Egypt. J. Soil. Sci. **48**, No. 2, pp.119 – 141 (2008)

Soil Enrichment with Heavy Metals as Affected by the Re-use of Drainage Water in Eastern Delta and Sinai

R. M. M. El-Kilani and W. A. M. Abdel Kawy
Soils and Water Department, Faculty of Agriculture, Cairo University, Giza, Egypt.

THE AIM of the current research is to check one of the constraints affecting the soil system behaviour and its sustainability. This is represented by the accumulation of heavy metals in the soil profile due to the reuse of highly polluted drainage water in irrigation either alone or mixed with fresh water.

Two case studies were investigated, the first is in Sahel El-Tina and South of Kantra areas, which is irrigated from El-Salaam Canal by mixing the drainage water of Bahr Hadous and El-Serow drains with Nile Water. The second is the south of Port Said area whose irrigation water comes from Bahr El-Bakar drain.

To do this, in both areas, a number of soil profiles were selected to represent the different mapping units in the two regions. Morphological description, physical and chemical characteristics of the different layers in the soil profile were carried out.

The heavy metals enrichment ratio for different soil profiles was used as indicator for heavy metal pollution by Co, Pb, Ni, Cd and Cr. The rate of accumulation in different soil profiles in both areas was calculated. It was shown that the current rate of accumulation in Sahel El-Tina, especially for cadmium was quite high with respect to the accepted standards. For example, the corrected rate of cadmium accumulation reached in some profiles 70 gm acre^{-1} year^{-1} with frequent values of 45 gm acre^{-1} year^{-1}. This is in comparison to 2 gm acre^{-1} year^{-1} for the Rhine River Basin in Western Europe. This rate of accumulation is quite high and threatens the sustainability of the ecosystem taking into account that the warning value for cadmium is only 5 mg/kg, *i.e.*, a value of 5 kg per acre for a depth of 20 cm.

For The south of Port Said area, very high deposition rates were obtained for Co, Pb, Ni and Cadmium. The very high corrected deposition rates for Co ranged from 185 to 261 gm acre^{-1} year^{-1}, for lead from 752 to 1547 gm acre^{-1} year^{-1}, for Ni from 471 to 1094 gm acre^{-1} year^{-1} and for cadmium from 43 to 96 gm acre^{-1} year^{-1}.

The numbers of years required to reach the warning value for the studied profiles for Co ranged from 120 to 286, for Pb from 64 to 135, for Ni from 66 years to 144 years, for Cd from 34 years to 74 years.

Cadmium pollution is the most limiting. All these values reflect a sustainability problem concerning the accumulation of heavy metals pollution and the existence of water and soil management problem.

A separation of the industrial and municipal wastewater streams has to be or a water treatment at the source of pollution has to be adopted.

In Egypt, the growing population expansion which mounts to about 1.2 million annum per year and the need to increase food self sufficiency puts an increasing demand on increasing the food production whether by horizontal or vertical expansion. In light of the restricted available water resources, the need to increase the cultivated area puts a stress on wise management of the available soil and water resources.

In Egypt, to meet the required aims in agricultural expansion which mounts to about 150 000 acres per annum, there is an increasing demand on the re-use of drainage water. Some of this water receives a considerable pollution load in going through the system. Its later re-use in irrigation represents a considerable pollution load on the soils of these irrigated areas.

Attia (1999) mentioned that there is a recycling of $12.92 * 10^9 m^3$ as official and unofficial reuse of drainage water.

Drainage water contains large amounts of contaminants, either in the form of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pesticides, nutrients, heavy metals and faecal bacteria. Recently El-Kabbany *et al.* (2000) reported that the drainage waters from agricultural districts and many industries in Egypt were highly polluted and contained much higher levels of pollutants residues.

Sahel El-Tina and South Kantra are irrigated from El-Salaam Canal. Drainage water supplied to El-Salaam Canal is estimated to be $2 * 10^9 m^3$ /year. This quantity is harvested from Bahr Hadous, Lower and Upper Serow drains together and if needed, Farasqour drain. This drainage water is mixed with equal amounts of Nile water used to irrigate 440,000 feddan in the East, North of Sinai Governorate. Bahr Hadous drain receives 80907 kg/day BOD and 116497 kg/day COD and 302442 kg/day total dissolved solids. The Serow drain receives 9010 kg/day BOD, 13225 kg/day COD and 20771 kg/day total dissolved solids (Ministry of Irrigation and Water Resources, 2002).

In South Port Said area farmers were forced to use drainage water, mainly from Bahr El-Bakar for irrigation irrespective of its quality and the environmental effects it may have. This phenomenon is called "The unofficial use of drainage water". Studies have shown that quantities used as unofficial drainage mount to no less that $3 * 10^9 m^3$ yearly (Alaam, 2001).

Bahr Al-Bakar drain receives very high organic load from domestic (point & diffuse sources) and industrial sources. A recently published report (Ministry of Water Resources and Irrigation, 2002) gives a pollution load estimate of 440462 kg/day BOD, 775635 kg/day COD and 1564 kg/day heavy metals to Bahr al-Bakar drain in the East of Delta.

The aim of the present research is to consider the status of pollution of the newly reclaimed area in Sinai and East Delta by the use of the heavy metals enrichment ratio of the surface layer with respect to the lower layers and correlate this increase to the irrigation by heavy metal loaded drainage water alone or mixed with Nile water.

Material and Methods

Sahel El-Tina and South Kantra Area

The location of the study area is shown in Fig.1. Fourteen different soil profiles representing the different mapping units in the area of Sahel El-Tina and south Kantra were chosen to represent the area under investigation.

The studied area represent approximately 323040 feddans, location on map 1 , bounded by longitudes 32° 15′ and 32° 45′ E and latitudes 30° 38′ and 31° 18′ N (Fig. 1).

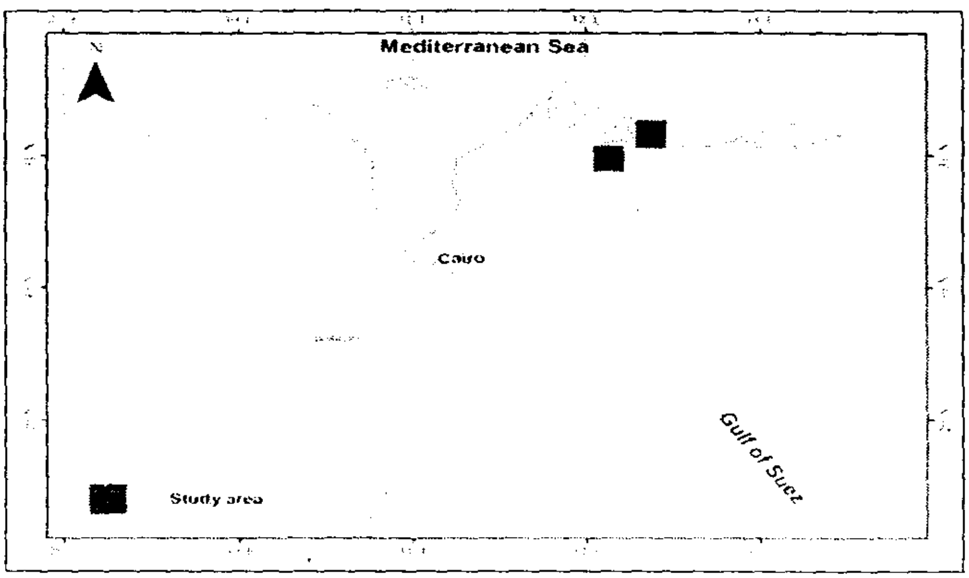

Fig.1. Location map of the study area .

