

## Speciation and Mobility of Lead, Chromium and Zinc in Soils of Abis Region, Egypt

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**ABSTRACT:** This study describes the chemical speciation of Pb, Cr and Zn in soils of Abis area in Egypt. The studied area is located at the North Western part of the Nile Delta, which represents soils developed from lacustrine deposits at Abis region south of Mariut Lake and covers about 40000 fed. Total 41 top soil samples (0-35 cm) were collected from the area for analysis. The total contents and fractions of Pb, Cr, and Zn were determined, and the mobility factor and potential mobility were calculated. Small amounts of Pb, Cr, and Zn retrieved from the soluble and exchangeable phases, the readily available for biogeochemical cycles in the ecosystem. Low quantities of Pb, Cr and Zn could be available to plants. Zn is present in negligible amounts lower than those of Pb or Cr. The results also indicate that most of the metals have high abundance in residual fraction indicating lithogenic origin and low bioavailability of metals in the studied soil. The values of average mobility factor for Pb, Cr and Zn in the soils of Abis area were 7.31, 6.74 and 0.51%, respectively which is less than 10%. Therefore, these elements are highly stable in soil. The average potential mobility of Pb, Cr and Zn were 15.05%, 34.79% and 8.25% respectively. The Zn had the least average potential mobility (8.25%). The order of average potential mobility of metals soils agrees with the percentage reduction in concentration of residual heavy metal.

**Keywords:** Lead, chromium, zinc, chemical speciation, mobility, potential mobility

### INTRODUCTION

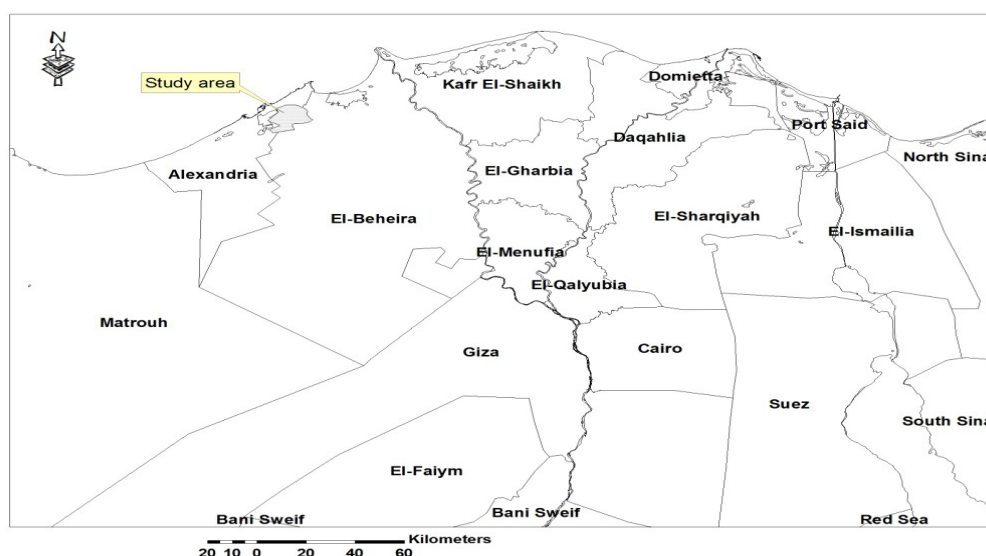
Soils are the reservoir for many harmful constituents, (elemental and biological), including heavy metals. Total elemental content of soils is useful for many geochemical applications but often the speciation of these metals is more of an interest agriculturally in terms of what is biologically extractable (Cottenie *et al.*, 1980). Speciation is defined as the identification and quantification of the different, defined species, forms, or phases in which an element occurs (Tack and Verloo, 1995) and is essentially a function of the mineralogy and chemistry of the soil sample examined (Tessier *et al.*, 1979). Quantification is typically done using chemical solutions of varying but specific strengths and reactivity to release metals from the different fractions of the examined soil (Ryan *et al.*, 2008). In terms of bioavailability, various species of metals are more biologically available in the ecosystem (Nelson and Donkin, 1985). Bioavailability and the mobility of metals are also related to each other, then higher concentration of mobile toxic metals in the soil which increases the potential for plant uptake, and animal/human consumption (Ratusny *et al.*, 2009). Heavy metals are included in soil minerals as well as bound to different phases of soil particles by a variety of mechanisms. Moreover, soil properties such as contents of organic matter, carbonates and oxides influence the heavy metal mobility (Kabata-Pendias and Pendias, 2001). It is widely recognized

that to assess the environmental impact of soil pollution, the determination of the metal speciation will give more information about the potential for release of contaminants and further derived processes of migration and toxicity (Usero *et al.*, 1998). Therefore, in geo-environmental studies of risk assessment, chemical partitioning among the various geochemical phases is more useful than measurements of total heavy metals contents (Quevauviller *et al.*, 1996). There is no information available in the literature on heavy metals speciation, mobility, availability and toxicity in soils of Abis region in Egypt. Herein, the objectives of this study were aimed at determining the speciation and mobility of Pb, Cr and Zn metals in the top soil of this area.

