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Evaluation of Heavy Metals Pollution by Using Pollution Indices in the Soil of Assiut District, Egypt

H.S. Mekky, E.A. Abou El-Anwar*, S.A. Salman, A.A. Elnazer, W. Abdel Wahab and A.S. Asmoay

Geological Sciences Department, National Research Centre, 33 El Bohouth Street (Formerly El Tahrir Street), P.O. Box 12622, Dokki, Giza, Egypt.

ASSIUT District represents an important part of central Nile Valley. It is a complex district containing many big industries, urbanization and agricultural activities. These activities can lead to the pollution of agricultural soil with toxic heavy metals. The aim of this work is the assessment of potential risks of these metals in soils using pollution indices; Enrichment Factor (EF), Index of Geoaccumulation (I_{geo}), Contamination Factor (CF), Ecological Risk Factor (E_r), Degree of Contamination (C_d), Pollution Load Index (PLI) and Potential Ecological Risk Index (PERI). The present study calculated the mentioned indices for eight heavy metals; As, Cd, Co, Cr, Cu, Ni, Pb, and Zn.

Pollution indices calculations revealed that the investigated area can considered generally moderately polluted with the studied heavy metals. The emission of heavy metals from the factories as well as agricultural practices, urban runoff and sewage stations in the zone may be the source of that pollution. Consequently, control methods must be functional to the area adjacent to the factories to diminish the pollution. Finally, the studied cultivated soils showed low pollution than other cultivated soils in Australia, Canada, Germany, Tanzania, Netherlands, USA, as well as other areas in Egypt.

Keywords: Heavy metals, Pollution indices, Assiut, Contamination, Cultivated soil.

Introduction

"Heavy metals" term called on a group of metals and metalloids with density >4 g/cm^3 and have environmental concern [1]. Some of them are essential micronutrients (e.g. Cu, Fe, Mn and Zn) and others are highly toxic (e.g. Cd, Hg and Pb) even at low concentrations. Heavy metals are generally non-biodegradable in natural environments with low concentrations and some of them are essential micronutrients [2]. Elevated concentrations of heavy metals in the environment can threaten the food chain, causing various harmful problems for plants, animals, and humans [3]. Introduced heavy metals hazards to food chain are related to their bioaccumulation and bio-magnifications through biogeochemical processes [4], their toxicity, persistence, and non-biodegradability [5].

Accumulation of heavy metals in soil caused deterioration of soil and vegetation quality [6]. Heavy metals enrichment in the soil can be resulted from both anthropogenic and/or natural activities [7]. Natural sources include lithogenic and pedogenic weathering [8]; precipitation [9, 10]. The natural content of metals in parent material can be considered as the geochemical background in soil [8]. The main anthropogenic sources of heavy metals are industrialization, urbanization, vehicle exhaust and agricultural activities [11]. The resulted metals from anthropogenic activities are more mobile and harmful for the environment than those resulted from the natural process. Mostly, heavy metals highest levels are recorded in the surface layers of soil profile because of direct and indirect human activity [7]. Soil pollution with toxic metals, often linked to a site near the industrial zones and vehicle roads.

*Corresponding author e-mail: abouelanwar2004@yahoo.com
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Pollution indices application is considered the most comprehensive method for soil pollution evaluation. The most widely used pollution indices are the Enrichment Factor (EF), Index of Geoaccumulation (I_{geo}), Contamination Factor (CF), Ecological risk factor (E_r), Degree of Contamination (C_d), Pollution Load Index (PLI) and Potential Ecological Risk Index (PERI) [12, 13, 14]. Pollution indices assist in the evaluation of environmental risk and soil degradation, the prediction of future ecosystem sustainability as well as provide the opportunity to increase environmental awareness in society [7, 15]. Thus, the aim of this research was the assessment of the agricultural soils of Assiut District by using pollution indices to provide information on the sources of contamination and health hazards and, finally try giving recommendation to decrease its effect.