The units from which the fourteen profiles were taken are shown (Fig.2). Table 1 is the legend of the physiographic- soil map of Sahel El-Tina and South Kantra study area. Representative disturbed soil samples have been collected from the studied soil profiles according to the morphological variation and used for laboratory analysis.

TABLE 1. Legend of the physiographic - soil map of the Sahel El-Tina and South Kantra studied area .

Landscape	Relief	Lithology / Origin	Land form	Mapping unit	Area (Km)	Soil sets	Type of soil sets
Plain	Almost flat to gently undulating	Marine deposits	Sand sheet	P111	11.95	Typic Psammaquents	Consociation
			Shore ridge	P112	5.35	---	---
			Dry sabkha	P113	56.32	Gypsic Haplosalids	Consociation
			Wet sabkha	P114	44.23	Typic Aquisalids	Consociation
			Salt marches	P115	42.11	---	---
			Dried swamps	P116	43.47	---	---
			Seasonally submerged land	P117	35.50	---	---
			Gypsiferous swamps	P118	43.93	---	---
			Gypsiferous flats	P119	40.78	---	---
		Fluvio – marine deposits	High old terraces	P121	11.85	Typic Torripsamments	Consociation
			Moderately high old terraces	P122	17.20	Typic Torripsamments	Consociation
			Low old terraces	P123	37.89	Typic Torripsamments	Consociation
			Basins	P124	34.90	Typic Aquisalids	Consociation
			Low clay flats	P125	112.64	Vertic Torrifluvents	Consociation
			High clay flats	P126	73.65	Typic Torrifluvents	Consociation
	Gently undulating	Aeolian deposits	Low level sand sheet	P231	95.71	Typic Torripsamments	Consociation
			High level sand sheet	P232	109.58	Typic Torripsamments	Consociation
	Undulating		Longitudinal sand dune	P333	158.40	Typic Torripsamments	Consociation
			Low barkhan dune	P334	201.28	Typic Torripsamments	Consociation
			High barkhan dune	P335	139.15	Typic Torripsamments	Consociation
			Sand bar	P336	25.88	---	---
	Water bodies			W	4.25	---	---

Total area = 1346 Km^2, *i.e.*, 323040 feddans

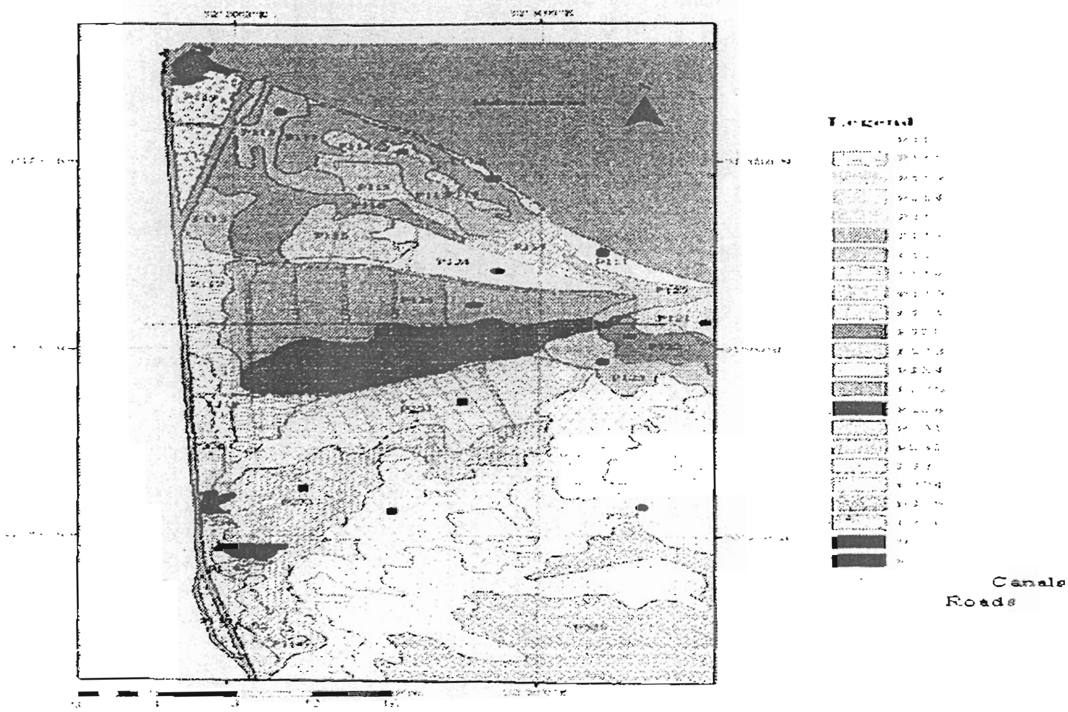

Fig. 2. Physiographic soil map of the selected profiles for Sahel El-Tina and South Kantra Areas (• profile site).

South Port Said Area

The studied area incorporates an area of approximately 80192.19 feddans. It is bounded by longitudes 32° 00` W and 32° 15` E and latitudes 30° 45` and 31° 00` N (Fig. 3).

Five soil profiles were chosen from 22 localities to represent the different soil units (Fig.3 and Table 2).

The main physical and chemical characteristics of the studied soil profiles are shown on Table 3a, b and c.

Laboratory analysis

Disturbed soil samples were collected for laboratory analyses, which include: mechanical analysis, Piper (1950) & Klut (1986)., $CaCO_3$, O.M & EC, Jakson (1967) & U.S.D.A (1991), Soil reaction pH, Richard (1954), Cation exchange capacity after Piper (1950), as modified by Gohar (1954), Exchangeable sodium according to Tucker modified method (1971) and heavy metal content in the soil was determined by the use of *aqua regia* method (Cottenie *et al.*, 1982) and measured by AAS

The dissolved heavy metals in the water were determined, after filtration and acidification by HNO_3 and the use of AAS, according to Water and Waste Water Examination (APHA, 1998).