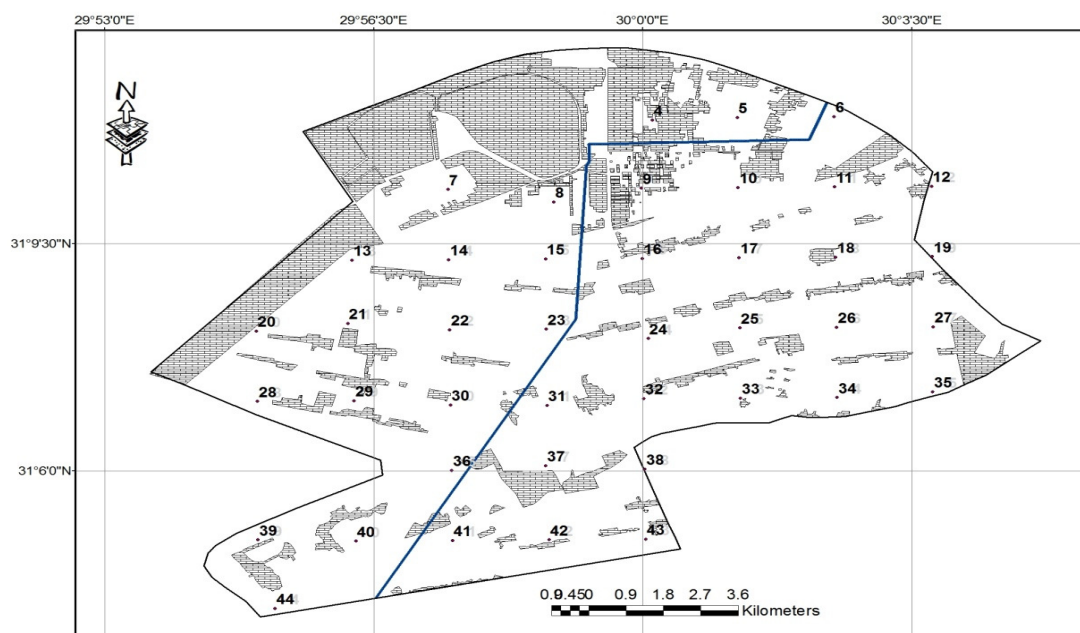
## MATERIAL AND METHODS

### Site description and soil samples

The studied area is located between 31° 00' to 31° 30' N and 29°30' to 30° 30'E at the north western delta fringes south of Mariut Lake which named Abis (Map 1). It covers parts of Alexandria and El-Behira Governorates with total area about 40000 Fed. Forty one surface (0-35 cm) soil samples representing the studied area were taken as shown in Map 2. The soil analysis for pH ,EC , CaCO<sub>3</sub> %, soluble cations, soluble anions and particle size distribution were carried out using the methods described by Page *et al.* (1982) as presented (Yehia *et al.*, 2014). Also, the organic matter was determined using Walkley-Black wet combustion method (Tan, 1996). The statistical characterization of soil samples are presented in Table (1).



**Map (1): The general location of the study area**



**Map 2: The soil sample locations of the study area**

### **Total heavy metals measurement**

Total concentrations of heavy metals (Pb, Cr, and Zn) were determined by wet digestion in soil according to (Page *et al.*, 1982); 1 g of collected surface soil was placed in a Teflon crucible 5 mL HNO<sub>3</sub>, 10 mL HF and 12 mL HClO<sub>4</sub> were added in to the soil and oscillated for 10 h then under constant temperature (80°C). After the sample was almost dried, 10 mL nitric acid (1:1) was added to dissolve the solids continually. The dissolved soil sample was transferred constantly to 50 mL volumetric flask to determine the total contents of the tested metals in soils.

### **Estimating forms of the tested heavy metals**

Sequential extraction procedure was carried out using 2.0 g soil was involved to the five following steps (Tessier *et al.*, 1979; Tessier *et al.*, 1980):

#### **1. Water soluble:**

Samples of finely grounded air-dried soil were transferred top shaking bottle followed by 16 ml of deionized water and samples were shaken on a reciprocating shaker for 1 h. The suspension was centrifuged for 30 minutes and then the supernatant was filtered through whatman 42 filter papers.

#### **2. Exchangeable fraction:**

The same soil sample was placed in contact with a high ionic strength solution, in order to release the so-called exchangeable fraction of metal by altering the sorption–desorption superficial processes. In this step 16 ml of 1 M NH<sub>4</sub>OAc (pH=7) were added to the sample and the supernatant was shaken for 2 h.

### **3. Fraction bound to carbonate:**

The fraction of metal bound to carbonates, present in the sample, may be selectively labialized by varying the pH of the sample itself with a slightly acidic extraction solution. 16 ml of 1 M of  $\text{CH}_3\text{COONa}$ , plus  $\text{CH}_3\text{COOH}$  (pH= 5) were added to the residue obtained from the former extraction, and the suspension was shaken for 5 h.

### **4. Fraction bound to iron and manganese oxides:**

The residue from fraction 3 was extracted under mild reducing conditions of 13.9g of hydroxylamine hydrochloride ( $\text{NH}_2\text{OH}\cdot\text{HCl}$ ) was dissolved in 500mL distilled water to prepare 0.4M  $\text{NH}_2\text{OH}\cdot\text{HCl}$ . The residue was extracted with 20mL 0.4M  $\text{NH}_2\text{OH}\cdot\text{HCl}$  in 25% (v/v) acetic acid with agitation at 96°C in a water bath for 6 hours. The extracted metals solution was decanted from the residual soil which was used for the next extraction.

