J. of Soil Sciences and Agricultural Engineering, Mansoura Univ.,Vol 10 (10): 637 - 648 , 2019

Journal of Soil Sciences and Agricultural Engineering

Journal homepage: www.jssae.mans.edu.eg
Available online at: www.jssae.journals.ekb.eg

Forms and Mobility of some Heavy Metals in Irrigated Soils with Bahr El-Baqar Drain Water and their Effect on the Growing Plants

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ABSTRACT

Soil and plant samples from areas adjacent to Bahr El-Baqar main drain (El-Sharkia Governorate) were collected to study the fate and hazards of some heavy metals, i.e. Pb, Cd, Ni, Zn, Cu, Co …etc. Pollution associated with the studied heavy metals was valued following international norms. The fate and risks of studied pollutants were assessed and appraised using enrichment factor (EF), geo-accumulation index (Igeo), contamination factor (CF), degree of contamination (DC), modified degree of contamination (m Cd), pollution load index (PLI), soil pollution index (SPI). Moreover, the mobility indices and bioaccumulation (BAC) of most hazards selected pollutants were strong-minded in varied plant species grown the in study area including clover, onion, wheat, lettuce and garlic. Meanwhile, correlation analyses between soil properties and heavy metals concentrations in the grown crops were determined. Results showed that the disparity in the properties of sampled soils significantly shaped heavy metals distribution, concentrations as well as speciation. The total contents of Pb, Co, Cd, Ni…etc., exceeded the permissible levels set by Canadian Soil Quality Guidelines (CSQG), European Union Risk Assessment (EU), and the average of the earth crust. Data also exhibited that irrigation with Bahr El-Baqar low quality water is the main source of heavy metals pollutants found in the soils. Other heavy metal might be originated from certain adverse human activities. Regarding the contents of heavy metals found in plants grown in the studied area involving clover, onion, wheat, garlic and lettuce, gained results confirmed that the highest mean value of Cd was detected in all plants, despite other pollutants were also found in the studied plants, yet at variable concentrations. All indicators calculated in the current work pointed to the worth of reducing pollutants by proper remediation techniques.

Keywords: Soils adjacent to Bahr El-Baqar drain, Heavy metals, Clover, Onion, Wheat, Garlic, Lettuce

INTRODUCTION

Agricultural expansion in Egypt necessitates the rational use of all available agricultural resources, particularly, land and water on an economic basis to meet the overgrowing population needs from safe food. To face the current shortages in natural sources in Egypt especially irrigation water, national strategies should be set and directed towards using the low-quality waters, such as agricultural drainage water, treated sewage effluent and/or ground waters in irrigation. Low quality waters are in most cases contaminated with inorganic pollutants such as heavy metals and organic pollutants like pesticides and enteric pathogens that arise mainly from the intensive use of chemical fertilizers, industrial by-products, sewage effluent and municipal solid wastes generated from households (Mateo-Sagasta *et al.,* 2017). Theses wastewaters are also rich in organic components that are able to furnish high concentrations of heavy metals within the surface soil layers (Abbas and Bassouny, 2018). Moreover, the hydraulic continuities probably exists, totally or partially, between the wastewater of the main drain and the underground waters of the nearby arable lands possess potential hazards on the food quality harvested from these areas (Farid *et al.,* 2019). In consequence, periodical monitoring of heavy metals should take place in areas irrigated with wastewaters to follow their potential hazards on man and animal. In Egypt, farmers in some hot spot regions such as Bahr El-Baqar, and El-Gabal el-Asfar were obliged to use low quality waters in irrigation. Many other regions in Egypt also considered wastewaters for complimentary irrigations. In the eastern area of the Nile Delta, Mohamed *et al.,* (2014) evaluated the pollution associated with heavy metals using some indexes to compile a map of soil contamination in such regions. He found that the area nearby Bahr El-Baqar Drain was highly contaminated with heavy metals and that the concentrations of such metals were 6 folds higher than the corresponding permissible levels or more..

At the time being, it is now well recognized in Egypt that soil pollution is a great threat to plants grown in some polluted arid areas. Inorganic pollutants such as heavy metals have various modes to invade to food chain thus accumulating in other living organisms (O'Connell *et al.,* 2008; Nannoni *et al.,* 2011; Sprynskyy *et al.,* 2011; and Liu *et al.,* 2013: Abdelhafez *et al.,* 2015). Heavy metals have a significant impact on the quality of foodstuffs and environmental nutrient cycles as well since the growing plants usually absorb and accumulate significant concentrations of toxic metals from soil and water ecosystems, as well as from contaminated air (TokalıoÈlu and Kartal, 2003; ElShazly *et al.,* 2019).

Inorganic pollutants uptake is usually linked with their fate and speciation in soil ecosystems. Unfortunately,

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DOI: 10.21608/jssae.2019.63264

these chemicals always find their way to plant the editable portions of plants before invading to human body causing serious adverse health impacts (Kaplan *et al*., 2011; Abdelhafez *et al*., 2015) such as nausea, anorexia, vomiting, gastrointestinal abnormalities, and dermatitis (Chui *et al*., 2013; Tchounwou *et al*., 2012). Toxicity of heavy metals could also disorder and/or damage important organs (Lindemann *et al*., 2008), like mental and central nervous systems (Gybina and Prohaska, 2008), kidneys failure for human been (Reglero *et al*., 2009), troubles in blood combination (Cope *et al*., 2009), lungs damage marking (Kampa and Castanas, 2008), livers probles (Lindemann *et al*., 2008and Sadik, 2008). Furthermore, they might cause Alzheimer's disease (Kampa and Castanas, 2008). Heavy metals may causes Parkinson's disease in late stages (Guilarte, 2011), muscular dystrophy and in some cases it cause multiple sclerosis (Turaberlidze *et al*., 2008). Lung cancer and damage to human's respiratory systems at high rate exposure to heavy metals.

In arid and semi-arid regions like Egypt, accumulation of heavy metals in soil ecosystems are influenced by their properties e.g. soil pH that represents a key parameter (Jieng-feng *et al*., 2009), calcium carbonate content (Bashir *et al.*, 2019), soil organic matter, soil texture (Pepper *et al.*, 2019), type of clay minerals (ElShazly *et al*., 2019), redox potential and cation exchange capacity (Selim, 2013; Bolan *et al*., 2014 and Wijayawardena *et al*., 2016).

The main objectives of the present work are to 1) investigate the fate of some heavy metals in Bahr El-Baqar area, (Egypt) compared to the international critical levels of heavy metals in soil ecosystems.(2)evaluation of inorganic pollutants in soil and plant ecosystems through some important pollution indicators represented by Enrichment Factor (EF), Geo-accumulation index (Igeo), Contamination Factor (CF), Degree of contamination (DC), Modified Degree of Contamination (mCD), Pollution Load Index (PLI), (3) Status of heavy metals in different selected plant species cultivated in the studied area including onion, clover and wheat (4 Studying the relation between concentrations of pollutants in cultivated plants with the soil properties of different soils selected.