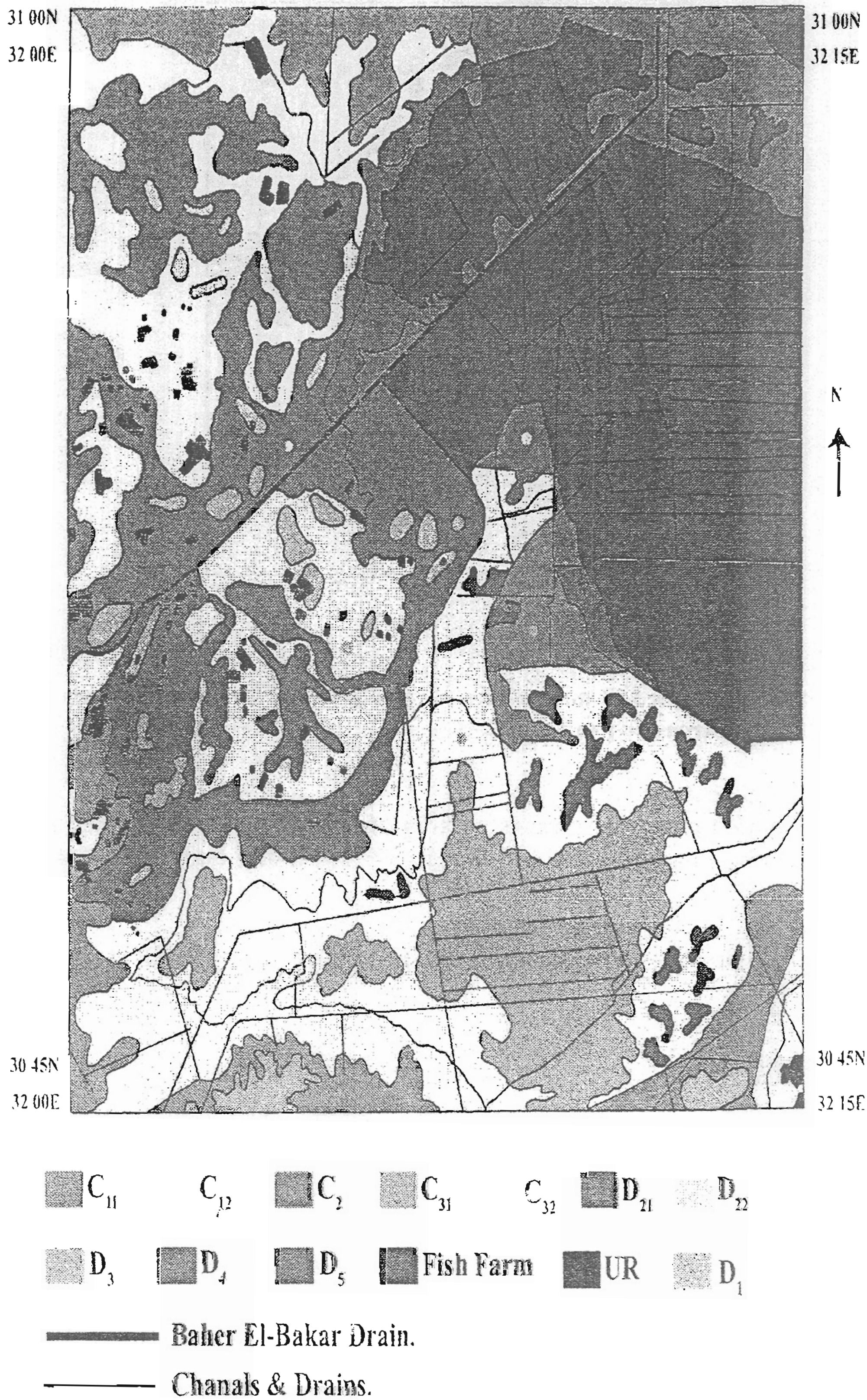

Fig. 3. Physiographic soil map of the South Port Said Area. (• profile site) .

TABLE 2. Physiographic and soil map legend of the South Port Said Area.

Landscape	Relief	Lithology/ori_gin	Land form	Mapping unit	Rep. Profiles	Soil sets	Type of Soil sets.
Coastal plain	Gently undulating	Fluvio-marine deposits	* clay flats				
			Relatively high	C_{11}	1	Vertic Torrifluvents	Cons
			Relatively low	C_{12}	2	Vertic Torrifluvents	Cons
			* clay swamps	C_2	5	Typic Aquisalids	Cons.
			* old sandy deposits. Remnants.				Cons. Cons
			Relatively high	C_{31}	6	Typic Torripsamments	
			Relatively law	C_{32}	9	Typic Torripsamments	
Young sub-deltaic deposits	Flat to almost flat	Alluvial deposits	* scattered small hills (Hummocks)	D_1	12	Typic Torrifluvents	Cons .
			* flat plains.				Cons.
			Relatively high	D_{21}	14	Typic Torrifluvents	
			Relatively low	D_{22}	22	Typic Torrifluvents	
			* marches	D_3	-	-	-
			* intermittent wet land.	D_4	-	-	-
			* Gypsiferous deposits.	D_5	-	-	-

TABLE 3a . Main physical and chemical characteristics of fine textured soils (Sahel El-Tina Soils) .

Mapping unit	Soil profile	Depth (cm)	Particle size distribution					Texture class	O.M %	$CaCO_3$ %	pH 1:2.5	EC dS/m	CEC Cmol/kg soil	ESP%
			G. %	C. S %	F. S %	Silt %	Clay %							
P125	8	0-10	0.00	0.5	3.0	31.4	65.1	Clay	0.63	0.60	7.5	63.4	61.2	10.6
		10-80	0.00	0.6	19.0	28.1	52.3	Clay	0.31	0.80	7.7	81.6	46.8	11.8
		+80	Water table level											
P126	9	0-25	0.00	0.8	31.4	21.7	46.1	Clay	0.72	1.10	8.0	23.8	41.1	12.6
		25-90	0.00	1.1	31.2	24.1	43.6	Clay	0.30	1.20	8.0	30.2	39.0	13.0
		+90	Water Table level											
P124	7	0-15	0.00	0.5	27.5	21.8	50.2	Clay	0.60	1.40	8.2	101.4	43.9	15.6
		15-55	0.00	0.7	26.8	19.1	53.4	Clay	0.21	0.60	8.4	90.2	46.4	16.8
		+55	Shells layer											
P112	14	0-10	0.00	27.5	46.2	10.7	15.6	Sandy Loam	0.30	8.6	7.9	121.6	10.1	11.6
		10-60	0.00	22.1	24.6	23.6	29.7	Sandy Clay loam	0.11	4.3	7.8	134.9	21.0	10.1
		+60	Shells layer											
P114	3	0-15	0.00	0.5	24.9	31.0	43.6	Clay	0.80	5.60	8.1	161.5	36.5	16.4
		15-40	0.00	0.7	21.9	36.4	41.0	Clay	0.46	2.60	8.3	143.1	31.9	17.0
		+40	Water table level											
P113	2	0-15	0.00	0.6	44.0	9.0	46.4	Clay	0.86	4.80	8.3	172.1	36.2	15.1
		15-45	0.00	1.1	56.0	1.7	41.2	Clay	0.40	1.24	8.3	161.6	36.3	15.8
			Water table level											

TABLE 3b . Main physical and chemical characteristics of the South Kantra Soils.

