.05	<30	884	3768	<1.5	>10%	260	18	<0.8	<0.6
Mncozeb	<0.05	<0.05	<30	>10%	<10	<1.5	17,500	<0.7	<0.7	<0.8	<0.6
Maneb	<0.05	2.0	10,911	19,980	11,474	23	923	6	20	322	17
Manganes	<0.05	4.0	<30	>10%	<10	<1.5	1875	<0.7	<0.7	56	<0.6
Foscthyl-aluminum	<0.05	<0.05	440	<10	843	<1.5	8	3	7	4	8
Copper chloride	<0.05	<0.05	<30	<10	4000	>10%	<1	<0.7	<0.7	<0.8	<0.6
Cyger sulfate	<0.05	<0.05	<30	<10	5977	>10%	<1	<0.7	<0.7	<0.8	<0.6
Metalaxyl	<0.05	<0.05	<30	>10%	<10	<1.5	20,927	73	12	<0.8	<0.6
Simzin	<0.05	>10	<30	<10	116	<1.5	<1	10	<0.7	70	11
Captan	<0.05	<0.05	2155	16	3072	306	14	72	22	20	30
Mineozab	<0.05	<0.05	<30	>10%	<10	<1.5	10,288	<0.7	<0.7	<0.8	<0.6

for all soils was 6 mg/kg. The average of As was 5 mg/kg, while the site near the solid waste dumping site reached 19 mg/kg. Finally, the average of Hg in the soils of Gaza was 10 μg/kg, with many samples being below the detection limit of the analytical method.

4. Discussion

The Palestinian environmental strategy (MEnA, 2000) has established that several threats cause the deterioration of soil quality in the Gaza Strip. The accumulation of solid and hazardous wastes, discharge of untreated wastewater, extensive use of fertilizers and fungicides, overgrazing, soil salinization, urbanization, vegetation removal, and soil erosion are examples of these threats. The agricultural areas are exposed to one or more of these threats.

The average content of AOX in the sludge of Gaza was (550 mg Cl/kg), which exceeds the standards of industrial countries (Shomar et al., 2004a). Despite this, the AOX in the tested soils was very low, with the highest value being 24 mg Cl/kg. Moreover, the presence of AOX in soil may be due to the effect of living organisms during natural abiogenic processes (Müller, 2003).

The results revealed that the occurrence of trace metals in the different soils of the Gaza Strip was dependent not only on the soil type but also on the location of the soil, the vegetation cover, and the agricultural activities. They showed that the levels of trace metals in the soils planted with the same crop were similar when the soil type, the irrigation water, and the fertilizers used were the same. The five soils from open lands in the different geographic regions of the Gaza Strip were almost the same.

Soils covered by wastewater during some of the flooding episodes of the winter season showed high contents of trace elements. The owners used them for agricultural purposes for the rest of the year, and insufficient care was taken to avoid contamination. Moreover, these soils were found to have Zn and Cu enrichments, and this may have been due to recycling by microorganisms (Blaser et al., 2000).

The soils exposed to the solid wastes showed high levels of trace metals. The wastes were disposed to the tested soils for long periods before they were transferred to the central dumping site. During the period of accumulation of the solid wastes, leachates may have percolated through soil, increasing the levels of trace metals.

The greenhouses showed a clear variation in the contents of trace metals. The field surveys indicated that the average age of a greenhouse in Gaza is 5 years. They are used for vegetables such as tomatoes, cucumbers, eggplants, and others, with some exceptions in the area of Beit Lahia (North), where flowers and strawberries are planted beside the vegetables. The farmers use large amounts of fertilizers and fungicides. More than 200–250 tons of formulated fungicides are applied annually in the Gaza Strip (Safi, 2002), and the majority is used in the greenhouses without monitoring. The analyses of trace metals in the most common fertilizers and fungicides revealed that they contain considerable amounts of several metals, such as Fe, Mn, Cu, Zn, and Cr, and as a consequence these elements may increase in the soils of the greenhouses. The greenhouses of the Khan Yunis area showed higher levels of several trace metals and other elements; levels of Fe, Zn, Cu, Ni, Pb, and Cr were higher than those in the greenhouses of the north area of Beit Lahia, being 12.4, 84, 17, 10, 19, and 74 mg/kg, respectively. The reason for this variation could be the soil structure, which is sandy in the north and clay in Khan Yunis (south). In addition, the soil of Khan Yunis is affected by traffic contamination. The greenhouses of Khan Yunis were 10 m from the main highway of Gaza. These results agree with findings from other authors (Manta et al., 2002; Navas and Machin, 2002; Fakayode and Owolabi, 2003).

Variations in the amounts of rainfall strongly influence the crops grown in Gaza. The groundwater quality deteriorates from north (Cl = 40 mg/L) to south (Cl = 3000 mg/L) (Shomar et al., 2004b). Consequently, strawberries and flowers are planted only in Beit Lahia, while rain-fed agriculture is located in the southeastern parts of Gaza. The presence of considerable amounts of $CaCO_3$ in soils is likely due to evapotranspiration exceeding the rainfall in Gaza. Soils with a higher rate of precipitation in the northern area, which leads to a higher rate of percolation, carbonates are easily dissolved and leached out. The amount and particle size of $CaCO_3$ minerals can increase the precipitation of calcium phosphate minerals on the surface (Sparks, 1995). This could explain the low levels of P in the northern areas of Gaza, where soils are sandy and the annual precipitation is higher than in the southern clay soils. In addition, high P levels were found in the greenhouses where P fertilizers were commonly used. It is assumed that in neutral and calcareous soils of Gaza, inorganic P in the soil solution precipitates as calcium phosphate minerals. The low contents of Ca in several soils of Gaza could be explained as being a result of soil erosion, urbanization, and vegetation removal (Sparks, 1995).

5. Conclusions

1. The soil types, crop patterns, and specific location factors largely control the distribution of trace metals (Pb, Cu, Zn, Cd, and Mn) in soils. Linear regression analysis found a correlation coefficient of $r = 0.85$ between Zn and Cd concentrations in soils with highways nearby.
2. The irrigation water, the applied fertilizers and fungicides, and the nearby sludge and wastewater have played a major role in and contributed significantly to the enrichment of several soils with Zn, Pb, Cu, and Fe. Soils affected by sludge, solid wastes, and wastewater showed similar contents of trace metals.
3. In a global context, one may note that the values for the trace metals in the different soils of the Gaza Strip were well within average worldwide soil values. These levels were still low and probably harmless to the soil ecosystem. However, the distribution pattern for Zn, Cd, and Cu in several soils clearly indicates that soil contamination due to anthropogenic factors was on the rise and may become alarming if mitigation measures are not taken.

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