MATERIALS AND METHODS

Site description

The investigated area is located close to Bahr El-Baqar drain, northeastern Delta, Egypt. The studied sites are located between 30º 25`48.1`` N and 31º 34` 17.5`` E to 31º 11` 0.5`` N and 32 º 13` 13.7`` E (Map 1).

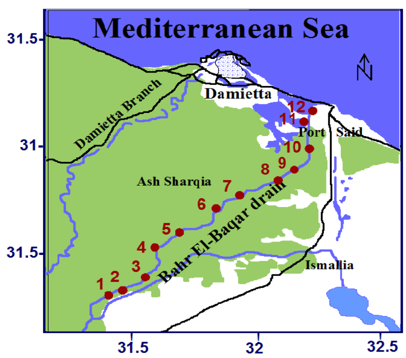
Soils and plants sampling

To assess the pollution status in this region, twelve surface soil samples (0-30 cm) were collected from different farms adjacent to Bahr El-Baqar drain. These samples were air-dried, crushed and passed through a 2 mm sieve, then investigated for their physical and chemical properties as outlined by Klute (1986) and Page *et al.,* (1982) as shown in Table (1).

The representative soil samples are dominated by clay to clay loam texture except for the sample no.1, which has a sandy clay loam texture. In the studied soils, the percentage of sand fraction ranged between 10.48% and 58.80%, Silt fraction ranged between 10.00% and 37.16%, while the clay content ranged between 23.20% and 61.58%. Soil pH ranged from 7.12 to 8.11 denoted that selected soils are in neutral to alkaline conditions. Electrical conductivity (EC) ranged between 0.72 dSm^{-1} and 36.80 dSm^{-1}, indicating non-saline to extremely saline conditions. $CaCO_3$ contents ranged between 3.6 and 48.2 gkg^{-1} and the organic matter contents between 28.1 and 79.7 gkg^{-1}. Cation exchange capacity ranged between 29.70 and 96.00 cmolc Kg^{-1}.

Table 1. the average of the main chemical and physical properties of the studied soils

Limit	pH	EC (dSm^{-1})	OM (gkg^{-1})	CaCO3 (gkg^{-1})	Sand (%)	Silt (%)	Clay (%)	CEC (Cmolc Kg^{-1})
Minimum	7.12	0.72	28.1	3.6	10.48	10.00	23.20	29.70
Maximum	8.11	36.80	79.7	48.2	58.80	37.16	61.58	96.00
Mean	7.39	9.09	48.7	28.1	30.18	24.50	45.44	63.84



Map 1. Location of the studied area and the sites of soil and crop samples.

Extraction of heavy metals from selected soil samples

Soil samples were analyzed for their total contents of heavy metals after being digested by HNO_3, H_2SO_4 and 60% $HClO_4$ as described by Hesse (1971), gained results are documented in Table (3).

Plant sampling and analyses:

Different plant species (Table 2) were collected from the studied area washed and cleaned with fresh water, distilled water, oven-dried at 60°C, and ground into powder with an electric grinder. Afterwards, 0.5 g of the plant samples were taken into Pyrex beaker and digested using a mixture of acids (H_2SO_4, HNO_3 and $HClO_4$). Heavy metal contents were then determined according to the method adopted by Norvell (1984). Digested plant samples were diluted in 50 mL with redistilled water. The edible portions of five selected crops were digested using the abovementioned method and their heavy metals contents were determined and tabulated in Table (11).

Instrument of heavy metals analyses

The concentrations of heavy metals in soils and plants (total and in sequential extraction solutions) were determined using Inductively Coupled Argon Plasma, ICAP 6500 Duo, Thermo Scientific, England. 1000 mg/l multi-element certified standard solution, Merck, Germany.

Table 2. Types of the sampled plants and their edible parts:

Usual name of plant	Scientific name of plant	Part consumed
Lettuce	*Lactuca sativa*	Leaves
Wheat	*Triticum aestivum*	Cereals
Onion	*Allium cepa*	Leaves
Garlic	*Allium sativum*	Tubers
Clover	*Trifolium alexandrinum*	Fodder (Shoots)

3. Statistical analyses

All induces such as mobility factor were calculated according to Salbu *et al*., 1998 and Kabala and Singh, 2001. Excel software (Excel Inc, 2003) was used to calculate the significant variation between the total metal contents of the different studied pollutants. Correlations coefficient analysis was calculated as described by Minitab Inc. (1992).

4. Indices selected to express heavy metals status and overall analyses

A second method for assessing the heavy metal status was tried using certain indices assessing the environmental impacts of heavy metal pollution in soil ecosystems at Bahr EL-Baqar Region.

Pollution indices were classified into two type's single and integrated indices (Caeiro *et al.* 2005). The studied indices might be summarized as follow:

1. Soil Enrichment factor

To evaluate the magnitude of contaminants in the environment Enrichment factor (EF) was used in this work and Iron (Fe) as reference element was chosen (Seshan *et al*., 2010).

The EF values < 2 means that metal is from crustal materials or natural processes; whereas EF values > 2 means that the sources of pollution are more likely to be anthropogenic (Liaghati *et al*., 2003). The following model represents EF calculation:

$$EFs = [C/Fe_{(sample)}] / [C/Fe_{(Earth's\ crust)}]$$

Where: EFs is the enrichment factor, C/Fe is the ratio between metal and Fe concentration of the sample and C/Fe is the ratio between pollutant(s) and Fe concentrations in the system (Sutherland, 2000).

2. Contamination Factor (CF)

Contaminated factor (CF) represents the ratio between the concentrations of each pollutant in the soil system and background value (Tomilson, 1980). The equation represents CF is:

$$\text{Contamination Factor } CF = C_{metal} / C_{background}$$

The limits of this factor could be summarized as follow: factor:

CF less than 1 (low contamination factor);
CF between 1 - 3 meaning moderate contamination status
CF between 3-6 means considerable contamination status; and CF ≥ 6 represents very high contamination status.

3. Degree of Contamination (DC) and Pollution Load (PLI) indices

The PLI calculated for site is the root of number (n) of multiplied contamination factor or CF values. This index could be calculated by using the following equation:

$$PLI = (CF1_* CF2_* CF3_* \ldots .^* CF_n)^{1/n}$$

Where

n: number of metals studied
CF: contamination factor.
PLI value of zero meaning perfection;

A numerical value of one indicates baseline levels of pollutants, and values above one indicate progressive deterioration of the site quality (Saad *et al.,* 1981), (Environmental Protection Agency, 2002).