Mapping unit	Soil profile	Depth (cm)	Particle size distribution						Texture class	O.M %	$CaCO_3$ %	pH 1:2.5	EC dS/m	CEC Cmol/ kg soil	ESP%
			2-1 mm	1-0.5 mm	0.5-0.25 mm	0.25-0.125 mm	0.125-0.063 mm	<0.063 mm							
P334	13	0-20	3.61	19.16	36.60	31.94	7.41	1.28	Sandy	0.3	0.4				
		20-70	3.11	20.10	27.38	42.11	6.51	0.79	Sandy	0.1	0.1	7.5	0.6	4.8	9.0
		70-110	4.62	26.73	22.92	40.00	5.20	0.53	Sandy	0.0	0.6	7.7	0.4	3.1	8.1
P333	12	0-15	0.76	12.78	32.28	51.24	3.00	0.20	Sandy	0.2	0.3	7.2	1.6	4.7	7.0
		15-80	0.61	9.75	40.72	46.18	2.64	0.10	Sandy	0.1	0.8	7.3	1.0	5.5	7.1
		80-130	0.52	12.51	42.40	41.33	3.12	0.12	Sandy	0.0	1.2	7.5	0.4	6.2	8.2
P231	10	0-30	1.41	14.82	32.76	46.20	4.16	0.35	Sandy	0.3	1.4	7.3	0.8	4.3	8.1
		30-100	0.63	7.93	39.19	48.14	3.17	0.44	Sandy	0.1	0.8	7.6	0.6	3.5	7.3
		100-130	0.42	10.14	35.67	50.27	3.15	0.35	Sandy	0.0	0.3	7.8	0.5	4.0	8.3
P232	11	0-30	1.00	21.62	37.44	33.65	5.16	0.13	Sandy	0.4	1.4	8.0	1.7	3.1	7.4
		30-100	0.56	13.18	40.35	38.21	6.18	1.52	Sandy	0.2	1.0	7.8	1.3	4.8	8.3
		100-130	0.31	19.00	28.76	41.67	9.26	1.00	Sandy	0.0	0.6	7.7	1.2	4.2	7.8
P121	4	0-25	0.68	8.65	40.51	42.71	7.14	0.31	Sandy	0.3	0.8	7.5	2.4	5.2	8.1
		25-80	0.52	9.16	49.53	31.16	9.52	0.11	Sandy	0.1	0.3	8.0	1.9	3.2	8.9
		80-120	0.48	11.24	26.60	51.22	10.17	0.29	Sandy	0.0	0.1	8.1	1.0	2.8	7.6
P122	5	0-30	0.16	12.41	42.01	36.14	9.31	0.12	Sandy	0.2	0.9	7.2	1.9	3.6	9.6
		30-80	0.10	14.32	47.32	21.92	16.20	0.14	Sandy	0.0	0.5	7.5	1.3	4.6	8.8
		80-130	0.11	16.74	33.66	39.12	10.11	0.26	Sandy	0.0	0.3	7.4	0.7	3.1	7.3
P123	6	0-20	2.73	21.19	40.39	29.25	5.79	0.65	Sandy	0.2	1.2	7.6	1.5	1.8	8.1
		20-70	2.00	16.00	43.32	31.15	6.14	0.32	Sandy	0.1	1.0	7.5	0.8	3.4	7.4
		70-110	1.14	10.25	47.22	30.00	10.24	1.15	Sandy	0.0	0.6	7.5	0.8	5.2	7.2
P111 (North of Sahel El-Tina)	1	0-15	1.22	10.51	50.31	31.12	4.73	2.11	Sandy	0.3	3.4	7.8	11.8	1.0	10.6
		15-90	1.02	10.11	49.44	35.21	2.60	1.62	Sandy	0.1	4.6	7.7	18.2	1.0	12.8

TABLE 3c . Main physical and chemical characteristics of the South Port Said Soils.

Mapping unit	Rep. Profile No.	Depth in cm.	Particle size distribution %					Texture class	pH	O.M %	$CaCO_3$ %	EC dS/m	CEC meq./ 100 gm soil	ESP %
			Gravel	C. sand	F. sand	Silt	Clay							
C_1	1	0-35	0.0	0.64	2.17	25.56	71.63	Clay	8.6	1.8	10.2	17.6	68.2	16.4
		35-110	0.0	0.79	3.24	22.36	73.61	clay	8.7	1.5	9.6	15.3	68.9	17.6
		Water table level												
C_2	5	0-20	0.0	0.71	1.86	30.02	67.41	clay	8.8	1.9	9.7	19.1	60.3	20.2
		20-45	0.0	0.43	2.19	25.56	71.82	Clay	8.7	1.4	6.8	16.2	60.8	18.7
		Water table level												
C_3	9	0-45	0.0	4.83	55.55	16.31	23.31	SCL	8.7	1.7	11.7	18.2	13.1	18.3
		45-80	0.0	11.72	78.40	3.72	6.16	Sandy	8.6	1.2	10.3	15.4	2.2	16.9
		Water table level												
D_1	12	0-40	0.0	0.57	3.31	42.38	53.92	clay	8.5	1.6	12.6	10.6	47.8	15.8
		40-100	0.0	0.16	2.68	37.25	59.64	clay	8.5	1.2	10.4	9.2	51.1	16.3
		Water table level												
D_2	22	0-30	0.0	0.18	2.36	37.25	60.21	clay	8.8	1.8	13.5	11.3	54.2	16.4
		30-75	0.0	0.27	2.11	32.7	64.92	clay	8.6	1.1	11.2	8.7	56.3	15.5
		Water table level												

Results and Discussion

Heavy metal accumulation in the soil layers

Table 4 lists the results of the heavy metals content (mg/kg dry soil) of the surface soils for five, mainly fine textured soils at Sahel El-Tina, five coarse textured soil at South of Kantra and five soils of South Port Said Area respectively, at different layers, as determined by the use of *aqua regia* (Cottenie *et al.*, 1982) and measured by AAS.

The second row of the table contains the warning values of the heavy metals Co, Pb, Ni, Cd and Cr in (mg/kg). These values, give the concentration values of the different heavy metals that, when reached, is a warning of a problem of pollution which requires further investigation. For example, the value of Cadmium is about 5 mg/kg. If this value is reached, there is an indication of pollution. A value of 12 mg/kg cadmium in the soil, which has been lowered from the 20 mg/kg of Moen *et al* 1986, is the new intervention value. At this value, the No Observed Effect Concentration (NOEC) has been exceeded for 50% of the microbial population in the soil. For the reference value, which has been lowered to 0.8 μg/g cadmium from 1.0 μg/g, the NOEC of 5% of the microbial population in the soil has been exceeded (Vegter, 2004).

The values of the heavy metals concentration and the enrichment ratio in different layers are tabulated next. The Enrichment ratio (Enrich), for different layers of Co, Pb, Ni, Cd and Cr, was calculated as

$$\text{Enrichment ratio} = \frac{C_{\text{layer}}}{C_{\text{lowest layer}}}$$

Where C_{layer} is the heavy metal concentration in the layer under consideration and $C_{\text{lowest layer}}$ is the concentration in the lowest layer in the profile.

If the enrichment ratio is larger than one, it indicates a source of heavy metal deposition at the soil surface or a variation in the chemical composition in the parent material with depth. A horizontal variation with the studied area of this enrichment ratio excludes this latter possibility. So, the values in Table 4 give an indication of heavy metals accumulation in the upper surface layers.