### **5. Fraction bound to organic matter and to sulphides:**

The residue from fraction 4 was oxidized as follows: 6mL 0.02M  $\text{HNO}_3$  and 10mL 30% (v/v) hydrogen peroxide was added to the residue from fraction 4. The mixture was heated to 85°C in a water bath for 2 hours with occasional agitation and allowed to cool down. Another 6mL of 30% hydrogen peroxide, adjusted to pH 2 with  $\text{HNO}_3$ , was then added. The mixture was heated again at 85°C for 3h with occasional agitation and allowed to cool down. Then, 10mL of 3.2M ammonium acetate in 20% (v/v) nitric acid was added, followed by dilution to a final volume of 50 mL with de-ionized water.

### **6. Residual fraction:**

It is the metal fraction present as scatter within the crystal lattice of the rocks and minerals that constitutes the soil. It was calculated from the difference between the concentration of total metal and the sum of the first four fractions.

After each extraction, the suspension was subjected to centrifugation for 20 min at 4000 rpm. The solution was separated, while the precipitate was washed with 10 ml of high purity water and centrifuged again for 5 min. The washing water then was added to the supernatant, while the precipitate was used for the subsequent extractions. The extracts were diluted to 50 ml by distilled water and analyzed for the selected heavy metals by atomic absorption spectrometer (Analytike Jena, Germany)®.

### **Classic statistical analysis and Kriging maps**

The important information about variables is provided by descriptive statistics using the Statistical Package for Social Science (SYSTAT) version 12.0. Measures of tendency of variables were determined by mean and median as well as computing the dispersion of a variable in variance, standard deviation, Coefficient of Variation (CV) and range (Cen *et al.*, 2006). Geostatistical analyses of any parameter readings were calculated for their semivariogram. A semivariogram indicates autocorrelation as a function of distance (semivariance versus distance separation) to plot spatial variability (Shibusawa, 1998). Its components which include fitted model type, nugget variance ( $C_0$ ), structural variance sill ( $C_0+C$ ), range (A), Residual Sum of Square (RSS), coefficient ( $r^2$ ) and proportion

( $C0/[C+C]$ ) were calculated by Geostatistical analysis software through GS<sup>+</sup> Geostatistics for the Environmental Science (Gamma Design Software, Version 9, LLC Plainwell, Michigan). Variability has been identified as spatial, temporal and predictive. Spatial variability of total heavy metal contents was obtained in this study to monitor difference in maps of this measured parameter. These data were interpolated using ArcGIS 10.1 through spatial analysis extension on semivariogram results for Geostatistical Software (GS<sup>+</sup>).

## RESULTS AND DISCUSSION

### 1. Characterization of the studied soils

The minimum, maximum and average values of main physical and chemical properties of soil are shown in Table 1. The data show that the studied soils are characterized by sandy loam to sandy clay loam texture in most samples. Data of total soluble salts, as expressed by the electrical conductivity and sodium adsorption ratio indicate that most of the studied soils are characterized by their moderate to high EC and SAR values. The EC values ranged between 0.77 and 10.91 dS/m, SAR values being in the range from 2.05 to 16.00 dSm<sup>-1</sup>, total carbonate content ranged between 2 and 34%. pH values ranged between 7.92 and 8.83. The amounts of sand, silt and clay varied from 47.70 to 83.04, 2.00 to 17.74 and 8.96 to 44.00%, respectively.

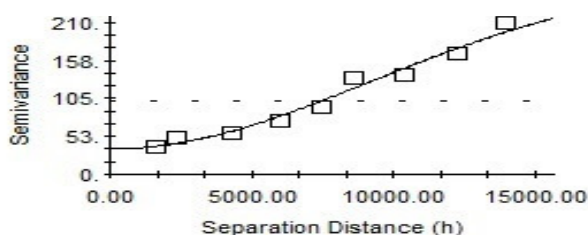
**Table (1). Statistical parameters of the estimated properties and total heavy metals of the soil samples**

Soil Properties	Average	Range		SD	Median	CV %	Var.
		Min.	Max.				
pH	8.17	7.92	8.83	0.19	8.18	2.31	0.04
EC, dSm <sup>-1</sup>	3.32	0.77	10.91	2.28	2.81	69.00	5.19
CaCO <sub>3</sub> , %	15.60	2.00	34.00	9.90	18.50	64.00	98.00
O.M, %	1.80	0.28	3.76	0.79	1.88	43.89	0.62
SAR	7.59	2.05	16.00	4.54	7.39	1.46	20.64
<b>Soluble Cations( meqL<sup>-1</sup>)</b>							
Ca <sup>+2</sup>	7.44	1.00	34.00	6.83	5.00	92.00	46.64
Mg <sup>+2</sup>	9.43	1.00	31.00	7.70	6.00	82.00	59.23
Na <sup>+</sup>	23.18	4.00	80.00	18.85	19.00	81.00	355.40
K <sup>+</sup>	0.46	0.12	1.20	0.28	0.40	61.00	0.08
<b>Soluble Anions( meqL<sup>-1</sup>)</b>							
HCO <sub>3</sub> <sup>-</sup>	3.66	1.00	10.00	2.80	2.50	77.00	7.84
Cl <sup>-</sup>	21.07	3.00	101.50	19.80	17.50	94.00	391.95
SO <sub>4</sub> <sup>=</sup>	15.57	0.30	56.66	13.62	13.66	87.00	185.46
<b>Particle size distribution (%)</b>							
Sand	69.02	47.70	83.04	8.98	69.70	13.01	0.64
Silt	10.34	2.00	17.74	3.93	11.00	38.01	15.44
Clay	20.70	8.96	44.00	8.29	12.20	40.05	68.72
<b>Total Heavy Metals (mgkg<sup>-1</sup>)</b>							
Pb	25.64	14.73	65.05	11.20	22.20	43.68	125.48
Cr	21.20	2.72	47.83	10.04	20.04	47.36	100.86
Zn	85.45	45.18	142.20	24.81	84.85	29.03	615.56