Degree of contamination (DC) index is the sum of all CF values for a specific location (Hakanson, 1980). This index could be calculated using the equation:

$$DC = \sum^{n}_{i=1} CF$$

Where

CF is the single contamination factor and
n is the count of the presented pollutants.
DC values less than n would indicate low degree of contamination and DC more than 2n represents moderate degree of contamination, meanwhile, DC values between 2n and 4n meaning considerable degree of contamination. The value of DC more than 4n means very high degree of contamination.

4. Modified Degree of Contamination (mDC):

The modified formula of mDC values represent the degree of contamination as the sum of all DC values for a given set of pollutants divided by the number of analyzed pollutants (Abrahim and Parker (2008); Hakanson (1980).

The modified degree of contamination is given from the following equation:

$$mDC = \sum^{n}_{i=1} CF/n$$

Where n is the number of pollutants and CF is the contamination factor.

5. Geo-Accumulation Index (Igeo)

Index of geo-accumulation (Igeo) was used to determine pollutants contamination in soils by comparing pollutant(s) concentrations with critical level(s). The Igeo index could be calculated using the following model:

$$I_{geo} = \log_2 (C_n / 1.5\, B_n)$$

Where:

C_n is the measured concentration of pollutants in contaminated soil
B_n is the geochemical background value in average 1.5 background matrix correction due to anthropogenic influences.

According to Buccolieri *et al*. (2006), the (Igeo) was divided into seven classes:

Class 1: Igeo less than or equal 0 represents unpolluted soil
Class 2: From 0 < Igeo ≤ 1 represents from unpolluted to moderately polluted status;
Class 3: From 1 < Igeo ≤ 2 represents moderately polluted status;
Class 4: From 2 < Igeo ≤ 3 represents moderately to strongly polluted status;
Class 5: From 3 < Igeo ≤ 4 represents strongly polluted status;
Class 6: From 4 < Igeo ≤ 5 represents strongly to extremely polluted status;
Class 7: From Igeo > 5 represents extremely polluted status

5. Mobility factor

Mobility factor (MF) was also determined by speciation of heavy metals in the studied soils as mention by Tessier *et al*., (1979) after modification carried out by Kashem and Singh (2001). The obtained results were applied in the model:

$$MF = (F1 + F2 + F3) / (F1 + F2 + F3 + F4 + F5 + F6) * 100$$

Where F1-F6 represents the distribution of heavy metals to other different fractions in the used soils

RESULTS AND DISCUSSION

1. Heavy metals status in selected soil samples at Bahr El-Baqar area:

Table (3) represents the total concentrations of heavy metals in Bahr El-Baqar site area. Generally, the levels of most pollutants were above the average upper earth crust (except for Fe). Concentrations of some heavy metals like Zn were below the safe limits presented by CSQG and EU in some sites and this probably occur because of the continuous removal of these metals by crops grown in selected farms and/or leaching of these metals from the soil surface into deep layers of soils and/or to groundwater.

The total Pb contents in selected soil samples fluctuated between 40.21and 59.02 (mg/kg). According to AbLatif Wani *et al.* (2015) the main sources of Pb in Bahr El-Bakar soils are probably the industrial waste disposal associated with the other human activities and motor vehicle exhausts that might enrich the nearby arable lands with Pb.

Cadmium (Cd) concentrations in selected soils ranged between 10.67and 15.90 mg/kg. These results agree with El-Bady (2016) who found that Cd concentration in Bahr El-Baqar area far exceeded that given in both Canadian Soil Quality Guidelines (CSQG, 2007) and European Union Risk Assessment (EU, 2002) as well as the average content in upper earth crust.

Nickel concentrations presented in Table (3) ranged between 22.30 and 80.20 (mg/kg). The main source of Ni in soil ecosystems might be originated from the continuous and high applied levels of agricultural fertilizers containing this element as an impurity such as phosphate fertilizers (Benson *et al.*, 2014). Also, the high content of content of clay in the used soils, led to retain high amounts of Ni in these soils. From the obtained results, it seems that high Ni concentrations were correlated with the colloidal particles in soil such as clay and organic matter (Farid *et al.*, 2015).

Results in the same table indicated that Cobalt (Co) concentrations in investigated soil ecosystems ranged between 21.31and 75.74 mg/kg. This result might be linked with the variations in soil texture and existing presence of heavy clay. In addition, irrigation of the studied area by low quality water led to accumulate Co into the surface soil layer.

Other pollutants such as Zn and Cu, although considered as micronutrients; their concentrations were higher than AUEC. In this concern, Zn concentration varied from 194 to 227 mg/kg, Copper (Cu) concentration ranged between 162 and 187.4 mg/kg, manganese (Mn) concentration ranged between 1.12 and 736 mg/kg. All these elements showing significant values should be taken into consideration for the synergistic mechanism between them especially between Zn, Cu and Ni (Saber, *et al.*, 2012).

Table 3. Average of the total contents of the heavy metals(mg/kg) in soils of Bahr El-Baqar area

	Heavy metals (mg/kg)										
	Fe	**Al**	**Mn**	**Zn**	**Cu**	**Pb**	**Cd**	**Ni**	**Co**	**Cr**	**Sr**
Minimum	7355	968	115	102	101	43	12	83	121	129	18.75
Maximum	29295	14985	376	182	168	69	20	103	133	164	58.30
Average	18152	12231	249	128	138	50	14	95	128	147	43.18
Median	16932	13866	249	116	142	45	13	95	128	148	45.39
CSQG (mg/kg)				200	63	70	1.5	50	40	64	
(EU, 2002)				300	140	300	3	75	-	150	
AUEC (mg/kg	30890			52	14.3	17	0.1	18.6	11.6	35	

Where:
SD: Standard deviation
CSQG: Canadian Soil Quality Guidelines (2007),
(EU) European Union Standards European Union, (2002),
AUEC: Average of upper earth crust, after Wedepohl (1995).

2. Assessment of contamination indicators used to evaluate heavy metal status in the contaminated soils at Bahr El-Baqar

1. Single model

1. Contamination Factor (CF)

Table 4 shows that CF values of Cr was lower than 1, low contamination status, while Zn and Ni values ranged between low and moderate contamination status. Copper and cobalt (Cu and Co) values represent moderate contamination status (CF > 1), the same trend was also observed in Pb values which varied between 2.01 to 2.95 (moderate contamination status). The CF values of Cd, however, were very high that represented extremely contamination.

As shown in Table 4, the average of CF values of the studied heavy metals had the ascending order of Cd>Co>Cu>Pb>Cr>Ni>Zn>Fe>Mn>Al>Sr, suggesting that studied soil ecosystems are extremely enriched with Cd, while Pb exhibited only a significant enrichment. In contrast, the rest of studied heavy metals showed moderate to minimal enrichment in the study area. Regarding CF values of different pollutants, high CF values for Cd were found in the samples No. 8, 1 and 2 respectively. Numerically, the CF values for these samples reached to 66.33, 64.17 and 60.03. For Cobalt, the highest CF values were found in samples 2 and 10 reaching 4.39 and 4.36, respectively.