The enrichment ratio differs for different heavy metals, following different mobilities. Lead, for example has very low mobility, since its retardation factor is very large. The possibilities for movement is by ploughing the soil or through chelate aided leaching (El-Kilani & Belal, 2005). The enrichment for Pb ranges from 2.89 for profile no. 5 and reaches 32.5 for profile no.7. The enrichment ratio for profile no. 7 is higher than the enrichment ratio for profile no. 3 because the denominator in profile no.7 is much lower. Profile 3 is for a clayey soil and profile 7 is for a sandy soil. The denominator is the concentration in the lowest layer of profile 7, which is 0.02 (mg/kg) while for profile 3, it is 0.3 (mg/kg).

TABLE 4.a The heavy metals concentration as determined by the use of aqua regia for fine textured soil profiles at Sahel El-Tina area.

Profiles of fine Textured soils (Sahel El-Tina)												
Element			Co		Pb		Ni		Cd		Cr	
warning values (mg/kg)			50		150		100		5		250	
Profile no.1 P125	Texture	layer depth	Con	Enrich	Con	Enrich	Con	Enrich	Con	Enrich	Con	Enrich
	Clay	0-10	0.74	2.31	1.23	3.84	1.20	3.87	0.21	1.75	0.21	3.5
	Clay	10-80	0.32		0.32		0.31		0.12		0.06	
		+80	Water table level									
Profile no.2 P124		layer depth	Con	Enrich	Con	Enrich	Con	Enrich	Con	Enrich	Con	Enrich
	Clay	0-15	0.58	1.93	1.10	3.67	1.08	2.25	0.26	2.60	0.18	4.50
	Clay	15-40	0.30		0.30		0.48		0.10		0.04	
		+40	Shells layer									
Profile no.3 P112 Shore ridge		layer depth	Con	Enrich	Con	Enrich	Con	Enrich	Con	Enrich	Con	Enrich
	Sandy loam	0-10	0.44	1.69	1.30	4.33	1.10	2.39	0.31	1.94	0.20	6.67
	Sandy Clay Loam	10-60	0.26		0.30		0.46		0.16		0.03	
		+60	Shells layer									
Profile no.4 P111 Sand Sheet	Sandy	0-15	0.36	1.71	1.20	5.71	0.90	3.00	0.28	1.75	0.19	9.50
	Sandy	15-90	0.21		0.21		0.30		0.16		0.02	
		+90	Water table level									
Profile no.5 P114	Clay	0-10	0.30	1.66	1.10	2.89	1.13	3.7	0.20	1.81	0.20	6.67
	Clay	10-25	0.18		0.38		0.30		0.11		0.03	
		+25	Water table level									

TABLE 4.b. Heavy metals concentration as determined by the use of aqua regia for coarse textured soil profiles at Sahel El-Tina, South of Kantra area.

Profiles of Coarse Textured soils (South kantar and North of Sahel El-Tina)													
	Texture	Layer Depth	Conc	Enrich	Con	Enrich	Con	Enrich	Con	Enrich	Con	Enrich
profile no.6	Sandy	0-20	0.52	7.43	0.73	18.25	0.65	21.67	0.10	10.00	0.07	7.00
P334	Sandy	20-70	0.15	2.14	0.19	4.75	0.16	5.33	0.05	5.00	0.03	3.00
South Kantra	Sandy	70-120	0.07		0.04		0.03		0.01		0.01	
		groundwater is not hit										
Profile no.7	Sandy	0-30	0.58	9.67	0.65	32.50	0.60	60.00	0.08	0.80	0.10	10.00
P231	Sandy	30-90	0.16	2.67	0.16	8.00	0.11	11.00	0.04	0.40	0.03	3.00
	Sandy	90-130	0.06		0.02		0.01		0.10		0.01	
		groundwater is not hit										
Profile no.8	Sandy	0-25	0.46	9.20	0.76	25.33	0.51	51.00	0.09	9.00	0.08	8.00
P121	Sandy	25-80	0.16	3.20	0.18	6.00	0.10	10.00	0.02	2.00	0.03	3.00
uncultivated	Sandy	80-120	0.05		0.03		0.01		0.01		0.01	
		groundwater is not hit										
Profile no.9	Sandy	0-30	0.38	12.67	0.68	6.80	0.60	30.00	0.12	12.00	0.10	10.00
P122	Sandy	30-80	0.10	3.33	0.21	2.10	0.12	6.00	0.04	4.00	0.05	5.00
	Sandy	80-130	0.03		0.10		0.02		0.01		0.01	
		groundwater is not hit										
Profile no.10	Sandy	0-20	0.45	5.63	0.71	17.75	0.64	64.00	0.10	10.00	0.12	12.00
P123	Sandy	20-70	0.21	2.63	0.15	3.75	0.13	13.00	0.05	5.00	0.07	7.00
	Sandy	70-110	0.08		0.04		0.01		0.01		0.01	
		groundwater is not hit										

TABLE 4.c. Heavy metals concentration as determined by the use of aqua regia for different soil profiles at Port Said Area.

South of Port Said												
Profile no.1	Clay	0-35	1.32	6.29	7.68	6.98	3.93	6.14	0.42	4.20	0.29	3.625
C1	Clay	35-110	0.21		1.10		0.64		0.10		0.08	
		+110	Water table level									
Profile no.2	Clay	0-20	1.05	5.25	7.00	7.00	4.11	6.85	0.40	5.00	0.32	5.33
C2	Clay	20-45	0.20		1.00		0.60		0.08		0.06	
		+45	Shells layer									
Profile no.3	Clay	0-45	0.80	7.27	3.41	3.71	2.24	6.79	0.20	6.67	0.16	5.33
C3	Clay	45-80	0.11		0.92		0.33		0.03		0.03	
		+80	Shells layer									
Profile no.4	Clay	0-40	1.16	5.52	6.82	9.61	4.68	7.67	0.46	4.60	0.33	3.30
D1	Clay	40-100	0.21		0.71		0.61		0.10		0.10	
		+90	Water table level									
Profile no.5	Clay	0-30	1.10	6.11	8.93	19.41	3.00	10.00	0.42	3.82	0.36	4.50
D2	Clay	30-75	0.18		0.46		0.30		0.11		0.08	
		+75	water table level									

The enrichment ratio depends on the shape of the solute front or the shape of pollutant breakthrough curve. The breakthrough curve depends on exchange isotherm of the pollutant being convex upwards (favourable exchange) which lead to very steep front and thus a high enrichment ratios or concave upwards (unfavourable exchange) which lead to very spread front (Bolt, 1978). The enrichment ratio also depends on the stage we are in the breakthrough curve. The Breakthrough curve of the clayey soil is in much advanced stage than the sandy soil.

The highest enrichment ratio (Enrich) values for the clay textured soils of Sahel El-Tina were recorded for Pb (3.67-5.71) and Cr (3.5-9.5), while the lowest one was recorded for Cd (1.75) due to its high mobility. The Enrich values for the sandy textured soils were much higher than for the clayey soils since the absolute values are much lower. The corresponding Enrich values in sandy soils ranged from 17-32 for Pb and 30-64 for Ni whereas for Cd it reached up to 16.

