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ENVIRONMENTAL RISK ASSESSMENT OF MERCURY AND ARSENIC IN SOME SOILS - AL BAHARIYA OASIS – EGYPT

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ABSTRACT:

Occurrence and assessment of the environmental risk of mercury(Hg) and arsenic (As) in Al Bahariya Oasis have not been given due attention although it has diverse agricultural areas. This study was carried to assess the environmental danger of mercury and arsenic in agricultural soils in the northern part of Oasis, near the mining area. Sixty-four (0-30 cm) soil samples and thirty-two plant samples were collected from four locations; EL Harra (A1), Mendisha (A2), Al Kaser (A3), and Al Bawiti (A4). Samples were analyzed for mercury and arsenic in all soil samples and their fractionations were determined. Indices of contamination factor (Cf), enrichment factors (EFs), potential ecological risk (PER), and Geoaccumulation index (Igeo) were calculated to evaluate the level of pollution. Results showed high content of Hg and as than the background level and WHO limit in soil and plants. Based on Igeo and ER value, soils were strongly polluted and had very high ecological risk in case of mercury. Soils were moderately contaminated and had moderate ecological risk in case of As. According to CF and EF soil had very high contamination factor and was considered extremely polluted by Hg, while it had a significant degree of contamination and significant level of enrichment by As. Fractions distribution showed that carbonate-bound and exchangeable fractions were the predominant fraction of elements, which interoperated absorption of these elements by plants. Anthropogenic activities might be the most responsible source

of contamination especially mining activities, Hence, Pollution must be controlled in this area

Keywords: heavy metals, mining, pollution indices.

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INTRODUCTION:

Heavy metal (loid)'s pollution is considered a hot research topic because of its toxicity and persistence. Heavy metal (loid)s are naturally present in the Earth's crust and are also released into the soil as a result of a number of anthropogenic activities; increasing the levels of heavy metals in soil to unsafe levels is a major concern all over the world. Due to their ability to be bound by dust, heavy metals may be received from both close and far-off sources of pollution, allowing them to be deposited in place or moved over long distances (Mohamed et al. 2014; Ripin et al., 2014; Mazurek et al., 2016). There are two main sources of heavy metal(oid)s; natural and anthropogenic sources. Natural sources include geological processes such as mineral weathering, erosion, volcanic eruptions, and continental dust. However, industrial activities such as mining, smelting, electroplating, and the discharge of industrial effluent, agricultural practices such the use of pesticides and phosphate fertilizers, as well as, the release of agricultural wastes, are all examples of anthropogenic activity (Kose et al., 2019; Antoniadis et al., 2017; Mahar et al., 2016). The nature of the parent material and the site's pedogenesis might provide either favorable or unfavorable circumstances for heavy metal buildup. Therefore, weathering of the parent material is a natural process that influences the amount of heavy metals in the soil (Kierczak et al., 2016; Chen et al., 2015).

Heavy metals content in agricultural soil is affected by the parent rock material, organic material usage, landfilling, aerosol particles from fossil fuel burning and pollutants in fertilizers (Bolan et al., 2014). (Chen et al., 2011; Cui et al., 2004; Wang et al., 2004) revealed five different pathways for heavy metals to get into plants: sludge fertilization, using contaminated water in irrigation, atmospheric deposition, a multi-heavy-metal environment (including waste accumulation of heavy metals pollution from metal mines), and farmers' agricultural practices. Subsequently, Heavy metals may accumulate to hazardous amounts in the soil, become enriched in the food chain, groundwater, and pose a serious risk to human health (Moore et al., 2016; Lee et al., 2005).

Mercury is a resistant metalloid element, where it can spread from point source to non-point source locations through atmospheric deposition, so it is a global pollutant (Malcolm et al., 2018). Mercury is emitted from several sources through a number of natural processes, which involve the widespread weathering of mercury-containing rocks in the Earth's crust, geothermal emissions, or Hg released during episodic occurrences such as volcanic eruptions (AMAP/UNEP, 2013). The majority of Hg forms are very dangerous to heavily exposed individuals; nevertheless, even a small amount can significantly and badly impact the central nervous system (Nance et al., 2012). Moreover, (Dixit et al., 2015) reported that many diseases are caused by mercury such as drowsiness, autoimmune diseases, fatigue, depression, hair loss, loss of memory, insomnia, restlessness, disturbance of vision, tremors, brain damage, lung and kidney failure, and temper outbursts. On the other hand, mercury is far more persistent in soils than in seas, lakes, and other biomes (Tangahu et al., 2011). The background level of Hg in various types of soils across the world is 0.07mg/Kg (Kabata-Pendias, 2011).

Arsenic is a metalloid found in soil due to mineral dissolution, pedogenic content as well anthropogenic activities (Smedley and Kinniburgh, 2002). Mining activities is one of the most important anthropogenic sources of As in soil (Camm et al., 2004). (Stojić et al., 2019) stated that concentrations of As in the environment increase through both point and diffuse sources that may be natural (volcanic emissions, rock weathering, and discharge from hot springs) or anthropogenic activities (smelting, and the use of arsenicals as pesticides and herbicides, mining processes, and wood preservatives). Arsenic affects essential cellular processes such as ATP synthesis and oxidative phosphorylation because it has toxic effect (Dixit et al., 2015). The average value of total arsenic for various soils is estimated as 6.83 mg/kg (Kabata-Pendias, 2011).