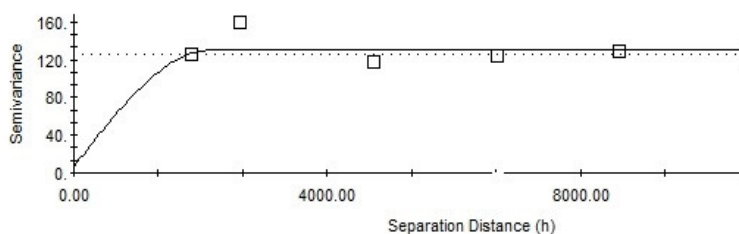
SD: standard deviation; CV: Variation coefficient; Var: Variance

## 2. Total concentrations of Pb, Cr and Zn in soil

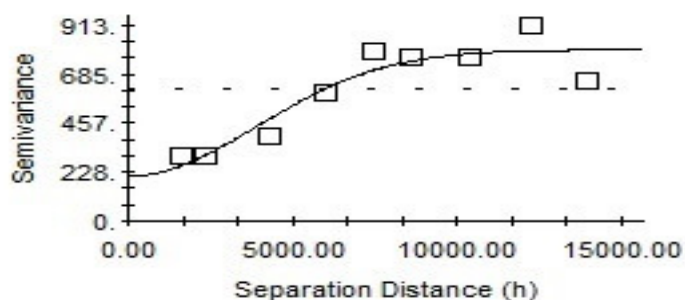
The concentration of heavy metals in the soils of Abis area was determined and the statistical parameters of the estimated total heavy metals in the soil samples are presented in Table 1. The mean concentrations of Pb, Cr and Zn were 25.64, 21.20, 85.18 mgkg<sup>-1</sup>, respectively. High metal concentrations in the soils were found for Zn, while Cr had the least concentrations. The mean values of the heavy metal contents can be ranked in the order of Zn >Pb >Cr (Table 1). According to Jones and Jarvis (1981), processes of metal mobilization-immobilization are affected by a variety of soil properties. To examine this influence, data from this study were statistically analyzed to illustrate the relationship among total content of heavy metals, EC, pH, organic matter, clay, sand and silt are listed in Table 2. A positive correlation was recorded between Zn and clay ( $r= 0.358^*$ ). Also, a negative correlation between total Zn and sand ( $r=-0.404^{**}$ ) was observed. Geostatistical analyses of total heavy metals were presented according to its semivariogram. As mentioned in material and method, semivariogram has different components and the variograms of total Cr, Pb and Zn were prepared as shown in Fig. 1., Fig.2 and Fig.3. The classification approach using raster calculator, which was available in the spatial analyst for calculating the total Pb, Cr and Zn and calculated maps were produced. The classification technique of manual, which was introduced by ArcGIS software, was selected to visual variability as groups. This study decided to zone the area into 5 zones which could be manageable and also easy to compare.



**Fig (1) : Isotropic semivariogram of total Cr, Exponential model (C0= 35.3; C0+C = 271.5; Ao= 12970; R<sup>2</sup>= 0.976; RSS = 665)**



**Fig(2): Isotropic semivariogram of total Pb, Spherical model, (C0= 7.10; C0+C = 130.4; Ao= 2150; R<sup>2</sup>= 0.008; RSS = 1190)**



**Fig(3): Isotropic semivariogram of total Zn, Gaussian model (C0= 210; C0+C = 799.5; Ao= 5530; R<sup>2</sup>= 0.87; RSS = 52595)**

Map 3 shows the distribution of total Pb in the soil representing the study area using weighted average. It is clear that, total Pb is variable and ranged from 23 to 32 mg kg<sup>-1</sup> soil. The dominant total Pb class was 23 to 25 mg kg<sup>-1</sup> soil covered about 29.17% of the area and mostly found in the northern part of the study area and is found in Alexandria Governorate. Also another dominant class had 26-27 mg kg<sup>-1</sup> covered about 38.16 % and mostly found in Behira Governorate.

Total Cr ranged from 0.2 to 43 and classified into five classes as shown in Map 4. The dominant classes had 25 to 31 mg/kg soil and covered about 27.06% of the area and mostly found in El Behira Governorate. Also, another dominant class had 20 to 24 mg kg<sup>-1</sup> soil covered about 30.63% of the area and found in Alexandria Governorate.