As for Port Said clayey soils, which is irrigated directly from Bahr El-Bakar drain, the enrichment ratio values are much higher compared to those of Sahel El-Tina and south El-Kantra. The Enrich values in Port Said ranged between 7-19 for Pb and 6-10 for Ni while it was 4-7 for Cd. This could be rendered to the high concentration of different heavy metals in Bahr El-Bakar compared with those in El-Salaam Canal .

This could reflect the higher mobility of Cd and Co relative to the low mobile metals of Cr and Pb which tend to accumulate in the surface layer.

The tested heavy metals could be arranged according to their Enrich values as follows

Cr> Pb> Ni> Cd for clayey soils of Sahel El-Tina
Ni> Pb> Cr> Cd> Co for sandy soils of South Kantra

These sequences are in agreement with Martley, *et al.* (2004) and Zhang *et al.* (2006).

The deposition rates

The corresponding quantities of heavy metal existent in every soil layer, of the five mentioned above heavy metals were calculated as

$$Q_i = {C_i A \Delta z \rho_b}/{1000}$$

where
Q_i is the heavy metal content of the corresponding soil layer (gm).
C_i is the concentration of the heavy metal in the corresponding layer in mg/kg .
A is the are of one feddan (4200 m^2) .
Δz is the corresponding soil layer thickness (m).
ρ_b is the bulk density of the soil (kg m^{-3}) .

The 1000 factor is used to convert the heavy metal content in the layer from mg to gm. The uncorrected rate of heavy metal accumulation in different soil layers for the different heavy metals was calculated .

$$Rate_{i,uncorrected} = Q_i / n$$

The total heavy metal content for the soil profile was calculated by summing up Q_i for different layers.

The heavy metal content was divided by the total number of years since irrigation started (n=10), since the irrigation works ended in 1992. The total rate of accumulation the whole profile was then calculated by summing the yearly rates of accumulation for the different layers in the profiles.

To take account of the background concentration, a soil profile which is not cultivated, was taken as the reference value. This is profile no. 5, which has the lowest enrichment value for Pb (1.66) and it is a wet Sabkha. The value of the calculated deposition for this reference profile was subtracted from the total yearly accumulation rate to give a conservative corrected estimate of the deposition rate value of the heavy metals. Any net accumulation in the other profiles after subtracting the reference profile should be an indication of real deposition.

$$Rate_{corrected} = \Sigma Q_i / n - \text{refrence profile or refrence value}$$

$$\text{Number of years} = \frac{\text{Warning Value}}{\text{Rate corrected}}$$

In Table 5, the final values of the corrected accumulation and the number of years required to reach the warning values for different heavy metals are tabulated.

For the Sahel El-Tina plain, from Table 5, the number of years required to reach the warning values are the lowest for the case of cadmium. This shows that cadmium is the most limiting factor for sustainability for the system. These values are as low as 100 year or even less; 59 years for soil profile P111. A 100 year years is a value which indicates no sustainability of the established agricultural ecosystem. When compared with the Rhine Valley in Europe, the number of years required to reach the warning value is 2500 years. Cadmium yearly rate of accumulation values for the Rhine valley in Western Europe is about 2 gm acre^{-1} year^{-1} (United Nations University, 1994). The corrected accumulation rate reaches even higher values from 18 to 84 gm Cd acre^{-1} year^{-1}. These are very high values and indicate a source of pollution which has to be handled.

P111 is coarse textured soil. The accumulation could be due to lower movement of irrigation water through the profile and the accumulation of the pollutants in the irrigation water due to evaporation from the soil surface.

TABLE 5. The corrected rate of heavy metal accumulation and the number of years required to reach the warning values.

Element		**Co**		**Pb**		**Ni**		**Cd**		**Cr**	
Warning Value (mg/kg)		**50**		**150**		**100**		**5**		**250**	
Sahel El-Tina	Texture	Rate	Years	Rate	Years	Rate	Years	Rate	Years	Rate	Years
P125	Clay	162.0	309	121.0	1240	120.3	831	46.0	109	21.8	11447
P124	Clay	40.3	1240	18.8	7972	34.9	2862	18.5	271	4.4	57234
P112	Sandy clay loam	78.6	636	76	1975	122.3	818	50.1	100	7.1	35431
P111	Sandy	103.8	482	114.6	1309	135.7	737	84.3	59	12.8	19580
P114 Reference	Clay	38	-	112	-	106	-	24.5	-	16.5	-
Profiles of Coarse textured soils (south Kantra and Sahel El-Tina)											
P334		-	-	-	-	-	-	8.4	595	-	-
P231		47	1048	-	-	42.7	2343	33.9	147	7.7	32350
P121 Uncultivated Reference for Kantra		149.8	-	202.3	-	125.3	-	25.0	-	27.2	-
P122		-	-	39.	3849	42.7	2343	15.8	317	13.1	19078
P123		2.7	18601	-	-	7.1	14172	7.7	647	15.1	16534
Profiles of fine textured soils South Port Said											
C1		261.1	120	1547	64	773.9	80	75.3	34	49.4	2304
C2		114.3	286	806.4	135	471.7	153	43.	74	34.9	5553
C3		208.6	187	752	120	577.6	132	51.4	74	39.3	4509
D1		255.3	126	1642.3	71	1094	66	96.8	30	61.8	1938
D2		185.5	181	1707.6	77	544.3	144	62.5	42	62.5	2583

For the coarse textured soils in South kantra soils (second part of Table 5), the values of the accumulation rate are much lower. This is shown by the number of years required to reach the warning values. They range from as low as 147 years to 647 years for cadmium. For other heavy metals studies, the number of years is much larger. This does not mean the problem is not there but that the retardation factor, and so the retention capacity of the soil for cadmium or other heavy metals pollutants in irrigation water is much lower in the coarse textured soil than in the fine textured soils. A comparison between Table 3.a and 3b show the much higher values of the CEC for the fine textured soils of Sahel El-Tina with respect the coarse textured soils of South Kantra . A comparison between Table 3a and 3b show the higher values of the organic matter and to a lower degree the $CaCO_3$ content of these same soils. All these factors go into the higher retention capacity and so, the higher retardation factor for the fine textured soils with respect the coarse textured soils. So, If pollutants are added to the soil in irrigation water, it will held or retarded in the fine textured soils and move much faster in the coarse textured soils. The retardation factors for different heavy metals differ. For Lead, it is very high. It could reach values of thousands, while for Cadmium in soils is much lower.

For the Port Said Area . The background concentration was assumed equal to the concentration in the lowest layer in every soil profile.