Materials and Methods

The study area

The studied samples are located in Assiut District between latitudes 27° 9' and 27° 13' N and longitudes 31° 6' and 31° 10' E (Fig. 1). The study area characterized by complex activities; including big industries (cement chemical, fertilizers, detergents and food), urbanization and agriculture. In addition, there is a main sewage station (El-Madabgh sewage station) which is used to irrigate many crops.

Many authors studied geology (Fig. 2) and structural geology of the area [16-20]. The area composed of sedimentary succession ranges from Tertiary to the Recent. The geology of the study area, land use and source rocks have a great impact on the chemistry of soil [21].

Sampling and analyses and Pollution equation

Sixteen soil samples (30 cm depth) were collected using hand-driven stainless steel augers from the cultivated farms around the industrial sites in the study area (Fig. 2). Standard sampling techniques, high purity chemicals and clean apparatus and glassware were used during all stages of samples collecting, handling and analyzing to prevent contamination. The samples were air-dried, ground, passed through a 2-mm sieve and then oven-dried at 110° C for 3 h. Each sample was ground to pass through a 63-mesh sieve and homogenized for analysis. For the determination of total metal concentration, exactly 1 g of powdered soil sample was digested with aqua regia (HNO_3: HCl = 1: 3). The elements were determined in the extract by the atomic absorption spectroscopy (Buck Scientific 205 AA) [22].

Pollution indices calculations

The enrichment factor (EF), index of geoaccumulation (I_{geo}), contamination factor (CF), degree of contamination (C_d), pollution load index (PLI), ecological risk factor (E_r) and the potential ecological risk index (PERI) were calculated according the following equations. The average world soil content of elements (Table 1) was used as background ($\mathbf{B_m}$) in this study. The classes of each index were presented in the results (Tables 2-5).

The enrichment factor (EF) is given by the following equation [23]:-

$$EF = (C_m/B_m) / (R_s/R_c)$$

Where, $\mathbf{C_m}$ is content of the examined element in the soil, $\mathbf{B_m}$ is content of the examined element in the world soil, $\mathbf{R_s}$ is content of the reference element in the soil and $\mathbf{R_c}$ is content of the reference element in the world soil. In this study, zirconium was used as a conservative tracer to differentiate natural from anthropogenic components. Zirconium is generally considered as mainly originated from natural lithogenic sources (rock weathering of mineral zircon) and has no significant anthropogenic source [24, 25].

The index of geoaccumulation (I_{geo}) was calculated by the following equation [26]:-

$$I_{geo} = Log_2 (C_m/1.5*B_m)$$

Where Cm is the measured concentration of the examined metal in the soil samples and Bm is the geochemical background value of the same metal. The constant 1.5 is used for the possible variations of the background data due to the lithogenic effects. Muller [26] has distinguished seven classes of the Igeo (Table 3).

The Contamination Factor (CF), Ecological Risk Factor (E_r), Degree of Contamination (C_d), Pollution Load Index (PLI) and Potential Ecological Risk Index (PERI) were determined using the following equations [27]:-