The calculated values for Cu in different soil ecosystems showed that most of selected locations have between moderate to considerable contamination conditions. The highest CF value for Cr (1.82) was found in the sample no. 11, the rest of other samples ranged from 1.44 to 1.77. Results in given in Table 4 showed also that CF values of most of pollutants like Al, Mn, Zn, Fe and Sr metals in the study area, were low in their numerical values that represent low degree of contamination.

Nevertheless, CF values for some heavy metals like Cu and Co showed a considerable contamination degree and this result might be ascribed to the influence of some external discrete sources like industrial activities, agricultural and other anthropogenic inputs, hence it seems reasonable to conclude that Cd was the only heavy metal that showed a high and significant degree of contamination.

Table 4. The contamination factor (CF) for heavy metals in the studied soils

	Contamination factor (CF)										
no.	**Fe**	**Al**	**Mn**	**Zn**	**Cu**	**Pb**	**Cd**	**Ni**	**Co**	**Cr**	**Sr**
1	0.16	0.08	0.12	1.07	3.32	2.49	64.17	1.39	4.15	1.44	0.06
2	0.34	0.18	0.40	1.09	3.84	2.21	60.03	1.40	4.39	1.49	0.18
3	0.24	0.15	0.23	1.10	3.62	2.20	41.50	1.36	4.28	1.50	0.19
4	0.56	0.17	0.25	1.20	3.78	2.19	39.93	1.50	4.27	1.66	0.15
5	0.25	0.01	0.21	1.09	3.14	2.89	42.50	1.50	4.04	1.61	0.07
6	0.60	0.19	0.27	1.26	3.91	2.16	42.30	1.52	4.42	1.61	0.19
7	0.38	0.16	0.23	1.09	4.21	2.26	42.23	1.41	4.18	1.64	0.18
8	0.62	0.18	0.26	1.92	2.72	2.83	66.33	1.22	4.40	1.74	0.14
9	0.60	0.17	0.31	1.81	2.54	2.85	48.67	1.34	4.30	1.77	0.13
10	0.24	0.18	0.30	1.32	3.87	2.17	42.23	1.36	4.36	1.65	0.12
11	0.25	0.18	0.30	1.90	3.24	3.45	44.20	1.33	4.19	1.82	0.16
12	0.38	0.17	0.29	1.37	3.49	2.30	42.73	1.43	4.09	1.66	0.16
Aver	0.38	0.15	0.26	1.35	3.47	2.50	48.07	1.40	4.26	1.63	0.14
Grade	1	1	1	2	3	2	4	2		2	1

2. The Geo-Accumulation Index (Igeo)

Results given in Table 5 showed that Igeo indicator values recorded negative values for Fe, Cr, Co, Cu and Zn. According to the classification of Muller (1979) this result confirmed that the soil ecosystems adjacent to Bahr El Baqar suffer from moderate to high pollution status, as far as the above-mentioned heavy metals are considered. The results of geo-accumulation index values for Pb showed non-pollution to moderately pollution status for such element (class 1). Also, the Igeo of Cd values indicated a strongly to extremely pollution status in all trailed soil ecosystems that represent unsuitability of using such soils in agricultural purpose.

Table 5. The geo-accumulation index (Igeo) of heavy metals in the studied soils

Sample no.	**Fe**	**Al**	**Mn**	**Zn**	**Cu**	**Pb**	**Cd**	**Ni**	**Co**	**Cr**	**Sr**
1	-3.27	-4.17	-3.63	-0.48	0.98	0.73	5.42	1.98	1.47	-0.06	-4.59
2	-2.14	-3.03	-1.92	-0.46	1.19	0.56	5.32	1.99	1.55	-0.01	-3.06
3	-2.62	-3.32	-2.73	-0.44	1.10	0.55	4.79	1.95	1.51	0.00	-3.01
4	-1.42	-3.14	-2.60	-0.33	1.16	0.55	4.73	2.09	1.51	0.15	-3.35
5	-2.60	-6.95	-2.82	-0.46	0.90	0.94	4.82	2.09	1.43	0.11	-4.51
6	-1.33	-3.00	-2.50	-0.25	1.21	0.53	4.82	2.10	1.56	0.10	-2.95
7	-1.96	-3.26	-2.74	-0.46	1.32	0.59	4.82	2.00	1.48	0.13	-3.04
8	-1.27	-3.03	-2.53	0.36	0.69	0.91	5.47	1.79	1.55	0.21	-3.41
9	-1.32	-3.12	-2.29	0.27	0.59	0.93	5.02	1.93	1.52	0.24	-3.55
10	-2.66	-3.08	-2.33	-0.18	1.20	0.53	4.82	1.94	1.54	0.14	-3.59
11	-2.60	-3.03	-2.33	0.34	0.94	1.20	4.88	1.91	1.48	0.28	-3.23
12	-1.99	-3.10	-2.38	-0.13	1.05	0.62	4.83	2.02	1.45	0.14	-3.27
Av.	-2.10	-3.52	-2.57	-0.18	1.03	0.72	4.98	1.98	1.50	0.12	-3.46
Igeo Class	0	0	0	0	2	1	5	2	2	1	0

Igeo Class	**Igeo Value**	**Contamination Level**
0	$Igeo \leq 0$	Uncontaminated
1	$0 < Igeo < 1$	Uncontaminated/moderately contaminated
2	$1 < Igeo < 2$	Moderately contaminated
3	$2 < Igeo < 3$	Moderately/strongly contaminated
4	$3 < Igeo < 4$	Strongly contaminated
5	$4 < Igeo < 5$	Strongly/extremely contaminated
6	$5 < Igeo$	Extremely contaminated

The I-geo grade for the studied area varied among the different studied heavy metals and locations of soil sampling. Values of Fe, Al, Mn, Zn and Sr indicated that these pollutants remain in grade 0 (un-polluted) in all trailed locations, suggesting safe conditions for these heavy metals in trailed soils. The I-geo values for Cr found to be under grade 0 in some locations (un-polluted), while, attained in grade 1 in other ones. In other words, these soils were slightly polluted with Cr.

The I-geo index values pointed to that Ni, Co and Cu are in grade 2. As shown in Table 5, Lead (Pb) and Cr are in grade 1, however, Cd is in grade 5. These results suggested that Bahr El Baqar soil ecosystems have safe concentrations of Pb and Cr; such elements are practically changed by anthropogenic activities, while the concentrations of Cd, Ni Co, and Cu exceeded the normal standard averages. All mentioned pollutants might be derived from industrial waste and gasoline additives used in the factories adjacent to Bahr El-Baqar area and cars (Mwamburi 2003). Also, these elements might be derived through corrosion of the numerous abandoned launches along the drain as well as agricultural activities.