From the results in Table 5, it was found that cadmium is not the only limiting factor. The other studied heavy metals, namely Co, Pub, and Ni are also critical. Cadmium is the most limiting one. For the first soil profile, the number of years required to reach the warning value were 120, 64, 80 and 34 years for Co, Pb, Ni and Cadmium respectively. The number of years required to reach the warning value for Cr was 2304 Years, So, there is no problem with Cr accumulation. The calculated rates of accumulation show very high values for the deposition of different heavy metals. For example, the rate of lead deposition for the first profile was 1547 gm lead $acre^{-1}$ $year^{-1}$. The rate of deposition, in case of assuming the background concentration is zero, mounts to 2360 gm lead $acre^{-1}$ $year^{-1}$ (not in the table). The real rate of deposition is somewhere in between these two rates. In any case, both of them are very high value of deposition. In Table 5, the uncorrected rate of accumulation is not listed. Only the corrected rate of accumulation is listed.

For Cadmium, the corrected yearly rate of deposition for the first soil profile ranges from about 149 gm cadmium $acre^{-1}$ $year^{-1}$, when considering no source of cadmium in the original soil minerals to 75 gm cadmium $acre^{-1}$ $year^{-1}$ when subtracting the cadmium content in the second layer, as the background value. For the studied soil profiles, these values ranged from 67 to 43 gm cadmium $acre^{-1}$ $year^{-1}$ respectively. For the third profile, these values ranged from 67 to 51 gm cadmium $acre^{-1}$ $year^{-1}$. For the fourth profile, these values ranged from 163 to 97 gm cadmium $acre^{-1}$ $year^{-1}$. For the fifth profile, these values ranged from 117 to 62.50 gm cadmium $acre^{-1}$ $year^{-1}$. These corrected deposition values will need a period 30 to 74 years, for the corresponding soil to exceed the warning values, as given by

Moen *et al.* (1986) . These are very short time periods and reflect the existence of a very serious soil and water management problem. If we compare these numbers with numbers from the Rhine basin, we see that rate of deposition for the Rhine valley basin is about 5 gm hectare^{-1} year^{-1} (United Nations University, 1994).

For the second soil profile, the number of years required to reach the warning values for the first four heavy metals ranged from 74 to 286 for Co, Pb, Ni and Cd. The number of years for Cr mounts to 5553. So, the problem is the first four heavy metals and not the last one. Cadmium is the most limiting.

For the third soil profile, the number of years required to reach the warning values for Co, Pb, Ni and Cd ranged from 74 to 187. Cadmium is the most limiting.

For the fourth soil profile, the number of years required to reach the warning values for Co, Pb, Ni and Cd ranged from 30 to 126. This profile receives much higher pollution load than the second and the third and almost similar to the first profiie.

For the fifth Soil profile, the number of years required to reach the warning values for the first four heavy metals ranged from 42 to 181 for Co, Pb, Ni and Cd.

The problem and proposed solution

For the Sahel El-Tina, the source of Cadmium comes from irrigation water. A look at heavy metals content of El-Salaam irrigation water (Table 6) shows that the Cd dissolved content of the irrigation water is about 0.02 mg/l water. Using an amount of irrigation water of about 4000 m^3/acre per year will introduce an amount of Cd to the soil which is about 80 gm year^{-1} acre^{-1}. This is a very high value of yearly addition of cadmium and accounts for most of the calculated added cadmium to the soil.

TABLE 6. Heavy metal content of irrigation water of El-Salaam Canal as determined by AAS.

	Fe	Mn	Zn	Cu	Co	Pb	Ni	Cd	Cr
El-Salaam Irrigation water	0.2	0.2	0.04	0.07	0.03	0.02	0.03	0.02	0.03
Bahr El-Bakar irrigation water	-	-	-	-	0.05	0.07	0.06	0.04	0.08

The source of Cadmium in drainage water is the municipal waste water and industrial waste water and which shows that if we want to reuse or recycle drainage water, which is in fact a necessity, an awareness of the importance of heavy metals content in the drainage water and methods to reduce its content in industrial waste water before being discharged to the drainage system has to be introduced.

For the south of Port Said Area, the problem comes from using drainage water from Bahr El-Bakar drain which is highly polluted in irrigation. The industrial waster water is mixed with municipal waste water and then discharged into the drainage system. The industrial waste water contains large amounts of heavy metal pollution. A policy of separating the two wastewater streams has to be adopted and a treatment at the source of pollution has to be adopted.

The heavy metal content of Bahr El-Bakar Drain water is shown in Table 6. If the Bahr El-Bakar drain water, depending on the availability of irrigation water in the irrigation canals, form the sole source of irrigation water for most of the soils in this region and the dissolved Cadmium content is 0.04 ppm, which represents a 0.04 gram per cubic meter of the water used for irrigation. Depending on the fractional use of drain water in the irrigation which is one for most of the studied area, the use of 4000 m^3 per acre per year for irrigation, will increment the cadmium content of the surface layer by 160 grams per year per acre. The critical ceiling of 5 μg/kg dry soil, *i.e.*, 5 kg/acre for the upper layer of soil, assuming an initial content of 0.0 ppm, will be reached in 30 years.

Another point which is worth mentioning, is that the determined value of cadmium concentration in the drain water was that of the dissolved and not the total, which is higher due to the cadmium adsorbed to the suspended particles and which will shorten the time span even further. This point could explain the discrepancy between the observed high deposition for lead and the amount calculated from the dissolved in drainage water.

Conclusion

The enrichment ratio of the five heavy metals in mainly heavy clays soils of Sahel El-Tina, the fine textured soils of South Kantra and the fine textured soils in South port Said area, show that there is a problem concerning the use of drainage water, either mixed as in El-Salaam canal or alone as in South of Port Said Area, concerning the accumulation of these heavy metals in the soil profile. In the fine textured soils of Sahel El-Tina, Cadmium was the most limiting factor. In the fine textured soils of South Kantra, the soils have no problem due to its coarse texture which gives it a low retention capacity of pollutants in the soil. In the fine textured soils of South Port Said, the soils have a problem in the accumulation of Co, Pb, Ni and Cd to such an extent that it threatens the sustainability of the ecosystem. Cadmium was the most limiting. A budget study of the cadmium sources in the Egyptian Agricultural Ecosystem, its sources, and its adsorption and retention in Egyptian soils has to be initiated. A water treatment at the source of heavy metals or a separation of the industrial water stream and municipal water streams and separate treatment of the industrial stream has to be done.

Egypt. J. Soil. Sci. **48,** No. 2 (2008)

References

Alaam, M. N. E. (2001) *Water and Agricultural Land in Egypt, the past, the present and the future,* Academic Bookshop, Cairo, Egypt.

APHA (1998) *"Standard Methods for the Examination of Water and Wastewater"* S. Lenore; A. Clesceri; E. Greenberg and A. D. Eaton (Ed.), 20 th ed., Published by the American Public Health Association, the American Water Works Association and the Water Environment Federation.

Attia, B. (1999) Assessment of water resources in Egypt. Background paper presented for NEAP (National Environment Action Plan). August 1999.

Bolt, G. H. (1978) Transport and accumulation of soluble soil components. In: *"Soil Chemistry"*, A. Basic Elements. Developments in soil Science, G.H. Bolt and M. G. M. Bruggenwert (Ed.), Elesevier, Amsredam.

Cottenie, A.; M.Verloo; L. Kiekens; G. Velgh and R. Camerlynck (1982) *"Chemical Analysis of Plants and Soils"*, 63p., Lab. Anal. Agrochem. . State Univ., Ghent, Belgium.