$$CF = C_m/B_m$$

$$C_d = \sum CF$$

$$E_r = T_r * CF$$

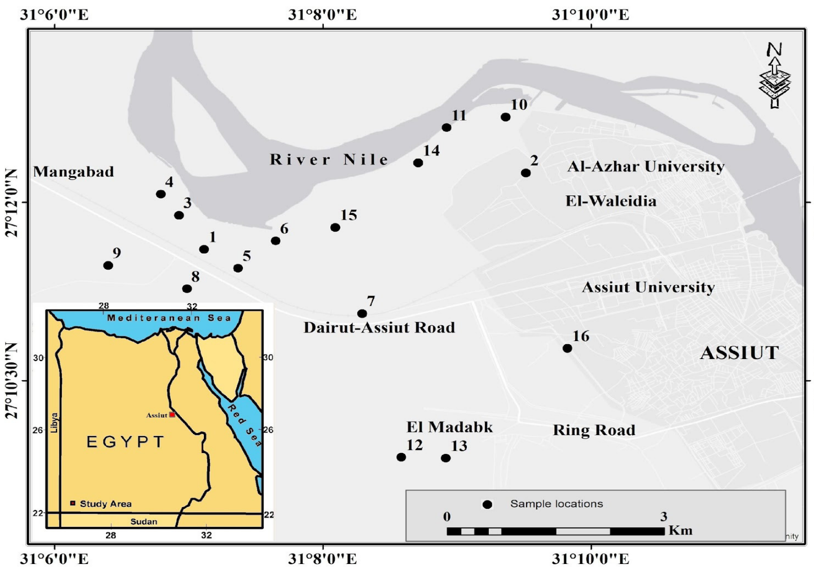

Fig .1. Location map of the studied soil samples

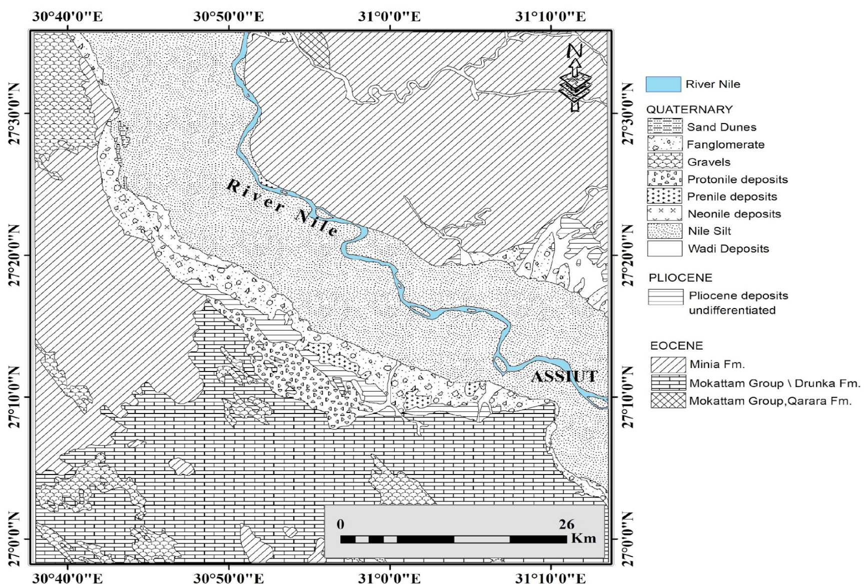

Fig. 2. Lithologic map of the studied Assuit area (After Conoco [28]).

$$PERI = \sum E_r$$

Where E_r is the single ecological risk index, T_r is the toxic-response factor for a given metal (Table 1) and CF is the contamination factor for the same metal.

In addition, the present study evaluated each site for the extent of metal pollution by applying the pollution load index (PLI) introduced by Tomlinson et al. [29], as following:

$$PLI= (CF1 * CF2 *......* CFn)^{(1/n)}$$

Where, n is the number of metals studied. The PLI gives simple comparative means for assessing a site quality.

TABLE 1. Heavy metals mean in worldwide soils (After Kabata-Pendias and Mukherjee [30]) and the toxic-response values (After Hakanson [27]).

Element	World Soil Average (B_m) mg/kg	toxic- response (Tr)
As	5	10
Cd	0.5	30
Co	7.9	5
Cr	54	2
Cu	20	5
Ni	22	5
Pb	25	5
Zn	63	1
Zr	300	-

Results and Discussion

The distributions of the studied elements were illustrated in Fig. 3. The decreasing order in the studied heavy metals is Zr > Zn > Cr > Ni > Pb > Co > Cu > As > Cd. The comparison of current results with world soils [31] has indicated that the studied soil (Fig. 4) contents of Cu, Pb and Zn were lower than those values recorded for the all countries. While, As and Cd values were lower than those values of Australia, Canada, Germany and Netherlands and higher than those values for Tanzania and USA. Cr value is lower than those of Canada, Germany and Netherlands; in contrast, they are higher than values recorded of Australia, Canada, Germany, Netherlands and USA. Finally, Ni is higher than those recorded for Australia and USA but lower than those of the other countries. Generally, the studied soils were mostly low polluted than the other cultivated soils in the world. On the other hand, the comparison with local adjacent areas; Sohag [32] and El Minya [33] Governorates indicated that (Fig. 5) the study area soil contains higher concentrations of As, Co, Ni, Pb and Zn than Sohag Governorate. However, it contains lower concentration of As, Cr, Cu, Ni, Pb and Zn than El Minya Governorate. This can give general impart that the pollution increased in the Nile Valley from south (Sohag) to north (El Minya) with As, Ni, Pb and Zn.