High concentrations of heavy metal(oid)s, particularly in agricultural soils, present a global environmental hazard due to the critical necessity of food supply and security (Kabata-Pendias 2011; Kelepertzis 2014; Chen et al., 2015). It has been suggested that the risk of heavy metal pollution from mining is a serious global environmental problem particularly in developing nations (Gupta et al., 2019). Agricultural fields near mining regions may be exposed to heavy metal (oid)s, so food crops cultivated in these polluted areas may uptake and store these elements, posing danger to human health (Gunalan et al., 2018). In regions affected by mining mercury, toxicity in the majority of soils poses a serious threat to ecosystems (Chen et al., 2024). Mercury (Hg) and Arsenic (As) are often investigated as typical elements because of their various sources (Shi et al., 2012; Duodu et al., 2017), toxicity (Calderón et al., 2001; Flanders et al., 2019), persistence (Beau et al., 2019; Kyle et al., 2012), and bioaccumulation performance (Kershaw and Hall, 2019; Greani et al., 2017). Consequently, pollution produced by As and Hg has received significant attention from researchers all over the world (Day et al., 2019; Zhao et al., 2015; Nyanza et al., 2020; Maage et al., 2017). Moreover, Hg and As are considered non-essential elements as they have no vital function in the body and pose serious health risks so they are classified as major pollutants by global environmental protection agency (Dixit et al., 2015 Jaishankar et al., 2014; Sarwar et al., 2017). Moreover, the Agency for Toxic Substances and Disease Registry and the United States Environmental Protection Agency (US EPA) list As and Hg among the top 20 hazardous substances (ATSDR, 2012).

Evaluation and monitoring of Hg and As pollution is vital to ensure the safety and quality of soils and cultivated crops. To evaluate their potential risks, it is essential to assess the concentrations of these potentially hazardous and toxic metals in the soil (Pillai et al., 2016; Chen et al., 2005). Many indices as the index of geo-enrichment factor (EF), accumulation (Igeo), contamination factor (CF) pollution load index (PLI), and pollution index (PI), have been used to categorize the danger level of heavy metals in soil by comparing the relative ratio of the current concentration to a reference value (Li et al., 2014). In addition, fraction analysis is important for understanding the mobility and distribution of heavy metal(oid)s in soil and sediment to provide information for risk assessment (Remon et al., 2005).

Bahariya Oasis is located in the northern part of the Western Desert of Egypt. (Salem 1980 and 1987; Khalifa 2006) stated, that agricultural activities in Bahariya Oasis´ Soils are promising because of good quality of ground water for irrigation and it has stratigraphic rock units. The iron ore from Bahariya is Egypt's sole source for the steel industry (Salem, 2017). (Baghdady et al., 2018) examined occurrence of some heavy meals as, Cr, Zn, Fe, Mn, V, Pb, and Cu in cultivated and uncultivated soils in Bahariya Oasis and demonstrated that metals concentrations vary across the oasis; the greatest levels found around the iron mines in the north, where mining operation is considered a source of heavy metals contamination in soil nearby these area (Arhin et al., 2016 and Chen et al., 2018).

There were no studies in literature focused on mercury and arsenic pollution in the agricultural soil at the northern areas of the Oasis near the iron mines as El Harra area. Where mining process may increase emission of these elements in adjacent agricultural soil and thus transfer to plants. So, the purpose of this study is to determine the content of mercury and arsenic in some agricultural soil and plant in Al Baherya Oasis as in El Harra (2.9 km^2) as a mining area and other three adjacent locations; (Mendisha, Al Bawiti and Al Kaser) and assess the environmental risk of these elements by using some indices of pollution, as well as to determine the fraction distribution of these elements to assess plant uptake of them from soil.

MATERIALS AND METHODS:

Study area and sampling:

The Bahariya Oasis is in Egypt's Western Desert. It is located around 270 km south west of Cairo and 180 km west of the Nile Valley, with hot, dry weather conditions, between longitudes 28° 35' and 29° 10' E and latitudes 27° 48' and 28° 30' N. The Bahariya formation is a case study of a fluvial to mixed fluvio-marine succession that accumulated on the African-Arabian plate's continental shelf during the Early Cenomanian period (Said, 1962; Issawi, 2002; Catu-neanu et al., 2006). Texture of Bahariya Oasis soils are muddy sand and sub mature to mature sand. These soils were inherited through physical weathering from the sedimentary succession and basaltic rocks that formed the depression scarps (Baghdady and Gad, 2013). The cultivated area in Bahariya Oasis is less than 1% of its total area, which is around 1200 km^2. This small area due to the restricted sites of ground water that utilized for irrigation (Baghdady et al., 2018) where around 65.5 of farmers use drip irrigation system (Risha, 2016).

Sixty-four surface soil samples (0-30 cm) and thirty-two plant samples were collected from four different locations. Soil and plant samples were collected from EL Harra (A1), Mendisha (A2) area, Al Kaser (A3) area, and Al Bawiti (A4) Figure (1). In each location, sixteen soil samples were taken, sample every 50 m^2.