El-Kabbany, S.; Rashed, M.M. and Zayed, M.A. (2000) Monitoring of the pesticide levels in some water supplies and agricultural land . in El-Haram, Giza, A.R.E. *Journal of Hazardous Materials* **72** (1): 11-12 .

El-Kilani, R. M. M. and Belal, M.H. (2005) A model of soil pollution load due to multiple industrial point sources. A paper presented in the Third international Conference on Soils of Urban, Industrial, Traffic, Mining, and Military Areas (SUITMA 2005), held in Cairo, Egypt in 17-25 November 2005, by the International Union of Soil Sciences.

Goher, A.A.L. (1954) The influence of exchangeable cations on the physical properties of Egyptian Soils, *M.Sc. Thesis,* Faculty of Agriculture, Cairo Univ., Egypt.

Jackson, M.L. (1967) *"Soil Chemical Analyses"*, Prentice-Hall Inc., Engle-Wood Cliffs, N.S. Constable & Co. Ltd., London.

Klut, A. (1986) *"Methods of Soil Analysis Part-1, Physical and Mineralogical Methods"*, 2nd ed., Amer. Soc. of Agron., Madisom, Wisconsing, USA.

Martley, E.; Gulson, B.; Louir H.; Wu M.; and Ping, D. (2004) Metal partitioning in soil profiles in the vicinity of an industrial complex, New South Wales,.Australia. Geochemistry: exploration, environment and analysis, Vol. 4, 2, pp. 171-179.

Ministry of irrigation and water resources (2002) Survey of Nile System Pollution Sources, Report no. 64.

Moen, J.E.T.; Cornet, J.P. and Evers, C.W.A. (1986) *"Contaminated Soil"* , J.W. Assink and W.J. Van Den Brink (Ed.), Martinus Nijhoff Dordrecht.

Piper, C.S. (1950) *"Soil and Plant Analyses"*, A monograph from the wait, Agric. Research Institute, Univ. of Adelaide, Australia.

Richard, L.A. (1954) " *Diagnosis and Improvement of Saline and Alkali Soils"*, U.S. Dept. of Agric., HandBook , No. 60.

Tucker, B.M. (1971) " *Basic Exchangeable Cations in Soils"*, Soil Tech. Pup, No. 8, Aust. and GRES. 5: 706-715.

USDA (1991) *"Soil Survey Laboratory Methods Manual"*, Soil Investigation Report, No. 42, version N. 1.0 Oct. 1991, 603 p.

United Nations University (1994) *"Industrial Metabolism: Restructing for Sustainable Development"*, Robert U. Ayres and Udo E. Simonis (Ed.), United Nations University Press, Tokyo, Japan.

Vegter, J.J. (2004) Soil protection. In: *"Soil Pollution and Soil Protection"*, F.A.M. Haan and M.I. Visser-Reyneveld, International Book Distribution Co. (Publishing division), India.

Zhang, M. K.; Fang, L.P. and Huang, C.Y. (2006) Competitive adsorption and mobility sequence of heavy metals urban soils of southeastern china: *Journal of Environmental Sciences*, no. 2 .

(*Received* 11/2007;
accepted 12/2007)

تراكم الفلزات الثقيلة فى أراضى مناطق شرق الدلتا و سيناء بتأثير إعادة استخدام مياه الصرف

رشدى محمد محمد الكيلانى و وائل أحمد محمد عبد القوى
قسم الاراضى والمياه – كلية الزراعة – جامعة القاهرة – الجيزة – مصر .

إن الهدف من هذا البحث هو فحص واحد من المحددات المؤثرة على سلوك نظام التربة واستدامته ويتمثل ذلك فى تراكم العناصر الثقيلة فى قطاع التربة نتيجة لاستخدام مياه صرف عالية التلوث فى الرى أما بصورة منفردة أو مخلوطة مع مياه النيل و قد تم دراسة حالتين : الأولى فى سهل الطينة وجنوب القنطرة التى تروى من ترعة السلام بواسطة خلط مياه الصرف لمصارف بحر حادوس والسرو مع مياه النيل و الثانية لمنطقة جنوب بورسعيد التى تأتى مياه ريها من مصرف بحر البقر.

ولكى نقوم بهذا فى كلا المنطقتين ، فقد تم اختيار عدد من قطاعات الأرض لكى تمثل الوحدات الخريطية المختلفة . وقد تم إجراء الوصف المورفولوجى وتقدير الخصائص الطبيعية والكيماوية للطبقات المختلفة . وقد استخدمت نسبة التغنية بالمعادن الثقيلة للقطاعات المختلفة كمؤشر للتلوث بالكوبالت و الرصاص والنيكل والكادميوم والكروميوم . ولقد تم حساب معدل التراكم فى قطاعات التربة المختلفة . ولقد أظهرت الحسابات أن معدل التراكم فى سهل الطينة ، خاصة الكادميوم مرتفع للغاية بالنسبة للمقاييس المقبولة. وعلى سبيل المثال فان المعدل المصحح لتراكم الكادميوم وصل فى بعض القطاعات ل ٧٠ جرام لكل فدان مع وجود قيم كثيرة تبلغ ٤٥ جرام لكل فدان لكل عام ، هذا بالمقارنة ب ٢ جرام لكل فدان لكل عام لحوض نهر الراين فى أوروبا الغربية. فان هذا المعدل للتراكم عال جدا ويهدد استدامة النظام البينى أخذا فى الحسبان أن قيمة التحذير للكادميوم تبلغ ٥ ملجم لكل كجم أى نحو ٥ كجم لكل فدان للطبقة السطحية حتى عمق ٢٠ سم. وبالنسبة لمنطقة جنوب بورسعيد ، وقد تم التوصل لقيم عالية لترسب الكوبالت ، الرصاص ، النيكل و الكادميوم. ولقد تروحت قيم الترسيب العالى للكوبالت من ١٨٥ جرام إلى ٢٦١ جرام للفدان فى العام وللرصاص من ٧٥٢ إلى ١٥٤٧ جرام لكل فدان لكل عام وللنيكل من ٤٧١ إلى ١٠٩٤جرام لكل فدان لكل عام وللكادميوم من ٤٣ إلى ٩٦ جرام لكل فدان لكل عام.

و تراوحت عدد السنوات المطلوبة للوصول للقيم التحذيرية للقطاعات المدروسة للكوبالت من ١٢٠ إلى ٢٨٦ عام و للرصاص من ٦٤ إلى ١٣٥ عام وللنيكل من ٦٦ إلى ١٤٤ عام و للكادميوم من ٣٤ إلى ٤٧ عام ويعتبر التلوث بالكادميوم هو أكثر العوامل تحديدا للنظام . و كل تلك القيم تعكس مشكلة استدامة فيما يختص بتراكم تلوث المعادن الثقيلة ووجود مشكلة إدارة مياه وتربة .

ولذلك فانه من اللازم فصل المياه العادمة من المصانع عن تلك من المنازل أو تبنى إجراء معالجة للمياه عند مصدر التلوث قبل إلقائها فى شبكة المجارى.