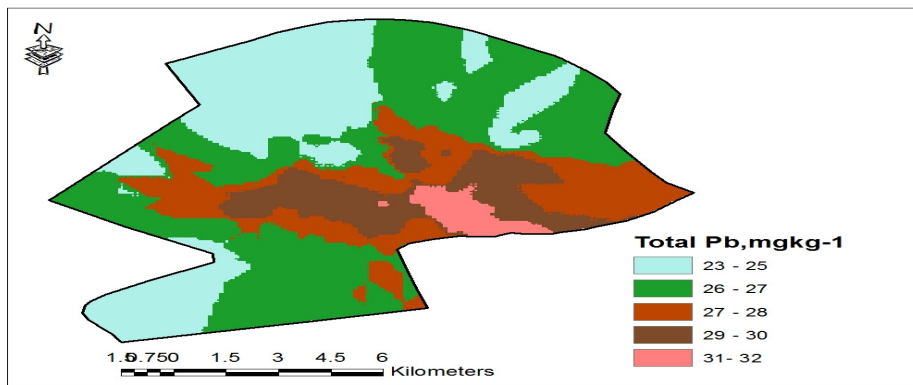
Total Zn contents ranged from 48 to 130 mg kg<sup>-1</sup> soil and classified into five classes as shown in Map 5. The dominant classes had 48 to 68 mg kg<sup>-1</sup> soil and covered about 32.07% of the area and mostly found in Alexandria governorate. The class which had the higher content of Zn (120 to 130 mg kg<sup>-1</sup>) was found in Behira governorate and covered about 9.65% of the area.

**Table (2): The correlation coefficients between total heavy metals and some properties of the soil samples**

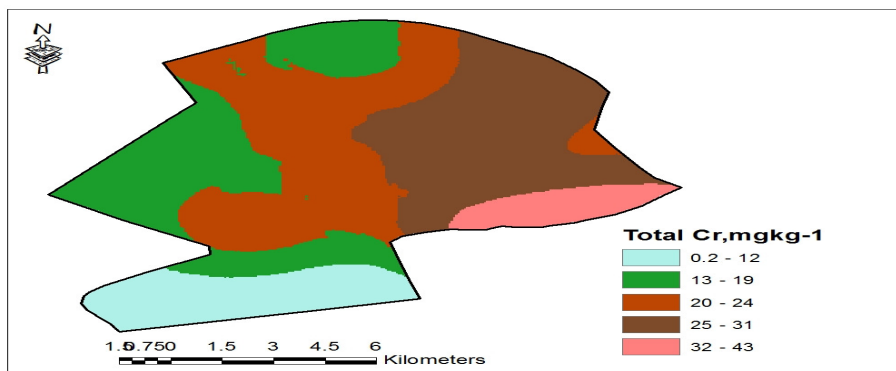
Heavy metals	EC dS/m	pH	CaCO <sub>3</sub> %	O.M. %	Clay %	Silt %	Sand %
<b>Pb</b>	0.002	-0.251	-0.007	0.074	0.120	-0.271	-0.014
<b>Cr</b>	-0.118	-0.100	-0.0512	-0.157	0.281	-0.176	-0.155
<b>Zn</b>	-0.088	0.069	0.144	-0.117	0.358*	0.129	-0.404**

\*Significant at 5% level,

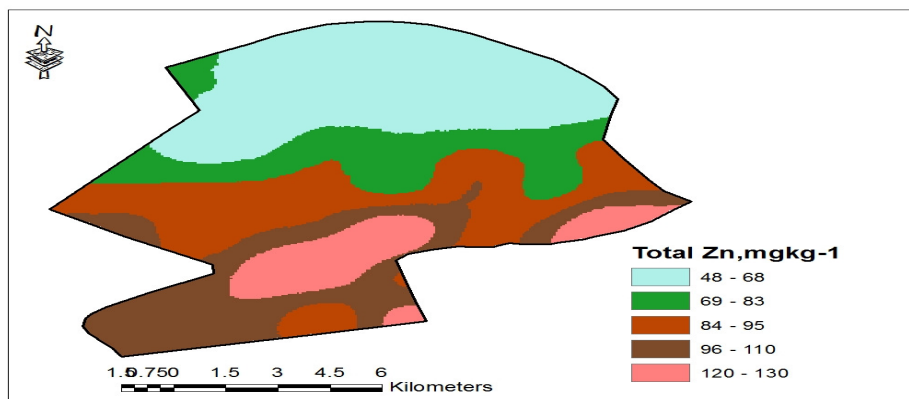
\*\*Significant at 1% level



**Map (3): Distribution of total Pb in the top soil of Abis area**



**Map (4): Distribution of total Cr in the top soil of Abis area**



**Map (5): Distribution of total Zn in the top soil of Abis area**

However, total heavy metals contents were found to be in the permissible limits reference values of heavy metals for agricultural soils according to the FAO (2001). The values of the limits reference of Zn, Pb and Cr were 300, 100, 100 mgkg<sup>-1</sup> soil, respectively.



### 3. Geochemical fractions of Pb, Cr, and Zn in soil

Metal chemical speciation carried out by sequential extraction is essential to the metal mobility (Tessier *et al.*, 1979). The obtained results (Tables 3 and 4) showed that the amounts of heavy metals extracted from each fraction vary widely. The order of mobility of the metals considering their abundance in the fractions is: soluble+ exchangeable > bound to carbonate > bound to oxides > bound to organics > residuals (Tessier *et al.*, 1979). Oxides exist as nodules and cement between particles. These oxides hold trace metals and can be mobilized under reducing and acidic conditions. The organic phase is relatively stable in nature but can be mobilized under strong oxidizing conditions due to degradation of organic matter (Haung *et al.*, 2007).