2. Combined index or indexes

3. Pollution Load (PLI), Degree of Contamination (DC) and modified Degree of Contamination (m DC) indices values in Bahr El-Bakar polluted soil ecosystems

Results given in Table (6) generally indicated that for different combined indices, heavy metals significantly accumulate in the investigated soil ecosystems. Values of the degree of contamination (DC) indicated a very high pollution status in all Bahr El Baqar soil ecosystems, reflecting the changes in soil occupation and the intensity of economic activities. Results showed that the soil samples no. 8, 1and 2 are the most contaminated soil ecosystems. These soils had the highest DC values compared to the other ones.

Numerically, the DC values were 82.38,78.45and 75.56 respectively, ranking them under very high contaminated incidence, on the other hand, the soil sample no. 4 displayed the lowest DC value reaching 55.66.

Pollution severity and its variation along the trailed sites were determined using pollution load index. This index is a quick tool comparing the pollution status in different sites. The values of the Pollution Load Indexes (Table 6) were found to be generally under class 1for all trailed soil ecosystems and/or under pollution conditions.

Table 6. Calculated indices represent pollution status in selected Bahr El-Baqar Soil samples

no.	PLI	DC	mDC
1	0.93	78.45	7.13
2	1.37	75.56	6.87
3	1.17	56.37	5.12
4	1.31	55.66	5.06
5	0.84	57.32	5.21
6	1.40	58.42	5.31
7	1.27	57.97	5.27
8	1.44	82.38	7.49
9	1.39	64.48	5.86
10	1.22	57.81	5.26
11	1.35	61.02	5.55
12	1.30	58.08	5.28
Aver	1.25	63.63	5.78

4-Enrichment factor (EF)

Data given in Tables (7 & 8) illustrates the EFs values of the different studied soil ecosystems and different heavy metals as well. Values of enrichment factors (EF's) of the studied heavy metals in soil ecosystems might be arranged as EF values ranged between <2 (1st category) representing deficiency to minimal enrichment category, the EF values 2-5 (2nd category) indicated that the investigated heavy metals were entirely come from crustal materials or natural processes. On the other hand, EF values > 5 (3rd category) suggested that their sources are more likely to be anthropogenic, EFs ranged between 20–40 (4th category) showed very high enrichment and, EFs>40 (5th category) extremely exhibited high enrichments (Liaghati *et al*., 2003).

According to abovementioned critical values, results showed that the EF values of Cd were the highest compared to other pollutants as they ranged between 231 and 600 (5th category), thus this pollutant is extremely characterized with a high enrichment category, while Cr and Ni ranged between 2-5, indicating that they are entirely originated from crustal materials and/or natural processes, the Iron Fe value, however, represented a lower category.

Results also indicated that the EF values for Zn were under the 2nd and 3rd categories, ranging from 1.92 to 10.35, Cu resembled Zn in the categories, its numerical values ranged between 2.18 and 8.45. For Pb, the EF values ranged between 7.00 and 19.90 in different soil ecosystems under the 3rd category. This result might indicate that the concentrations of these elements were within the significant enrichment categories. The EF values of Ni ranged between 1.19 and 4.30 being under the 2nd category with moderate enrichment values. Furthermore, the EF values of Co ranged between 4.51 and 16.25 (3rd category) under the significant enrichment categories. The EF values of Cr and Sr ranged between 0.65 and 2.59; 0.23 and 0.66, respectively, thus are within deficiency to minimal enrichment categories.

Generally, according to EF values, the studied pollutants could be arranged according to their EF values in the following ascending order:

Cr < Ni < Cu<Zn<Co <Pb<Cd

Cadmium could be seen as more abundant rather than other studied heavy metals; whereas Sr showed the lowest appearance in different soil samples.

Variations of the indices used in the current work might be ascribed to the difference in sensitivity of these indices towards the soil pollutants (Praveena *et al.* 2007). This, however, might confirm that Bahr El Baqar drain is the main source of adjacent soil and environmental pollution, especially with the injuries of inorganic heavy metals (Pb, Cd, Co, Cr and Ni) originating from the high-pitched rates of non-treated industrial wastes discharged in Bahr El Baqar drain. It might be concluded that when the combined index (MPI) exceeds 1, the concentrations of heavy metals are considered elevated and the ecosystem regarded as ''polluted''.

From the abovementioned results of different indicators used to evaluate the pollution status of different soil ecosystems and according to results given in Table 10, it seems reasonable to state that only Cd, Cr, Co, Pb, Mn and Cu are the most pollutants showing hazards on the trialed soil and plants ecosystems.

Table 7. The Enrichment factor (EF) for some heavy metals in the studied soils

Sample	Enrichment Factor (EF)								
No.	Fe	Al	Zn	Cu	Pb	Cd	Ni	Co	Cr
1	1.0	0.55	6.53	4.47	19.90	600	2.11	8.28	1.81
2	1.0	0.56	3.73	3.34	7.37	270	1.37	4.95	1.05
3	1.0	0.64	4.91	3.90	11.22	360	1.93	6.16	1.50
4	1.0	0.72	3.68	4.44	10.93	346	1.68	6.13	2.16
5	1.0	0.05	1.92	2.18	11.98	334	1.19	4.55	0.65
6	1.0	0.50	3.32	3.11	7.00	233	1.35	4.51	1.24
7	1.0	0.42	3.80	4.93	7.31	231	1.58	6.23	1.32
8	1.0	0.49	5.93	5.96	9.08	289	2.50	9.86	1.54
9	1.0	0.46	6.22	5.53	9.14	264	2.43	9.38	1.60
10	1.0	0.77	7.46	7.55	11.12	316	3.46	6.89	2.18
11	1.0	0.77	10.35	8.45	14.90	379	4.30	16.25	2.59
12	1.0	0.48	4.89	5.09	7.60	239	2.79	6.01	1.38

EF < 2 states deficiency to minimal enrichment **EF = 20 - 40 very high enrichment**
EF = 2 - 5 moderate enrichment **EF > 40 extremely high enrichment**
EF = 5 - 20 significant enrichment,

Table 8. The Enrichment factor (EF) for some associated elements in the studied soils

Element	Minimum	Maximum	Average	Std. Devision	Contamination categories on the basis of the enrichment factor
Fe	1	1	1		
Al	0.05	0.77	0.53	0.22	EF < 2 states deficiency to minimal enrichment
Zn	3.80	10.35	6.32	2.16	EF = 5 - 20 significant enrichment
Cu	5.53	18.07	10.52	3.96	EF = 5 - 20 significant enrichment
Pb	7.00	19.90	11.15	4.49	EF = 5 - 20 significant enrichment
Cd	232.52	872.42	367.06	204.10	EF > 40 extremely high enrichment
Ni	2.84	8.06	4.50	1.68	EF = 2 - 5 moderate enrichment
Co	17.24	42.27	24.07	8.39	EF = 20 - 40 very high enrichment
Cr	3.99	8.81	5.51	1.69	EF = 5 - 20 significant enrichment
Sr	0.23	0.66	0.42	0.14	EF < 2 states deficiency to minimal enrichment