These indices calculated from the contents of each metal in the soil, and can be used to classify soils into categories according to the degree of contamination. There are two types of pollution indices which used in this study; single and integrated indices. The applied single (EF, I_{geo}, CF and E_r) and integrated (C_d, PLI and PERI) pollution indices results are presented in Tables 2-5.

Single pollution indices

It is evident from the results of enrichment factor (EF) that As, Cd, Cr, Ni and Zn displayed, mostly, moderate enrichment, Co displayed significant enrichment, Cu and Pb displayed depletion (Table 2). The low EF values (<1.5) indicating the crustal source of an element while high EF values (≥1.5) indicating anthropogenic origin [34, 35]. Nearly, all the studied samples had EF values ≥1.5 for the studied metals indicating the anthropogenic origin of these metals. Thus, the enrichment of the toxic elements in the studied soils refers to its anthropogenic activities, which confirmed the geochemical results of Abou El-Anwar, et al. [36].

The I_{geo} values (Table 3) for the studied metals indicated that the soil samples can be categorized into three I_{geo} classes: (a) uncontaminated with Pb (b) uncontaminated to moderately contaminate with As, Cd, Cr, Cu and Zn, and (c) moderately contaminated with Co and Ni.

The calculated contamination factor (Table 4) showed that most of the studied soil samples are moderate contamination with Cr, Cu, Pb and Zn with CF values ranged between 1 and 3. On the other hand, most of the studied samples had considerable contamination with As and Ni. The soil flocculated between moderate and considerable contamination with Cd while it

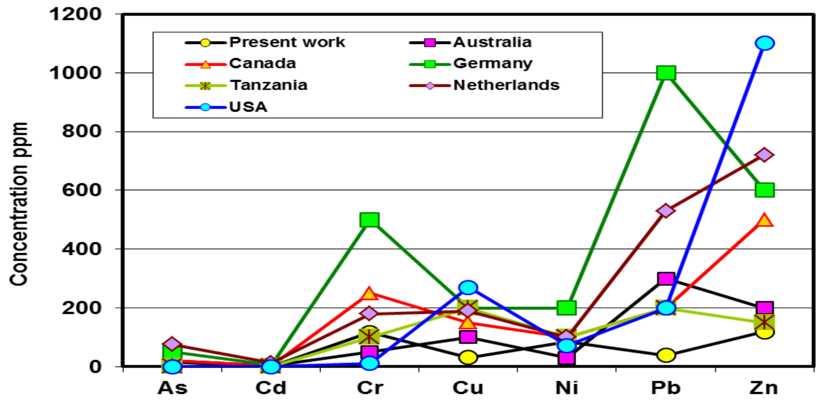

Fig. 3. Distribution of metal concentrations in the studied soil samples.

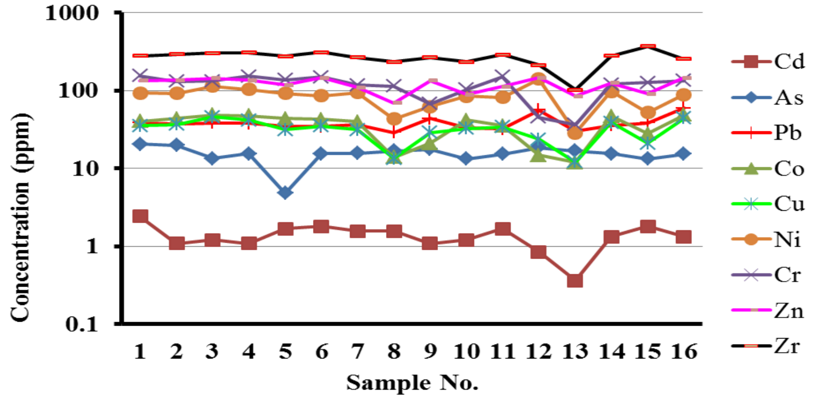

Fig. 4. Comparison of the current results with other countries (After He et al. [31]) soil content of elements.