Cultivated Plant samples were collected from these four locations and packed in paper bags. Eight plants from each location. Plants were represented by their leaves. Cantaloupe leaves (***Cucumis melo var***), water melon leaves (***Citrullus lanatus***), olive leaves (***Olea europaea***), bean leaves (***Phaseolus***), fodder plant leaves, purslane leaves (***Portulaca oleracea***), okra leaves (***Abelmoschus esculentus***), grape leaves (***Vitis vinifera***), eggplant leaves (***Solanum melogenic***), peanut leaves (***Arachis hypogaea***), mango leaves (***Mangifera indica)***, Molokhia leaves (***Corchorus olitorius***), guava leaves (***Psidium***).

Digestion and Chemical Analysis:

In laboratory, the soil samples were sieved through a nylon sieve (2-mm mesh) after air-drying. pH was measured in 1:2.5 suspension (w/v) soil/water using Jenway pH-meter model 3305, soil salinity was measured in 1: 2.5 (w/v) soil: water suspension using Jenway conductivity meter model 4310 (Black, 1965). By Collin's calcimeter total carbonate equivalent was determined. Particle size analysis of the fraction less than 2 mm was carried out using Pipette method (FAO, 1970). The sodium acetate method was used to determine cation exchange capacity (CEC). The Walkley Black method was used to calculate soil organic carbon (SOC) (Black, 1965) Table (1).

To determine total Arsenic and mercury, soil samples were digested using an optimal digestive system, aqua regia HNO_3-H_2O_2 (Zhang and Wang, 2021). In digestion tubes, 0.5 g of each sieved soil samples were mixed by 8 ml of HNO_3 and 2ml of H_2O_2 and then placed in a digester microwave (Ney Vulcan A550, USA) around 12 h to digest soil samples completely (EPA, 1996). Digested samples were filtered, then two elements were measured using inductively coupled argon plasma optical emission spectrometry (ICAP 6500 Duo, Termo Scientifc, England). To determine the fractions of arsenic and mercury in the soil samples, the sequential extract method (Tessier et al., 1979) was used. The fractions were divided into exchangeable, Carbonate-bound, oxides-bound, organic matter-bound, and residual fractions. In step -1 exchangeable fraction was extracted by 8 ml of 1 M $MgCl_2$ at pH 7 for 2 h at 25˚C.Then in step -2 fraction bound to carbonates was extracted by using 8 ml of NaOAc at pH 5.0 for 5 h at 25˚C. After that in step 3 fraction bound to oxides was extracted by 20 ml of 0.04 M hydroxylamine hydrochloride in 25% acetic acid at pH 2 for 6 h at 96˚C. Organic-bound fraction was extracted in step 4 by 5 ml of 30% H_2O_2 at pH 2 , 3 ml of 0.02 M HNO_3 ,3 ml of 30% H_2O_2 at pH 2 and 20 ml of a mixture of 3.2 M NH_4Ac plus 20% HNO_3 for 2 h at 85˚C. finally residual fraction was digested by using 8 ml of a mixture of HNO_3 and HCl 1:3 (v ratio) for 30 min at 25 ˚C. Inductively coupled argon plasma optical emission spectrometry (ICAP 6500 Duo, Termo Scientifc, England) was used for determination of these fractions.

Plant leaves were washed by tap and distilled water, then they oven dried for 48 hours at 70 ^{0}C, ground in a stainless-steel mill, and then digested according to (Wang et al., 2003). In digestion tube, 0.5 g of the dried grounded plant sample was mixed with 1 mL of $HClO_4$ and 10 mL of HNO_3 first, then after the solution up dried HNO_3 was added until no plant tissues were visible.

Mercury and arsenic were measured in the filtrate after filtering them through 0.45-mm membranes (Gelman Sciences, USA) by using inductively coupled argon plasma optical emission spectrometry (ICAP 6500 Duo, Termo Scientific, England) Table (2).

Assessment Methods:

Indices of pollution have been used to evaluate the serious degree of heavy metals (oid) contamination in the soil. Some useful measures have been widely applied to quantify metal accumulation in contaminated sediments and assess metals pollution, enrichment impact of sediment groups of the contamination factor (Cf), enrichment factors (EFs), potential ecological risk (PERI), and index of geoaccumulation (Igeo) (Hakanson 1980; Müller 1985).

Contamination Factor (CF):

By dividing the concentration of a certain element in soil by its background value, CF is obtained. So, contamination factor can be calculated based on the following equation:

$$CF= C_{metal} / C_{background}$$

Where C_{metal} is concentration of mercury or arsenic in soil samples and. $C_{background}$ is the concentration in unpolluted soil (earth's crust concentration) according to (Kabata-Pendias, 2011). On a scale from 1 to 6, the contamination levels can be categorized based on their strength Table (1) (Hakanson 1980 ; Islam et al., 2017).