Table 9. Heavy metals status under different indicators studied

HMs	CF	I_{geo}	PLI	DC	mDC	EF
Fe	-	-	-	-	-	-
Al	-	-	-	-	-	-
Zn	-	-	-	-	-	-
Cu	+	-	-		-	-
Pb	+	+	+	+	+	+
Cd	+	+	+	+	+	+
Ni	+	+	+	+	+	+
Co	+	+	+	+	+	+
Cr	+	+	+	+	+	+
Sr	-	-	-	-	-	-
Al	-	-	-	-	-	-

- + Over the critical level Under the critical level

5. Mobility factor MF

Fractionation of heavy metals in soils signified as water soluble WS, exchangeable and carbonate fractions (F1 + F2 + F3) are regarded to be the most mobile and available or bioavailable fractions for cultivated plants regardless soil type and soil conditions. The heavy metals mainly created from anthropogenic activities (Asagba *et al*., 2007). Heavy metals in these fractions are weakly or loosely bound to soil components, while Fe-oxide form F4, Organic form F5 and F6 (Residual form) are more retainded to soil components.

According to Salbu *et al*., 1998; Kabala and Singh, 2001, The relative calculated mobility of these pollutants was measured using the following model:

$$MF = (F1 + F2 + F3) / (F1 + F2 + F3 + F4 + F5 + F6) * 100$$

Generally, the studied pollutants in the exchangeable fractions are considered as readily available form, while the reducible or oxidizable fractions are relatively stable under normal soil conditions. Heavy metals in residual fractions are fixed in crystal structure of the clay minerals and represent the least mobile fraction compared to others. The mobility of heavy metals in soil might be evaluated on the basis of the absolute and relative content of weakly bound fractions. To measure mobility of heavy metals, some works have used the relative index to calculate mobility factor (MF) based on the ratio between exchangeable, carbonate-bound and reducible fractions to the sum of all fractions (Lu *et al*. 2007, Kabala and Singh 2001).

Mobility factor MF calculated for inorganic pollutants is a measuring of the potential mobility of a metal(s) in contaminated soils Lua *et al.* (2003). Increasing of MF meaning that metal(s) is in high mobility state, consequently, its availability or bioavailaty to the biological systems will be high (Huang *et al*. 2007; Olajire *et al*. 2003).

Figure 1 showed that MF of some pollutants fractions was strongly bound to soil components compared to those extracted in F1, F2 and F3 readily available forms. The MF of pollutants in used soil samples might be evaluated on the basis of absolute and relative content of fractions weakly bound to soil component such as clay content. The high Mobility Factor values have been explained as the symptom of high ability and biological availability of the heavy metals in soil (Kabala and Singh 2001; Narwal *et al*. 1999; Karczewska 1996). As shown in Figure 1, the MF used in this work showed that Mn (45.43%) > Co (40.6%) > Ni (35.1) > Zn (29.9%) > Pb (27.3%) > Cr (16.3%) > Cd (15.9%) > Cu (5.7%). The MF of all pollutants indicated that Mn was the most mobile pollutant and Cu was the lowest and stable pollutant. The same trend was observed by Zhou *et al.* 2008; Salbu *et al.* 1998; Lua *et al*. 2003 and Banat *et al.* 2005.

The high Mobility Factor values have been explained as symptoms of high and biological availability of heavy metals in soil ecosystems. Results of the MF imply the mobility of the the studied pollutants were declined according to order:

Mn > Co > Ni > Zn > Pb > Cr > Cd > Cu

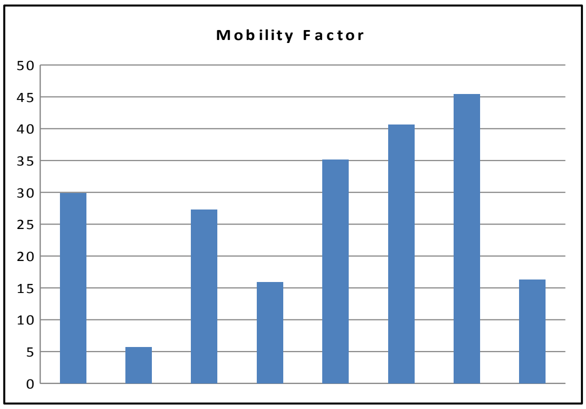


Figure 1. Mobility factor of heavy metals in the studied soils

Concentration of heavy metals in selected Bahr El-Baqar cultivated crops irrigated with low quality water

1. Lead (Pb)

Results presented in Table (10) showed that Pb concentrations in plants cultivated in Bahr El-Bakar area exceeded the permissible levels of FAO-EPA (2001). The range of Pb concentration in these crops in all investigated sites ranged between 1.82 and 12.85 mg kg^{-1}, specifically, Pb concentrations in clover ranged between 1.76 to 11.27 mg kg^{-1} in the different farms with significant variations among trailed soils as shown in the same Table.

Table 10. Range of heavy metals concentration in edible parts of different crops collected from cultivated soils adjunct to Bahr El- Baqar main drain.

Veg. name		Heavy metals (mg/kg)					
		Pb	Cd	Ni	Co	Zn	Cu
Clover	Min	1.76	0.11	2.77	0.39	24.90	26.63
	Max	11.27	0.20	3.83	0.93	54.70	33.09
	Mean	5.81	0.16	3.24	0.64	36.16	29.51
	SD	3.60	0.04	0.41	0.20	10.97	2.41
Wheat	Min	1.82	0.15	2.51	0.08	28.11	20.18
	Max	12.85	0.24	3.46	0.24	40.41	40.56
	Mean	6.28	0.21	2.87	0.15	34.33	28.64
	SD	4.26	0.03	0.37	0.06	4.90	7.99
Lettuce	Min	2.09	0.26	3.48	0.40	68.50	27.50
	Max	9.66	0.41	5.73	1.24	91.35	38.86
	Mean	5.46	0.31	4.11	0.72	78.40	31.38
	SD	3.07	0.07	0.84	0.29	8.08	4.11
Garlic	Min	1.66	0.14	2.27	0.06	17.60	15.00
	Max	9.00	0.23	3.88	0.20	24.60	21.83
	Mean	5.24	0.19	2.85	0.14	20.53	18.95
	SD	2.99	0.03	0.61	0.05	2.76	2.28
Onion	Min	1.96	0.14	2.10	0.03	18.25	23.00
	Max	8.76	0.24	2.84	0.10	40.10	29.20
	Mean	5.40	0.18	2.53	0.06	30.93	26.14
	SD	2.47	0.04	0.29	0.02	8.24	2.11

Data given in Table 11 revels that Pb concentration in onion plants ranged between 1.96 to 8.76 mg kg^{-1}. The high concentration of Pb in some plants might be attributed to the existence of this pollutant in irrigation water in addition to the nearby situation of the selected farms to highways traffic as given by (Qui *et al*., 2000). It should be mention that the highest concentration of Pb was found in wheat plants and reached to 12.9 mg kg^{-1}.