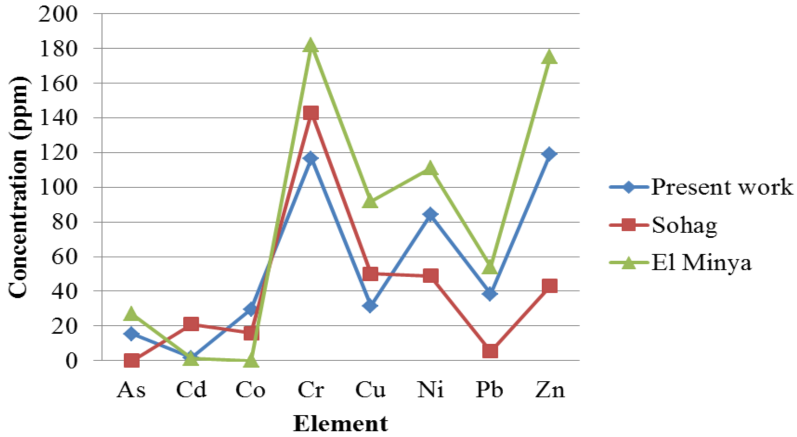

Fig. 5. Comparison of the current results with Sohag and El Minya Governorates.

ranged from moderate to very high contaminated with Co. The current values of EF, Igeo and CF for Cd, Cu, Pb and Zn are higher than those recorded by Mohamed et al. [37] around phosphate fertilizer plant at Assiut. This indicated the temporal increase in pollution in the study area.

According to the calculated ecological risk factor (E_r) the studied samples (Table 5) are of low ecological risk with respect to their content of As, Co, Cr, Cu, Ni, Pb and Zn. On the other hand, Cd produced the most ecological risk in the study area, where one sample (Sample No. 13) was of low risk, eight samples were of moderate risk and seven samples were of considerable risk. Cd is a highly toxic metal that poses a severe health risk to humans [38, 39]. In addition, it led to nutrient content, seed germination, shoot and root length reduction in plants [40].

Integrated pollution indices

Integrated pollution indices are based on the single pollution indices in the calculation of multi-element indices [41]. Each type of integrated pollution indices is composed of a separate single index [42]. The calculated integrated pollution indices results were presented in Tables 4 and 5.

The degree of contamination (C_d) index indicated that all the samples are of considerable contamination, except samples number (8 and 13) are of moderate degree of contamination (Table 4).

The results of pollution load index (Table 4) were found to be high (PLI > 1) in all the investigated samples (Table 5). The PLI values for all samples are >1 indicating the role of external discrete sources of soil pollution; vehicle exhaust, industrial and agricultural activities [12, 32, 43]. The PLI gives simple comparable tools for evaluating a site quality [42].

The PERI values for the study area were fluctuated between 150 and 300 (except sample No. 13 with PERI =80.6), which indicated a moderate potential for ecological risk (Table 5). The main contributor to PERI values is the ecological risk (E_r) of Cd because Cd had great E_r values, which are more than ten times higher than those of the other studied metals. The biological toxicity of Cd presents considerable PERI for ecosystem.

TABLE 2. Enrichment factor values of heavy metals in Assiut soil and its classes.