Table (1) Contamination factor CF (Hakanson 1980 and Islam et al., 2017)

CF	Degree of Contamination
$CF < 1$	low degree
$1 \leq CF < 3$	moderate degree
$3 \leq CF < 6$	a significant degree
$CF \geq 6$	extremely high degree

Geo-Accumulation Index (Igeo)

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

Where C_n is the heavy metal concentration in the soil samples and B_n is the background value (earth's crust value) (Kabata-Pendias, 2011). The constant 1.5 compensates for small anthropogenic impacts of a certain metal. (Müller 1969, Chen et al. 2015) introduced I_{geo} to evaluate metals contamination in sediments. In addition, it can be used to completely characterize the accumulation level of one or more heavy metals in soil while taking into account the effects of natural diagnosis and mineralization on the background values of the soil (Müller 1969).

Table (2) Levels of contamination according to geo-accumulation Index (I_{geo}) Müller 1969.

I_{geo} classes	I_{geo} values	Level of contamination
0	$I_{geo} \leq 0$	Uncontaminated
1	$0 < I_{geo} < 1$	uncontaminated to moderately contaminated
2	$1 < I_{geo} \leq 2$,	moderately contaminated
3	$2 < I_{geo} \leq 3$	moderately to heavily contaminated
4	$3 < I_{geo} \leq 4$	heavily contaminated
5	$4 < I_{geo} \leq 5$,	heavily to extremely contaminated
6	$I_{geo} > 5$	extremely contaminated

Enrichment factor (EF)

$$EF = \frac{(C_x / C_{Fe})_{sample}}{(C_x / C_{Fe})_{Reference}}$$

Where $(C_x$ and $C_{Fe})_{sample}$ is the ratio of the content of the element and Fe in the studied soil samples. $(C_x / C_{Fe})_{Referenc}$ is the ratio of the background concentrations of the element and Fe (Kabata-Pendiasis, 2011; Baghdady et al., 2018). Fe was used as a reference in this study because it is one of the major soil constituents. Enrichment factor (EF) is used to differentiate between natural and anthropogenic sources (Pan et al., 2016).

Table (3) Values of Enrichment factor and levels of pollution (Sutherland 2000):

Enrichment factor values	Levels of Enrichment
<2	Little
2-5	Moderate
5-20	Significant
20-40	very strong
>40	extreme Enrichment

Potential Ecological Risk (PER)

(Hakanson, 1980) stated potential ecological risk index (PER), which is employed to evaluate the ecological risk of heavy metals in soil. The PER for an individual metal (PERi) is defined by the following formula $PER_i = T_i *(C_i /C_{bi})$

Where PER_i is the ecological risk index for the element, C_i is the concentration of the element in the soil; C_{bi} is the background value of the element (Kabata-Pendias 2011). Ti is the metal's toxicity response coefficient. The Hg toxic-response factor is 40, however it is 10 for AS (Wang et al. 2015). Potential ecological risk factor (PER) categories are shown in Table (4)

Table (4) Potential ecological risk factor (PER) categories (Hakanson 1980):

Potential Ecological Risk	Categories of risk
$E_r \leq 40$	Low ecological risk
$40 < Er \leq 80$	ecological risk is Moderate
$80 < Er \leq 160$	ecological risk is significant
$160 < Er \leq 320$	ecological risk is High
$320 < Er$	ecological risk is very high

Bioaccumulation factor of mercury arsenic in plants:

The Biological Absorption Coefficient is defined as the proportion of an element's concentration in plant ash to the total metal concentrations in soils (Nagaraju and Karimulla, 2002). BAC was employed to assess the extent of plant uptake of the element.

Table (5) the Biological Absorption Coefficient BAC Nagaraju and Karimulla (2002):

BAC values	Degree of Absorption
0.001 - 0.01	very weak
0.01- 0.1	Weak
0.1-1	Intermediate
1-10	Strong
10 -100	intensive

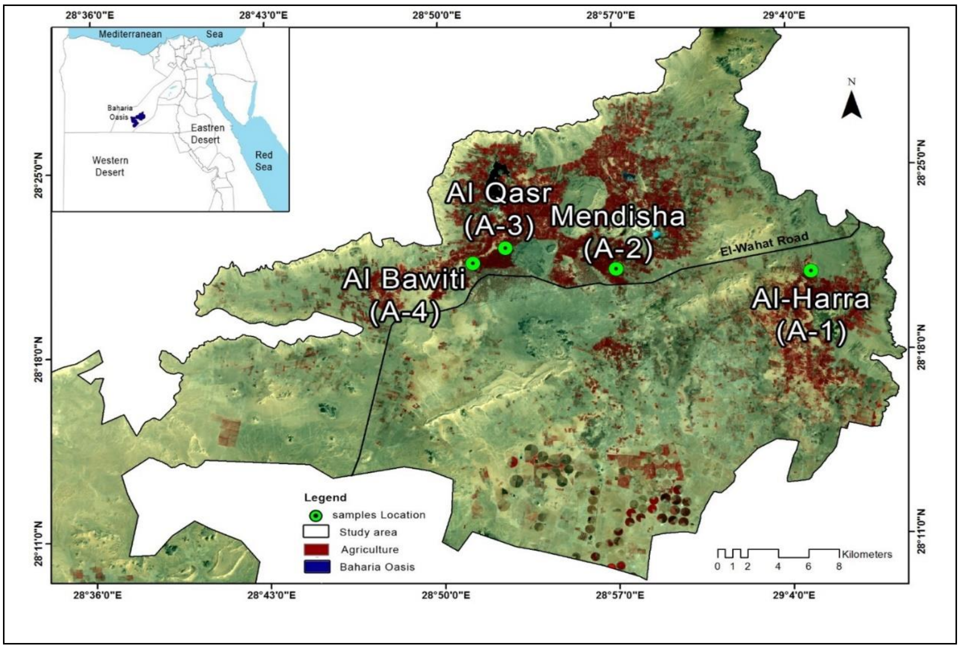

Figure (1) studied sites in Bahariya Oasis (Satellite image)

Statistical analysis:

Basic statistical parameters as mean, standard and Median deviations are done to all the data presented. Pearson's correlation coefficient and PCA were done using computer software programs SPSS version25 and Origin Pro 2021 version b9.5.0.193.