2.Cadmium (Cd)

Results listed in Table 10 revealed a high concentration of Cd clover plants ranging from 0.11 to 0.20 mg kg^{-1}. Cadmium concentrations in wheat and onion ranged between 0.15-0.24 and 0.14-0.24 mg kg^{-1}, respectively. The lowest mean level of Cd was detected in clover (0.11 mg kg^{-1}). These concentrations of Cd found in plant samples were higher than the permissible safe limits given by FAO/WHO (2001), 0.2 mg kg^{-1}, emphasizing the results of pollution indicators calculated.

3. Nickel (Ni)

Results in the same table showed that Ni concentrations in the vegetables cultivated in the studied farms were in range between 2-10 mg kg-1 in onion plants and 5.73 mg kg^{-1}in lettuce, meanwhile, the corresponding values of Ni pollutant in wheat and onion ranged between 2.51-3.46 mg kg^{-1}; and 2.10-2.84 mg kg^{-1} dry weight. Again, these values were higher than the safe level (0.1 mg/kg) recommended by the FAO/WHO (2002).

4. Cobalt (Co)

Cobalt (Co) is an essential element for some plants since it exercises some biochemical functions (Salvatore *et al*., 2009), for example, Co is essential for nitrogen fixation by rhizobium in legume nodules. In contrast, Collins and Kinsela (2011) documented that there is no evidence that higher plants have a direct requirement of cobalt. Results in the same table showed that the concentrations of Co were within the normal range of 0.01-1.00 mg kg^{-1} as reported by Khan *et al*., (2008). The lowest mean level of Co was detected for onion reaching 0.032 mg kg^{-1}.

Correlation analysis between heavy metals concentrations in different crops and soil properties:

Correlation analysis was done between soil properties and the heavy metal pollutants exerting the highest hazards, i.e., Ni, Pb, Cd, Zn and Cu. Results given in Table 11 showed that Pb uptake by different plant species was highly correlated and controlled by some soil properties. The correlation analysis showed that Pb uptake by clover was highly and negatively correlated with CEC (-0.93**), organic matter (-0.86**) and clay content (-0.93**) of trailed soils. The Pb uptake by wheat was correlated negatively and significantly with CEC, OM and clay contents in values of -0.92**, -0.88** and -0.94**, respectively. Onion uptake of Pb was significantly correlated with CEC (-0.99**), O.M (-0.99**) and clay content (-0.95**). The most effective soil properties that controlled Pb uptake could be arranged as follows: clay content > CEC > OM, while values of pH, EC, $CaCO_3$, and sand or silt fractions did not affect Pb uptake.

In case of Cd, its uptake by clover, lettuce, garlic and onion had significant negative correlation with CEC, OM and clay content. Cadmium uptake by wheat was highly significantly correlated with clay contents. This result might be ascribed to the reactions between certain organic components such as phenol, carboxyl, amine groups or clay with pollutants, forming complexes compounds. Jülide and Resat (2006) found that the surface sites are responsible for the sorption reactions and assumed that they retain ions since their permanent charge's and Cd ions are assumed to bind to the surface soils in outer sphere and inner-sphere mono-dentate complexes.

Table 11. Correlation coefficient between soil properties and heavy metals concentration in the cultivated crops

Soil property	Pb					Cd				
	Clover	Wheat	Lettuce	Garlic	Onion	Clover	Wheat	Lettuce	Garlic	Onion
pH	-0.36ns	-0.34ns	-0.30ns	-0.27 ns	-0.38 ns	-0.38ns	-0.55 ns	-0.29 ns	-0.39 ns	-0.31 ns
EC	0.29 ns	0.25 ns	0.28 ns	0.28 ns	0.21 ns	0.05 ns	0.01 ns	0.39 ns	0.14 ns	0.27 ns
CEC	-0.88**	-0.88**	-0.93**	-0.94**	-0.94**	-0.99**	-0.56 ns	-0.80**	-0.95**	-0.90**
CaCO3	0.12 ns	0.21 ns	0.14 ns	0.22 ns	0.17 ns	0.17 ns	0.26 ns	0.03 ns	0.23 ns	0.20 ns
OM	-0.84**	-0.86**	-0.89**	-0.93**	-0.92**	-0.96**	-0.69 ns	-0.74*	-0.93**	-0.88**
Sand	0.64 ns	0.68 ns	0.61 ns	0.66 ns	0.69 ns	0.53 ns	0.82**	0.54 ns	0.71*	0.70*
Silt	0.08 ns	0.03 ns	0.12 ns	0.03 ns	0.02 ns	0.17 ns	-0.43 ns	0.18 ns	0.09 ns	0.09 ns
Clay	-0.93**	-0.94**	-0.91**	-0.92**	-0.95**	-0.84**	-0.77**	-0.86**	-0.96**	-0.94**
	Ni					Zn				
pH	-0.39 ns	-0.40 ns	-0.36 ns	-0.33 ns	-0.36 ns	-0.41 ns	-0.33 ns	-0.40 ns	-0.41 ns	-0.36 ns
EC	0.27 ns	0.28 ns	0.20 ns	0.25 ns	0.10 ns	0.22 ns	0.27 ns	0.21 ns	0.24 ns	0.18 ns
CEC	-0.89**	-0.82**	-0.69 ns	-0.77**	-0.96**	-0.83**	-0.95**	-0.88**	-0.89**	-0.96**
CaCO3	0.12 ns	0.10 ns	0.23 ns	0.14 ns	0.30 ns	0.15 ns	0.16 ns	0.21 ns	0.11 ns	0.21 ns
OM	-0.86**	-0.78**	-0.64ns	-0.71*	-0.99**	-0.79**	-0.93**	-0.86**	-0.85**	-0.97**
Sand	0.64 ns	0.62 ns	0.70*	0.55 ns	0.72*	0.67 ns	0.64 ns	0.73*	0.61 ns	0.70*
Silt	0.09 ns	0.11 ns	-0.06 ns	0.17 ns	-0.07 ns	0.05 ns	0.08 ns	-0.02 ns	0.14 ns	-0.02 ns
Clay	-0.94**	-0.92**	-0.90**	-0.87**	-0.91**	-0.95**	-0.92**	-0.97**	-0.93**	-0.92**