#### 3.1. Fractionation of Pb

The statistical parameters of Pb fractions and their percentages of the total extracted are presented in Tables 3 and 4, respectively. The dominant fraction for lead in soils of Abis area was the residual fraction. This chemical form was closely followed by the exchangeable fraction. The partitioning of Pb varied among all the fractions. More than 80% of Pb (Table 4) was held in the residual form, which indicates the bioavailability potential of Pb. The stability of metals bound to sediments as inorganic compounds (metal oxides, hydroxides, carbonate and sulphides) is controlled primarily by the pH system (Poulton *et al.*, 1988). The order of the partitioning of Pb in the soils of Abis area is  $F_6 > F_2 > F_3 > F_4 > F_5 > F_1$ . This agrees with those found by Ramirez *et al.*, (2005), who reported that Pb was mostly associated with the residual fraction.

#### 3.2. Fractionation of Cr

Chromium is mostly abundant in residual fraction (Tables 3 and 4). The abundance of Cr in residual phase ranged between 0.06 to 43.88 mg kg<sup>-1</sup> soil with a mean of 15.58 mg kg<sup>-1</sup> soil (Table 3) and 65.63 % of total (Table 4). The calcium carbonate fraction is the second in abundance after the residual fraction, the range was from 0.22 to 7.41 mg kg<sup>-1</sup> with a mean value of 2.70 mg kg<sup>-1</sup> soil and the abundance was 18.04% of total. Abundance of Cr in other geochemical phases was very low. This means that Cr was less mobile in this environment.

#### 3.3. Fractionation of Zn

Zinc is mostly abundant in residual fraction in the range from 37.68 to 135.24 mg kg<sup>-1</sup> with a mean value of 79.13 mg kg<sup>-1</sup> soil (Table 3) and 91.33% of total (Table 4) while in the oxide fraction, the range of Zn was from 1.06 to 9.13 mg kg<sup>-1</sup> with a mean value of 2.69 mg kg<sup>-1</sup> soil (Table 3) and the abundance was 3.66% of total. Abundance of Zn in other fractions was low. Also, Zn in this environment was less mobile since the metals which were mostly abundant occurred in the Residual fraction. This is in agreement with the data reported by Zerbe *et al.*, (1999).

**Table (3): Range, mean, standard deviation (SD) of heavy metals in different geochemical fractions of soil samples**

Geochemical Fractions	Heavy metals(mgkg <sup>-1</sup> Soil)											
	Pb				Cr				Zn			
	Range		Mean	SD	Range		Mean	SD	Range		Mean	SD
	Min	Max			Min	Max			Min	Max		
F1	0.00	1.38	0.46	0.41	0.00	1.32	0.03	0.21	0.0	0.53	0.01	0.08
F2	0.19	2.81	1.08	0.57	0.00	3.98	1.26	0.83	0.0	1.33	0.40	0.22
F1+F2	0.19	3.66	1.62	0.76	0.00	3.98	1.29	0.89	0.0	1.33	0.41	0.22
F3	0.11	3.28	0.76	0.83	0.22	7.41	2.70	1.46	0.70	3.29	1.65	1.03
F4	0.00	6.22	0.60	1.26	0.14	0.93	0.35	0.16	1.06	9.13	2.69	1.69
F5	0.11	0.99	0.57	0.27	0.26	3.0	1.29	0.65	0.11	5.69	1.57	1.46
F6	10.22	57.41	22.50	11.02	0.06	43.88	15.58	9.72	37.68	135.24	79.13	25.24

F1: Soluble- fraction; F2: Exchangeable fraction; F3: Carbonate fraction F4: Fe+Mn-oxide fraction; F5: Organic matter fraction; F6: Residual fraction

**Table (4): Range, mean, standard deviation (SD) of heavy metals (% of total) in different geochemical fractions of soil samples**

Geochemical Fractions	Heavy metals(mgkg <sup>-1</sup> Soil)											
	Pb				Cr				Zn			
	Range		Mean	SD	Range		Mean	SD	Range		Mean	SD
	Min	Max			Min	Max			Min	Max		
F1	0.00	7.43	2.19	2.15	0.00	6.62	0.16	1.03	0.00	0.86	0.02	0.13
F2	0.87	15.39	5.09	3.33	0.00	49.87	6.57	7.80	0.00	4.17	0.58	0.63
F1+F2	0.87	18.73	7.26	4.19	0.00	49.87	6.73	7.96	0.00	4.17	0.60	0.63
F3	0.18	4.76	1.43	1.20	0.97	68.03	18.04	15.77	0.93	4.03	1.94	0.90
F4	0.00	18.89	2.58	4.85	0.49	16.05	2.92	3.56	0.98	11.64	3.66	2.81
F5	0.31	6.32	2.67	1.62	1.94	33.09	7.56	5.35	0.13	8.76	2.14	2.29
F6	66.45	96.19	85.95	6.96	1.88	91.74	65.63	23.46	77.53	96.86	91.33	5.10