Results and Discussion:

Characteristics of Soil Samples:

By using fundamental statistical parameters, Table (6) illustrated some characteristics of the studied soil samples. Mean of pH values in the studied soil samples revealed that the soil is alkaline in general with the highest value in El Harra soil (A1) 7.82 and the lowest value in Al Kaser soil (A3) 7.51. The alkaline reaction of soil samples may be attributed to the presence of alkali cations, gypsum and carbonate minerals, where this soil was formed under arid and semiarid conditions as displayed by (Elnaggar, 2017). These results, also were observed by

(Baghdady et al., 2018). The mean of electrical conductivity (EC) values of soil samples ranged from 2.023 ds/m in (A2) Mendisha area to 3.209 ds/m in (A3) Al Kaser area. According to (FAO, 1990) the soil is slightly saline. The mean value of calcium carbonate content ranged between 5.98% in Al Kaser soil samples and 12.33% in El Harra soil samples. These results assured by (Ismail et al., 2024) who suggested that there is high correlation between calcium carbonate content and parent material of this soil. Mean value of cation exchange capacity of soil samples ranged between 5.25 meq/100g in Al Kaser soil samples to 9.56 meq/100g in El Harra soil samples. Organic matter content in general was low, the mean value ranged from 2188 $mg.kg^{-1}$ in Mendisha soil samples to 6434 $mg.kg^{-1}$ in (A4) Al Bawiti soil samples. Percentage of clay content ranged from 12.33% in Al Kaser soil samples to 9% in Mendisha soil samples. The content of sand fraction is high in all soil samples. All above characteristics of soil samples might play a vital role in the distribution of bioavailability, and potential environmental risk of mercury and arsenic in studying area.

Arsenic and mercury content in soil samples

Arsenic and mercury content was shown in Table (6). The mean of total mercury concentration ranged from 2.88 mg. kg^{-1} in (A1) area to 1.44 mg kg^{-1} in (A2). In addition, the mean values of mercury in (A3) and (A4) are 1.62, 1.54 $mg.kg^{-1}$ respectively. All values in A1, A2, A3 and A4 were higher by 41.14, 20.57, 23.14 and 22 times than its background values reported by (Kabata-Pendias, 2011) respectively. These results were similar to the data obtained by (Rashed, 2010) who examined the concentration of Hg in soil nearby mining areas at Southeast of Egypt and stated that Hg concentration was within 0.03–2.7 mg $kg^{-1.}$ However, it was higher than the result mentioned by (El-Sawy et al., 2023) in Bitter Lakes´ sediments Egypt, where Hg recorded mean concentration around 0.45 $mg.kg^{-1}$. Results of this study were lower than average that recorded for mercury by (Romeh, 2021) in Egyptian agricultural soil near highways between Sharkia Governorate and Ismailia Governorate. This indicated that anthropogenic activities play a vital effect on mercury enrichment in soil. On the other hand, the mean of concentrations of arsenic ranged from 8.27 mg kg^{-1} in A1 to 5.30 mg kg^{-1} in A4. In addition, the mean values of arsenic in A2 and A3 were 6.00 and 6.58 mg kg^{-1}respectively. Data showed that arsenic concentration in A1 was greater than earth’s crust average as reported by (Kabata-Pendias, 2011) by 4.59 time. As well, the arsenic concentrations in A2, A3 and A4 were more than earth's crust average by 3.33, 3.66 and 2.94 time respectively. Likewise, in all locations of the study, the concentrations of arsenic were higher than 0.2 mg kg^{-1} WHO limit (FAO/WHO, 2011). Arsenic concentration in this study was lower than the concentration stated by (Asmoay et al., 2019) in El Minya Governorate, Egypt (27 $mgkg^{-1}$) and by (Salman et al., 2018) in soil at Southwest Giza Egypt (142.8 $mgkg^{-1}$) who attributed this high concentration to anthropogenic and geogenic sources. Furthermore, the result of study for As was higher than its concentration as reported by (Ahmed et al., 2023) (0.0193 mg kg^{-1}) in El- Menoufia Governorate, Egypt. Thus, the high concentration of mercury and arsenic might be attributed to natural process because Oasis soils were inherited through physical weathering from the sedimentary succession and basaltic rocks that formed the depression scarps (Baghdady and Gad, 2013). On the other hand, human activities might be the most responsible source of this contamination such the mining activities especially in El Harra, which is considered iron-mining area. These results were in agreement with (Baghdady et al., 2018) who demonstrated that cultivated soils in the northern areas of the oasis, near the iron mines (El Harra, El Gedida and Ghorabi), have high concentration of (Ba, Cr, Cu, Fe, V) above maximum allowable concentration (MAC). Therefore, the high levels of Hg and As in the four study locations might be due to the anthropogenic activities as mining activities. (Rashed and Shalaby, 2007) demonstrated a similar finding who reported that pollution is more likely located near mining operations through atmospheric aerosols and its deposited in the surrounding farmland. As well, (Selenius, 2010) stated that mining was a source of arsenic contamination because modifying the chemical characteristics of bedrock that naturally contains arsenic can promote metal leaching and reach to soil. Moreover, agricultural practices like use of pesticides, addition of phosphate fertilizers and release of agricultural wastes may cause soil pollution by mercury and arsenic (Ali et al., 2013; Mahar et al., 2016; Antoniadis et al., 2017). As well, (Salman et al., 2019) reported high concentration of As in Egyptian soil at El Obour (Orabi farms), it was around 147mg.kg^{-1} and attributed this high concentration to different agricultural practice as addition of fertilizers.