	Cu				
pH	-0.35 ns	-0.37 ns	-0.38 ns	-0.47 ns	-0.44 ns
EC	0.27 ns	0.29 ns	0.18 ns	0.17 ns	0.20 ns
CEC	-0.87**	-0.87**	-0.79**	-0.89**	-0.88**
CaCO3	0.23 ns	0.11 ns	0.25 ns	0.13 ns	0.18 ns
OM	-0.87**	-0.83**	-0.76**	-0.90**	-0.88**
Sand	0.73*	0.62	0.73*	0.74*	0.75*
Silt	-0.05 ns	0.11 ns	-0.05 ns	-0.07 ns	-0.07 ns
Clay	-0.95**	-0.93**	-0.95**	-0.94**	-0.97**

CONCLUSION

From the previous discussion, it could be concluded that:

- The risk assessment of heavy metals in soils depends on both their relative mobility and bioavailability and those pollutants are considered harmful for the life cycle of growing plants cultivated in such soil ecosystems. These pollutants habitually invade to food chain.
- The abundance of heavy metals measured in these soil ecosystems decreased according to the order: Fe>Al>Mn>Cr>Cu>Zn>Co>Ni>Pb>Sr>Cd
- Trailed soil ecosystems seemed to be highly enriched with Co, Cu, Pb and Cd, while Cu had a significant enrichment. It should be mention that Cd has extremely high enrichment factor compared to other pollutants. Cd>Co>Pb>Cu>Zn>Cr>Ni>Al>Sr . Cadmium was the most abundant heavy metal; whereas Sr showed the lowest appearance in different trailed soil ecosystems.
- The total concentrations of Co in different soil ecosystems were high in some sites due to irrigation with untreated water of Bahr EL-Baqar drain.
- Copper concentrations in editable parts were lower than other heavy metals pollutants due to their continuous removal from the soil ecosystems by leaching to ground water.
- Cadmium content was high in the investigated soil ecosystems samples due to the heavy application of phosphate fertilizers, irrigation by untreated wastewater of Bahr EL-Baqar drain and heavy texture of trailed soils that permitted the retain of heavy metal pollutants.
- All indicators used in the current study confirmed the toxic effects of Cd, indicating that Cd should receive more attention compared to other heavy metals studied.
- The concentrations of Pb were low due to the limiting sources of Pb added to the main drain used in irrigation.
- The concentrations of Ni and Cr were significant high in trailed soil ecosystems due to irrigation with untreated Bahr EL-Baqar drainage water and intensive use of agricultural fertilizers, in addition to the waste incinerations and fugitive emissions from industrial sites in Port Said and around the Cairo Ismailia road. The continuous removal of heavy metals by the food crops grown in this area and the leaching of heavy metals into the deeper layer of the soil and to the ground water could be also reasons in decreasing Cr concentrations.
- The determined values of Pb, Cd, Ni and Co in various crops (clover, wheat, Lettuce, Garlic and onion) grown in Bahr El-Baqar region significantly varied between plant species, however, these heavy metals pollutants exceed the permissible levels internationally recommended.
- The high concentration of Co was found in onion plants, while high concentrations of Cd were found in clover plants.
- The pollution indices used in this work gave a good indicator for pollution status in selected soil ecosystems.
- It is recommended that before using wastewater in irrigation, analyses and assessment of the harmful and toxic elements should be assessed.
- The Pollution Load Index was higher than 1 in most trailed soil ecosystems, indicating a serious pollution problem with heavy metals and the study area fell into “considerable” degree of contamination.
- The CF values showed that Cd was at a very high contaminated Class. According to the CF results, the Co and Cu concentrations of all trailed ecosystems are in the ‘considerably’ contaminated Classes. The CF for Ni, Pb, Cr and Zn showed that all samples are in moderately contaminated’ classes. Worthy, Fe, Al, Mn and Sr in trailed soil ecosystemss were in low,’ contaminated classes

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صور وحركة بعض المعادن الثقيلة فى التربة المروية بمياه مصرف بحر البقر وتأثيرها على النباتات النامية

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مركز بحوث الصحراء- المطرية. القاهرة

تتمثل أهمية هذة الدراسة فى ضرورة تقييم الأراضى من ناحية التلوث لضمان الحصول على غذاء امن للأنسان المصرى.في هذا العمل ، تم تجميع عينات من الاراضى والنباتات التي تنمو في المناطق المجاورة لمصرف بحر البقر الرئيسي (محافظة الشرقية) لدراسة مصير ومخاطر المعادن الثقيلة الممثلة في معادن:Pb و Cdو Niو Znو Cuو Co ... بغرض تقييم تللك الأراضى من ناحية مدى التلوث كذلك مدى الضرر الناشئ عن أمتصاص النباتات المأكولة النامية فى هذة المنطقة والتى من الممكن أن تسبب خطر داهم على صحة الانسان التى من الممكن أن يأكل تلك المحاصيل. تم إجراء التحاليل الكيميائية لهذه الأراضى والعينات النباتية لتقييم التلوث أعتمادا على قيم الحدود الدولية. أيضا طبقت بعض النماذج الرياضية لحساب بعض مؤشرات التلوث تتمثل فى عامل التخصيب (EF) ، مؤشر التراكم الجغرافي (Igeo) ، عامل التلوث (CF) ، درجة التلوث (DC) ، درجة التلوث المعدلة (m Cd) ،كذلك مؤشر حمل التلوث (PLI) لتقييم مدى الضرر ومصير ومخاطر تلك الملوثات الغير عضوية في الاراضى التى تم تقييمها. أيضا ، تم تحديد مؤشرات النقل والتراكم الأحيائي (MF)المتوقع لتلك الملوثات المختارة في انواع النبات المختلفة التى تم جمعها والتى تتمثل فى البرسيم والبصل والقمح والخس والثوم. بالإضافة إلى ذلك تم حساب الارتباط بين خصائص التربة المدروسة وتركيزات المعادن الثقيلة في المحاصيل المزروعة لأظهار تأثير تلك الخواص على أنتقال المعادن الثقيلة الى المحاصيل المنزرعة.وأظهرت الدراسة النتائج الأتية:بناءا على المعايير الدولية فإن تلوث تلك الأراضى فاق تلك الحدود وأن الأراضى المدروسة تعانى من مشكلة التلوث بالعناصر الثقيلة. كذلك فإن تلك المؤشرات الدولية المدروسة أثبتت هذا التلوث وأن هناك أختلافات معنوية توقفت على نوع الملوث (حيث كان الكادميوم أخطر هذة العناصر) ، نوع النبات المنزرع كذلك توزيع هذة العناصر الثقيلة داخل الأراضى المدروسة.محتوى النباتات المدروسة من العناصر الثقيلة فاق الحدود الدولية لتك العناصر الثقيلة وأن هذة النباتات غير صالحة للأستهلاك الآدمى. أظهرت النتائج أن هناك أرتباط واضح بين محتوى النباتات من العناصر الثقيلة وبعض الخواص الأرضية مثل المادة العضوية فى الأراضى ، السعة التبادلية الكاتيونية ومحتوى الأرض من الطين .