SN	As	Cd	Co	Cr	Cu	Ni	Pb	Zn
1	4.4	5.2	5.5	3.1	1.9	4.5	1.7	2.3
2	4.1	2.2	5.7	2.5	1.9	4.3	1.5	2.2
3	2.7	2.4	6.1	2.4	2.3	5.2	1.5	2.3
4	3.0	2.1	5.9	2.8	2.0	4.6	1.5	2.1
5	1.0	3.6	6.0	2.7	1.7	4.5	1.5	2.0
6	3.0	3.5	5.2	2.7	1.7	3.8	1.3	2.2
7	3.5	3.5	5.7	2.5	1.8	4.8	1.6	2.0
8	4.3	4.0	2.3	2.7	0.9	2.5	1.5	1.4
9	4.0	2.4	3.0	1.4	1.6	3.2	2.0	2.4
10	3.4	3.1	6.8	2.5	2.1	4.9	1.7	1.8
11	3.2	3.5	4.6	2.9	1.8	3.9	1.3	1.8
12	5.2	2.4	2.6	1.2	1.7	9.0	3.1	3.2
13	9.8	2.1	4.4	2.0	1.8	3.8	3.6	3.9
14	3.3	2.8	6.4	2.4	2.1	4.7	1.5	2.1
15	2.1	2.9	2.9	1.9	0.8	1.9	1.2	1.2
16	3.6	3.1	7.3	2.9	2.6	4.7	2.8	2.7

Enrichment Factor Classes [23]

EF < 2	Depletion to minimal enrichment	20≤EF<40	Very high enrichment
2≤EF<5	Moderate enrichment	EF≥40	Extremely high enrichment
5≤EF<20	Significant enrichment		

TABLE 3. Index of geoaccumulation values of heavy metals in Assiut soil and its classes.

SN	As	Cd	Co	Cr	Cu	Ni	Pb	Zn
1	1.5	1.7	1.8	0.9	0.2	1.5	0.0	0.5
2	1.4	0.5	1.9	0.7	0.3	1.5	0.0	0.5
3	0.8	0.7	2.0	0.7	0.6	1.8	0.0	0.6
4	1.0	0.5	2.0	0.9	0.5	1.6	0.0	0.5
5	-0.6	1.2	1.9	0.8	0.1	1.5	-0.1	0.3
6	1.0	1.3	1.8	0.9	0.2	1.4	-0.1	0.6
7	1.1	1.1	1.7	0.5	0.1	1.5	-0.1	0.2
8	1.2	1.1	0.2	0.5	-1.2	0.4	-0.4	-0.4
9	1.2	0.5	0.8	-0.3	-0.1	0.9	0.2	0.5
10	0.8	0.7	1.8	0.4	0.1	1.3	-0.2	-0.1
11	1.0	1.2	1.6	0.9	0.2	1.3	-0.2	0.2
12	1.3	0.2	0.3	-0.8	-0.3	2.1	0.6	0.6
13	1.2	-1.1	0.0	-1.1	-1.3	-0.2	-0.3	-0.2
14	1.0	0.8	2.0	0.6	0.4	1.6	-0.1	0.4
15	0.8	1.3	1.2	0.6	-0.5	0.6	0.0	-0.1
16	1.0	0.8	2.0	0.7	0.6	1.4	0.7	0.6

Index of geoaccumulation classes [26]

class	rank	class	rank
≤0	Practically uncontaminated	4	Heavily contaminated
1	Uncontaminated to moderately contaminated	5	Heavily to extremely contaminated
2	Moderately contaminated	6	Extremely contaminated
3	Moderately to heavily contaminated		

TABLE 4. Contamination factor, C_d and PLI of heavy metals in Assiut soil and their classes.