Table (6) some physical and chemical characteristics of the studied soil samples Using basic statistical parameters:

Location		pH	EC ds/m	OM (mg/Kg)	CEC Meq/100g	$CaCO_3$ %	Sand%	Silt %	Clay %	Hg (mg/kg)	As (mg/kg)
A-1	Median	7.80	1.99	2265	8.03	11.76	88.50	1.27	10.00	2.51	8. 26
	Mean	7.82	3.05	2719	9.56	12.34	87.99	1.39	10.62	2.88	8.27
	Min	7.60	0.96	1373	7.65	10.95	83.96	0.00	9.00	1.78	6.64
	Max	8.09	7.26	4976	14.53	14.89	91.00	3.00	13.49	4.74	9.94
	STDEV	0.17	2.58	1382	2.80	1.53	2.65	1.44	1.91	1.09	1.19
	Kurtosis	-0.99	-0.81	-0.66	-0.35	-0.61	0.90-	-2.23	-1.25	-0.65	-1.94
A-2	Median	7.78	1.95	1922	5.74	7.77	90.00	0.50	9.00	1.52	5.96
	Mean	7.80	2.02	2188	5.74	8.63	90.50	0.50	9.00	1.44	6.00
	Min	7.66	0.41	1657	3.06	5.82	90.00	0.00	8.00	0.97	4.95
	Max	7.99	3.79	3260	8.41	13.16	92.00	1.00	10.00	1.77	7.15
	STDEV	0.14	1.54	656	2.38	2.70	0.89	0.52	0.73	0.31	0.83
	Kurtosis	-0.19	-2.24	2.20	-2.17	-0.76	-0.44	-2.30	-0.91	-0.99	-1.39
A-3	Median	7.41	3.76	4890	4.39	6.58	84.67	3.84	10.27	1.79	6.61
	Mean	7.51	3.23	4651	5.26	5.99	80.49	7.18	12.33	1.62	6.58
	Min	7.07	0.29	1373	3.06	3.88	57.96	0.00	7.76	0.98	5.14
	Max	8.16	5.00	7412	9.18	6.90	92.24	21.02	21.02	1.94	7.96
	STDEV	0.40	1.47	2591	2.39	1.25	15.35	9.46	5.91	0.39	1.07
	Kurtosis	-0.87	**-0.73**	-2.05	-0.65	-0.504	3.25	3.07	3.34	0-.68	-1.51
A-4	Median	7.65	3.28	4632	5.69	11.76	88.92	2.00	10.08	1.38	5.39
	Mean	7.64	3.18	6434	5.74	10.65	89.28	2.25	9.47	1.54	5.30
	Min	7.51	1.00	2402	3.05	6.31	88.86	2.00	7.58	0.91	4.22
	Max	7.76	5.18	14069	8.41	12.51	90.42	3.00	10.14	2.45	6.19
	STDEV	0.07	1.73	4641	2.29	2.29	0.68	0.45	1.26	0.67	0.71
	Kurtosis	-0.93	-1.96	-0.57	-2.03	-0.05	-0.45	-0.44	3.99	-1.76	-1.14
	Background (earth crust conc.) *									0.07	1.8

(A-1) EL Harra, (A-2) Mendisha, (A-3) Al Kaser and (A-4) Al Bawiti *Kabata-Pendias 2011

Mercury and Arsenic content in plant samples:

Table (7) showed ICAP date of Hg and As concentrations of in leaves of plant samples collected from different locations. The total concentration of Hg in leaves of plants ranged from 4.25 mg kg^{-1} in cantaloupe (*Cucumis melo var*) to 2.07 mg kg^{-1} in water melon (*Citrullus lanatus*) in A1 location, from 4.53 mg kg^{-1} in purslane (*Portulaca oleracea*) to1.29 mg kg^{-1} in eggplant (*Solanummelongena*) in A2, from 4.54 mg kg^{-1} in fodder plant to 1.31 mg kg^{-1}in eggplant (*Solanummelongena*) in A3 and from 3.37 mg kg^{-1} in Molokhia (*Corchorus olitorius*) to 4.73 mg kg^{-1} in guava (*Psidium*). Data showed high concentration of Hg in the leave of plant samples than the recommended value mentioned by (FAO/WHO 2011) (0. 1 mg.kg^{-1}). As well as, As concentration ranged between 3.51 mg kg^{-1} in olive leaves (*Olea europaea*) and 8.84 mg kg^{-1} in cantaloupe leaves (*Cucumis melo var*) in A1, from 3.25 mg kg^{-1} in olive leaves (*Olea europaea*) to 6.02 mg kg^{-1} in cantaloupe leaves (*Cucumis melo var*) in A2. From1.01 mg kg^{-1} in peanut (*Arachis hypogaea*) to 5.04 mg kg^{-1} in eggplant leaves (*Solanummelongena*) in A3, and from 2.21 mg kg^{-1} in mango leaves (*Mangifera indica*) to 4.97 mg kg^{-1} in Molokhia (*Corchorus olitorius*). Data indicated, that the As concentration in plant leaves is higher than (FAO/WHO, 2011) limit value 0.2 mg. kg^{-1}. The high concentration of the two elements observed may be due to the ability of plants to absorb these hazardous elements from contaminated soils by their roots and might absorb elements that have been deposited on their leaves (Liu et al., 2005) particularly that plant leaves were taken in this study as representative samples.

Table (7) Mercury and Arsenic content (mg.kg^{-1}) in plant leaves and calculated BAC

Location	plant species	Hg(mg/kg)	BAC	Degree of Absorption	As(mg/kg)	BAC	Degree of Absorption
A1	cantaloupe (*Cucumis melo var*)	4.25	1.48	Strong	8.14	0.98	Intermediate
	water melon (*Citrullus lanatus*)	2.07	0.72	Intermediate	6.07	0.73	Intermediate
	olive (*Olea europaea*)	3.57	1.24	Strong	3.87	0.47	Intermediate
	bean (*Phaseolus*)	3.32	1.15	Strong	3.95	0.48	Intermediate
	cantaloupe (*Cucumis melo var*)	4.02	1.40	Strong	8.00	0.79	Intermediate
	water melon (*Citrullus lanatus*)	2.32	0.81	Intermediate	7.94	0.96	Intermediate
	olive (*Olea europaea*)	3.46	1.20	Strong	3.51	0.42	Intermediate
	bean (*Phaseolus*)	3.02	1.05	Strong	4.01	0.48	Intermediate
A2	purslane (*Portulaca oleracea*)	4.53	3.14	Strong	4.37	0.73	Intermediate
	okra (*Abelmoschus esculentus*)	2.37	1.64	Strong	6.10	1.02	Strong
	eggplant (*Solanummelongena*	1.29	0.89	Intermediate	5.21	0.87	Intermediate
	cantaloupe (*Cucumis melo var*)	3.91	2.71	Strong	6.02	1.00	Strong
	purslane (*Portulaca oleracea*)	4.08	2.83	Strong	4.02	0.67	Intermediate
	okra (*Abelmoschus esculentus*)	2.01	1.40	Strong	5.50	0.92	Intermediate

	water melon (*Citrullus lanatus*)	1.91	1.33	Strong	4.50	0.75	Intermediate
	olive (*Olea europaea)*	3.61	2.50	Strong	3.25	0.54	Intermediate
A3	grabe (*Vitis vinifera*)	1.56	0.96	Intermediate	3.02	0.46	Intermediate
	eggplant (*Solanummelongena*	1.31	0.81	Intermediate	5.04	0.77	Intermediate
	peanut (*Arachis hypogaea*)	3.02	1.86	Strong	1.01	0.15	Intermediate
	mango (*Mangifera indica*)	3.02	1.86	Strong	4.87	1.48	Strong
	grabe (*Vitis vinifera*)	1.60	0.99	Intermediate	3.17	0.48	Intermediate
	peanut (*Arachis hypogaea*)	2.93	1.81	Strong	1.17	0.18	Intermediate
	okra (*Abelmoschus esculentus*)	2.54	1.56	Strong	5.00	0.76	Intermediate
	fodder plant	4.54	2.79	Strong	2.52	0.38	Intermediate
A4	fodder plant	4.72	3.07	Strong	2.27	0.43	Intermediate
	mango (*Mangifera indica*)	4.82	3.14	Strong	2.43	0.46	Intermediate
	Molokhia (*Corchorus olitorius*)	3.37	2.19	Strong	4.97	0.94	Intermediate
	guava (*Psidium*)	4.73	3.08	Strong	3.50	0.66	Intermediate
	fodder plant	4.08	2.66	Strong	2.22	0.42	Intermediate
	Molokhia (*Corchorus olitorius*)	4.62	3.01	Strong	4.51	0.85	Intermediate
	olive(*Olea europaea)*	3.46	2.25	Strong	3.26	0.61	Intermediate
	mango(*Mangifera indica*)	4.52	2.94	Strong	2.21	0.42	Intermediate

(A1) EL Harra, (A2) Mendisha, (A3) Al Kaser and (A4) Al Bawiti. Readings are mean of 3 replicates

Assessment of Pollution Indices:

Contamination factor (CF):