F1: Soluble- fraction; F2: Exchangeable fraction; F3: Carbonate fraction F4: Fe+Mn-oxide fraction; F5: Organic matter fraction; F6: Residual fraction

**Table(5): Correlation between some soil properties and the fractions of the tested heavy metals**

	<b>Metals Fractions</b>	<b>pH</b>	<b>EC dS/m</b>	<b>CaCO<sub>3</sub> %</b>	<b>O.M %</b>	<b>Clay %</b>	<b>Silt %</b>	<b>Sand %</b>
<b>Pb</b>	Exchangeable	-0.017	0.186	0.091	-0.106	0.059	0.262	-0.166
	Carbonates	-0.175	0.271	0.242	-0.065	0.255	0.099	-0.272
	Oxides	0.167	-0.116	-0.310*	0.203	-0.045	-0.078	0.075
	Organic	0.267	-0.087	0.361*	0.213	-0.132	0.137	0.053
	Residuals	-0.029	-0.146	0.008	-0.099	0.111	-0.290	0.003
<b>Cr</b>	Exchangeable	0.248	0.021	-0.099	0.055	-0.358*	-0.109	0.368*
	Carbonates	0.113	-0.059	0.184	0.102	-0.203	-0.338*	0.341*
	Oxides	-0.300	0.186	0.332*	-0.20	-0.174	0.246	0.051
	Organic	-0.055	-0.065	-0.571*	-0.247	-0.099	-0.215	0.184
	Residuals	-0.158	0.152	-0.510**	-0.168	0.359	-0.105	-0.257
<b>Zn</b>	Exchangeable	-0.141	-0.198	-0.062	0.031	0.268	0.001	-0.266
	Carbonates	-0.072	-0.083	0.265	-0.059	0.262	0.071	-0.263
	Oxides	-0.056	-0.044	-0.511**	-0.210	0.026	-0.170	0.055
	Organic	-0.065	-0.065	-0.505**	-0.174	-0.104	-0.289	0.215
	Residuals	-0.077	-0.032	0.194	-0.090	0.343*	0.153	-0.400*

\*Significant at 5% Level, \*\* Significant at 1% Level

The results of the sequential extraction show that most of Pb, Cr and Zn are strongly retained in the residual fraction in all soils. These heavy metals are contained in the crystal lattices of minerals with strong bindings and consequently they will not be released into the environment. Metals present in the residual fraction are a measure of the extent of environmental pollution. The higher the metals present in this fraction, the lower the degree of pollution (Howari and Banat, 2001). Sum of concentrations of metals in different geochemical fraction can be used to express the potential mobility of metals. The exchangeable fraction represents the mobility and bioavailability heavy metal fraction. In this phase, the heavy metals have the more labile bounds and can be easily released into the environment. The presence of heavy metals in this fraction where they can be taken up by plants from the soils is the most hazardous to the ecosystem.

According to Jones and Jarvis (1981), processes of metal mobilization-immobilization are affected by a variety of soil properties. To examine this influence, correlations between pH, carbonate, organic matter and clay percentages and contents of Pb, Cr and Zn in five chemical fractions' of the sequential extraction have been calculated for all soil samples. As can be seen in (Table 5), a significant negative correlation between the carbonate contents and organic and residual fractions of Cr was observed. On the other hand, a positive correlation was found with oxide fraction. Also, a negative correlation and positive correlation were observed for oxides and organic fractions respectively. Cr from the exchangeable and carbonates phases is also positively related to sand contents. Zinc from the oxide and organic fractions are negatively related to CaCO<sub>3</sub> content.

Also, zinc in residual fraction is positively related to clay contents and negatively related to sand contents.

#### 4. Mobility and potential mobility of Pb, Cr, and Zn in soil

The used sequential extraction enables to assess the bioavailability and potential mobility of metals in soils. Assuming that bioavailability is related to solubility, then metal mobilization decreases in the order: soluble>exchangeable>carbonate>Fe-Mn oxide> organic>residual (Ma and Rao, 1997). Results gained by sequential extraction procedures can be summarized using the concepts of mobility factor (MF) and potential mobility (PM). Elements mobility in a soil is determined from mobility factor which is calculated from the following equation as described by (Kabala and Singh 2001) and (Oluwatson, 2008).

$$\text{Mobility Factor (MF)} = \frac{F_1 + F_2}{\text{Total}} \times 100$$

Also, the potential mobility (PM) can be calculated according to Ashraf *et al.* (2012) as follows:

$$\text{Potential Mobility (PM)} = \frac{F_1 + F_2 + F_3 + F_4 + F_5}{\text{Total}} \times 100$$

The mobility and potential mobility of heavy metals in soils are summarized in Table (6). The value of MF for elements provide information about their potential mobility in soils and availability to plants (Yusuf, 2007). The value of MF up to 10% for any element indicates that this element is highly immobile and unavailable for plants (Torri and Lavado, 2008). In addition to that, the value of MF up to 50% or greater than 50 % for a particular element suggests that this element is highly mobile and available for plants (Ahumada *et al.*, 1999). Oluwatson *et al.* (2008) reported, while studying the availability and mobility of Pb and Zn in the urban soils of North-West Nigeria that the percentage of mobility factor (MF) for Pb and Zn varied from 5 to 6, and 15 to 25%, respectively in all soils. They concluded that Pb was highly stable in soils hence unavailable to plants. The average mobility factor for Pb, Cr and Zn in the soils of Abis area is 7.31, 6.74 and 0.51%, respectively. Therefore, these elements are highly stable in soil and unavailable to plants.