SN	CF								C_d	PLI
	As	Cd	Co	Cr	Cu	Ni	Pb	Zn		
1	4.1	4.8	5.1	2.9	1.8	4.2	1.5	2.1	26.5	3.0
2	4.0	2.2	5.5	2.4	1.8	4.1	1.5	2.1	23.7	2.7
3	2.7	2.4	6.1	2.4	2.3	5.2	1.5	2.3	24.9	2.8
4	3.1	2.2	6.0	2.8	2.1	4.7	1.5	2.1	24.4	2.8
5	1.0	3.4	5.5	2.5	1.6	4.1	1.4	1.9	21.3	2.3
6	3.1	3.6	5.4	2.7	1.7	3.9	1.4	2.3	24.1	2.8
7	3.1	3.1	5.0	2.2	1.6	4.3	1.4	1.7	22.4	2.5
8	3.4	3.1	1.7	2.1	0.7	2.0	1.2	1.1	15.2	1.7
9	3.5	2.2	2.7	1.3	1.4	2.8	1.7	2.1	17.7	2.1
10	2.6	2.4	5.2	1.9	1.6	3.8	1.3	1.4	20.4	2.3
11	3.1	3.4	4.5	2.8	1.7	3.7	1.3	1.8	22.1	2.6
12	3.7	1.7	1.9	0.8	1.2	6.4	2.2	2.3	20.1	2.1
13	3.3	0.7	1.5	0.7	0.6	1.3	1.2	1.3	10.7	1.2
14	3.1	2.6	5.9	2.2	1.9	4.4	1.4	2.0	23.6	2.7
15	2.6	3.6	3.5	2.3	1.0	2.4	1.5	1.4	18.5	2.1
16	3.0	2.6	6.2	2.5	2.2	4.0	2.4	2.3	25.2	3.0

Classes of CF and C_d [27]		Classes of PLI [29]	
CF < 1	Low CF	PLI < 1	Not polluted
C_d < 8	Low C_d		
1 ≤ CF < 3	Moderate CF	PLI = 1	Baseline level
8 ≤ C_d < 16	Moderate C_d		
1 ≤ CF < 6	Considerable CF	PLI > 1	Polluted
16 ≤ CF/C_d < 32	Considerable C_d		
CF ≥ 6	Very high CF		
C_d ≥ 32	Very high C_d		

TABLE 5. Ecological Risk (E_r) factor of heavy metals and PERI in Assiut soil and their classes.

	Er								PERI
SN	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	
1	41.0	144.0	25.3	5.7	8.9	21.0	7.7	2.1	255.7
2	39.7	64.8	27.5	4.8	9.2	20.7	7.5	2.1	176.3
3	26.9	72.0	30.5	4.9	11.4	25.9	7.7	2.3	181.5
4	30.8	64.8	29.9	5.6	10.4	23.3	7.5	2.1	174.6
5	9.6	100.8	27.6	5.1	7.8	20.7	7.0	1.9	180.4
6	30.8	108.0	27.0	5.5	8.7	19.5	6.9	2.3	208.6
7	31.1	93.6	25.1	4.3	7.8	21.3	7.2	1.7	192.1
8	33.5	93.6	8.7	4.2	3.3	9.8	5.8	1.1	160.0
9	35.1	64.8	13.3	2.5	7.2	14.1	8.7	2.1	147.9
10	26.4	72.0	26.2	3.8	8.1	19.1	6.7	1.4	163.6
11	30.6	100.8	22.3	5.6	8.5	18.6	6.4	1.8	194.5
12	36.7	50.4	9.3	1.7	5.9	31.9	11.1	2.3	149.3
13	33.3	21.6	7.5	1.4	3.0	6.4	6.1	1.3	80.6
14	31.0	79.2	29.7	4.4	9.7	22.1	7.1	2.0	185.1
15	26.5	108.0	17.7	4.7	5.2	11.8	7.7	1.4	182.9
16	30.5	79.2	30.8	4.9	11.1	20.0	11.8	2.3	190.6

Ecological Risk Factor Classes [27]		Potential Ecological Risk Index Classes [27]	
$E_r < 40$	Low risk	PERI < 150	Low peri
$40 \le E_r < 80$	Moderate risk	$150 \le$ PERI < 300	Moderate peri
$80 \le E_r < 160$	Considerable risk	$300 \le$ PERI < 600	Considerable peri
$160 \le E_r < 320$	High risk	PERI $\ge$ 600	Very high peri
$E_r \ge 320$	Very high risk		

Conclusions

Fortunately, the current results showed the low pollution of the studied soil than the soils of some other countries worldwide. Generally, the pollution in the Nile Valley is increasing from south to north as indicated from the comparison of the current results with adjacent areas. In addition, the enrichment factor presented the anthropogenic input of the studied heavy metals into Assiut soil. The I_{geo} and CF indicated the load of the studied samples with As, Cd, Co and Ni with respect to the other metals. The exposure to polluted soil with the heavy metals could cause adverse human health effects as indicated by PERI values. The ecological risk emerged because of the presence of unacceptable concentrations of Cd in the studied samples. The study area subjected to different sources of pollution; domestic wastes, urban runoff, vehicle exhaust, agriculture practices (Fertilizers, pesticides, and herbicides) and industrial output. Finally, the pollution of soil with heavy metals can be easily transported into food chain and adversely impact human health. So, the pollution sources, such as leaded fuel, agricultural fertilizers and pesticides application, industrial outputs and untreated wastewater disposal into the environment should be controlled.

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تقييم تلوث التربة الزراعية بالمعادن الثقيلة باستخدام مؤشرات التلوث في مركز أسيوط، مصر

حامد صديق مكى، عصمت احمد ابوالانوار، سلمان عبدالرءوف سلمان، احمد عبدالفتاح الناظر، وائل عبدالوهاب و احمد عبدالعظيم اصمعى

قسم العلوم الجيولوجية - شعبة الصناعات الكيماوية غير العضوية والثروات المعدنية – المركز القومى للبحوث - الجيزة - مصر.

تمثل محافظه اسيوط منطقه هامه فى منتصف وادى النيل حيث تحتوى على العديد من الصناعات الكبرى (مثل الاسمنت والاسمدة وتوليد الكهرباء) و الامتداد العمرانى والنشاطات الزراعية. تلك الانشطة ممكن ان تودى الى تلوث التربة الزراعية بالمعادن الثقيلة السامه. يهدف البحث لتقييم المخاطر المحتملة لتلك المعادن فى التربة باستخدام موشرات التلوث: عامل الاثراء (EF) ، مؤشر التراكم الجيولوجى (I_{geo}) ، عامل التلوث (CF) ، عامل الخطر البيئي (E_r) ، درجة التلوث (C_d) ، مؤشر حمل التلوث (PLI) ومؤشر المخاطر البيئية المحتملة (PERI). تم خلال تلك الدراسة تقييم تلوث التربة الزراعية بثمانية عناصر ثقيلة وهي الزرنيخ، الكادميوم والكوبلت، الكروم، النحاس، النيكل، الرصاص، الزنك الدراسة الحالية المؤشرات المذكورة.

اشارت النتائج الكيمائية ومؤشرات التلوث الى تلوث التربة الزراعية ببعض العناصر الثقيلة السامة والضارة بصحة الانسان مثل : الزرنيخ، الكوبالت، الكروم، النحاس، النيكل، الرصاص، الزنك فى مركز أسيوط جنوب مصر. وأكدت الدراسة ان هذه التربة الزراعية على درجة متوسطة من التلوث.

ويعزى هذا التلوث الى النشاط البشرى فى المناطق المحيطة بالحزام الزراعى من نفايات المصانع والمنازل وكذلك عوادم السيارات الى جانب استخدام الاسمدة والمبيدات الحشرية فى الزراعة مما ادى الى ارتفاع تركيز هذه العناصر بالتربة الزراعية.

وبالمقارنه مع الدراسات التى تمت على محافظتى سوهاج والمنيا وجد ارتفاع تركيزات بعض هذة العناصر (الزرنيخ، النيكل، الرصاص، الزنك) عن مثيلاتها بمحافظة سوهاج وكانت اقل تركيزا عن محافظة المنيا, وهكذا يمكن تأكيد ارتفاع وازدياد مستوى التلوث كلما اتجهنا من جنوب الى شمال وادى النيل. وكذلك لوحظ زيادة معدلات التلوث بمحافظة اسيوط بمرور الزمن بالمقارنة بالنتائج السابقة لتلوث التربة باسيوط. وبالقارنة مع بعض البلدان الاخرى خارج وداخل القارة الافريقية مثل كندا، واستراليا، وامريكا، والمانيا, تنزانيا وهولندا لوحظ ان التربة الزراعية بأسيوط اقل تلوثا منهم جميعا.