The average potential mobility of Cr was 34.79% (Table 6). From the result of the sequential extraction in all the studied soil samples, Cr was mostly abundant in the residual fraction and the abundance was lower in the soluble and exchangeable fractions. High abundance of a metal in the residual phase compared with its abundance in other geochemical phases indicates lower mobility of the metal in the environment. This showed that Cr would not easily be released to the environment and not toxic. Zinc is mostly abundant bound to residual and the average potential mobility of Zn was 8.25%. Therefore, compared with other metals that were mostly abundant in the residue fraction, Zn was less available in the study soils. The average potential mobility of Pb is 15.05%, which is lower than the potential mobility of Cr and Zn which had the least average potential mobility

(8.25%). From Table 6, the order of average potential mobility of Pb, Cr and Zn in the studied soils agrees with the percentage reduction in residual concentrations (Table 3).

**Table (6) : Range, mean, standard deviation (S.D.) of mobility factor (%) and potential mobility(%)for the heavy metals in the studied soil samples**

Heavy metals	Mobility properties	Range		Mean	SD
		Min	Max		
Pb	MF	0.87	18.73	7.31	4.24
	PM	3.81	48.00	15.05	8.63
Cr	MF	0.00	49.87	6.74	7.95
	PM	8.26	98.12	34.80	23.25
Zn	MF	0.00	1.67	0.51	0.27
	PM	3.14	22.47	8.25	4.69

MF=Mobility factor, PM= Potential mobility

The potential mobility of the tested heavy metals were in the following order: Cr (34.80%) > Pb (15.05%) > Zn (8.25%). However, values of the percentage reduction in concentration for metals sometimes might be controlled not only by its speciation, changes in pH and salinity, but also by unknown factors (Haug *et al.*, 2007). Metals with anthropogenic origin are mainly extracted in the first step of sequential extraction procedures while lithogenic metals are found in the last step of the process corresponding to the residual fraction (Ramirez *et al.*, 2005). The Cr and Pb and Zn metals at Abis area, from the results of sequential extraction, were mostly lithogenic origin.

## CONCLUSION

The results obtained from sequential extraction procedure showed that most of Pb, Cr and Zn considered had the highest abundance in the residual fraction. This indicates that these metals were immobile. The largest proportions for Pb, Cr, and Zn were extracted in the residual fraction, in which metals are strongly retained in the soil minerals. This showed that soil in the environment was not likely to be polluted by these metals. The average potential mobility of Pb, Cr and Zn in the soil was quite low especially for Zn. The average potential mobility of the metals, arranged in decreasing order, was as follows: Cr > Pb > Zn. The obtained results have given the present status of metal pollution in the studied area. Further research can be carried out on the speciation of other heavy metals in Abis area.

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### الملخص العربي

## توصيف وحركة الرصاص و الكروم والزنك في أراضي منطقة أبيس - مصر

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توضح هذه الدراسة التوصيف الكيمائي لكل من الرصاص، الكروم والزنك في أراضي منطقة أبيس في مصر. وتقع منطقة الدراسة في الجزء الشمالي الغربي من دلتا النيل، التي تمثل التربة الناشئة من الرواسب البحرية في منطقة أبيس جنوب بحيرة مريوط والتي تغطي نحو 40000 فدان. وقد تم جمع عينات من التربة السطحية (0-30 سم) عددها 41 عينة من هذه المساحة لتحليلها وإجراء التجارب المعملية عليها. وتم تقدير المحتوى الكلي وصور كل من الرصاص، الكروم، والزنك، كما تم حساب عامل الحركة *Mobility factor* وجهد الحركة المحتمل *Potential mobility* من صور هذه العناصر. وقد لوحظ انفراد كميات صغيرة من الصور الذائبة والمتبادلة وهي المتاحة للدورات البيولوجية الكيمائية في النظام البيئي. و يتواجد الزنك بكميات ضئيلة وأقل من تلك التي من الرصاص أو الكروم. وانخفاض الصور المتحركة لهذه العناصر يستبعد مخاطر السمية في التربة. كما أوضحت النتائج الى أن معظم العناصر تتواجد بتركيز مرتفع في الجزء المتبقى مشيرا الى أنها من أصل معدني *Lithogenic* وانخفاض صلاحيتها في التربة التي شملتها الدراسة. وكان متوسط قيم عامل الحركة لكل من الرصاص، الكروم والزنك في هذه الأراضي من منطقة أبيس هي 7.31% و 6.74% و 0.51% على التوالي وهو ما يقل عن 10%. لذلك، فهذه العناصر في درجة عالية من الثبات في التربة وغير متاحة للنباتات. وكان متوسط جهد الحركة المحتمل لكل من الرصاص، الكروم والزنك هي 15.05% و 34.79% و 8.25% على التوالي. أي أن الزنك هو الأقل في متوسط جهد الحركة المحتمل (8.25%). وكان ترتيب متوسط جهد الحركة المحتمل في هذه الأراضي يتوافق مع الانخفاض في تركيز الجزء المتبقى من العناصر الثقيلة المختبرة.