The values of CF for Hg ranged from 67.64 to 25.32 with mean± S.D (41.20±15.60) in A1, from 25.18 to 13.64 with mean (20.61±4.43) in A2, from 27.64 to 14.04 with mean (23.19±5.59) in A3 and from 35.01 to 12.96 with mean (21.95±9.51) in A4. Based on categories reported in Table (1) by (Hakanson 1980 and Islam et al., 2017). The values showed extremely high degree of contamination by Hg in the four selected locations because the values of contamination factor were higher than 6. However, for arsenic the values of CF ranged from 3.68 to 5.52 with mean (4.60±0.66) in A1, from 2.75 to 3.97 with mean (3.34±0.46) in A2, from 2.85 to 4.42 with mean (3.65±0.60) in A3 and from 2.34 to 3.44 with mean (2.95±0.39) in A4. According to these obtained values and the values of CF in Table (1) soil in all locations were considerably contaminated by Arsenic. The elevated degree of contamination factor was due to the increased concentration of Hg and as in soil compared to their back ground values. Therefore, the soil should be remediated to decrease mercury and Arsenic risk. Values of contamination factor are shown in Figure (2) for studied locations.

Geo-Accumulation Index (Igeo):

Igeo has been used in various areas by many scientists to assess metal contamination of soils (Wu et al., 2015; Chen et al., 2015; Li et al., 2013). Igeo mean values of Hg in all locations was higher than 0 which indicated that studied area were strongly polluted. Figure (3) showed the values of Igeo. Data showed, that A1 has mean value ±SD (4.70±0.51). This means, that the soil in this area was heavily to extremely contaminated according to Müller 1969 Table (2). In the other three locations, Igeo values mean were (3.74± 0.34) (A2), (3.90±0.41) (A3) and (3.74±0.63) (A4) which indicated that the soils in these sites were heavily contaminated. With regard to As, the mean values of Igeo, for all studied locations, were as follows, in A1 Igeo values ranged from 1.30 to 1.88 with mean value (1.60±0.21). In A2 Igeo values ranged from 0.88 to 1.40 with mean (1.14±0.20). In A3 the data ranged from 0.93 to 1.56 with mean (1.26±0.24). In A4 the result was in between 0.64 and 1.20 with mean (0.96 ±0.20). The study results demonstrated that A1, A2, A3 and A4 were moderately contaminated where1 < Igeo<2 Figure (3).

Enrichment factor (EF):

Enrichment factor (EF) measures the effect of anthropogenic activity on soil heavy metals' contamination. Figure (4) showed EF for Hg and As. Values of Hg ranged from 124.02 to 29.82 with mean ± S.D value (51.62±25.66) in A1 location, it ranged from 62.78 to 20.17 with mean (41.31 ±13.86). In A2 site, it ranged from114.03 to 37.48 with mean (70.99±21.38). In A3 it ranged from 78.03 to 28.59 with mean value (53.15±22.03). According to (Sutherland 2000) Table (3), the current study values showed that the four locations in the north of Bahariya Oasis were extremely polluted by Hg. This index referred to anthropogenic activities that include atmospheric deposition (Islam et al. 2017). For As Figure (4) showed EF values, which ranged between 3.61to 10.25 with mean value (5.79±1.96) in A1, from 3.87 to 8.98 with mean (6.60±1.59) in A2, from 8.30 to 15.39 with mean (11.03±1.98) in A3 and 5.19 to 9.51 with mean value (7.22±1.47) in A4. Data showed that the level of enrichment is significant where the mean values of EF is between 5-20. This might be due to the impact of anthropogenic activities along with natural effect that is in agreement with (Zhang and Liu, 2002; Elias Gbadegesin ,2011; Abreu et al., 2016) who mentioned that if the EF value is between 0.5 and 1.5 this means, that heavy metal content in the soil is caused by the natural processes. However, if EF value exceeds 1.5, this means that the heavy metal contamination possibility occurred due to anthropogenic activities.

Potential ecological risk factor (PER)

Heavy metal contamination in soil causes environmental risk and harm to human health when they enter food chain through agriculture and animals' food. Potential ecological risk factor (PER) is a combination of biological toxicity of heavy metals, environmental chemistry, and ecology (Suresh et al., 2012). Figure (5) showed statistical values of PER for Hg and As in studied area. For Hg in A1, the value ranged from 2706 to 1013 with mean value (1648±624). In A2, the value ranged from1007 to 546 with mean (824 ±177). In A3, the value ranged from 1106 and 562 with mean 928±224, and in A4 the value between 1400 and 519 with mean value (878±380). According to categories mentioned by (Hakanson 1980), Table (4) data showed that ecological risk of Hg was very high in all 4 studied locations. However, for As the data in Figure (5) showed that the value of PER ranged between 36.81 to 55.19 with mean value (45.96±6.66) in A1, from 27.53 to 39.69 with mean (33.35±4.66) in A2, from 28.54 to 44.19 with mean (36.53± 5.98) in A3, and from 23.42 to 43.42 with mean (29.44 ±3.94) in A4. These values demonstrated that the soil samples in A1 location had moderate ecological risk of potential contamination where, mean value of PER>40 while A2, A3 and A4 have low ecological risk where, the mean value of PER<40 (Hakanson, 1980) Table (4).

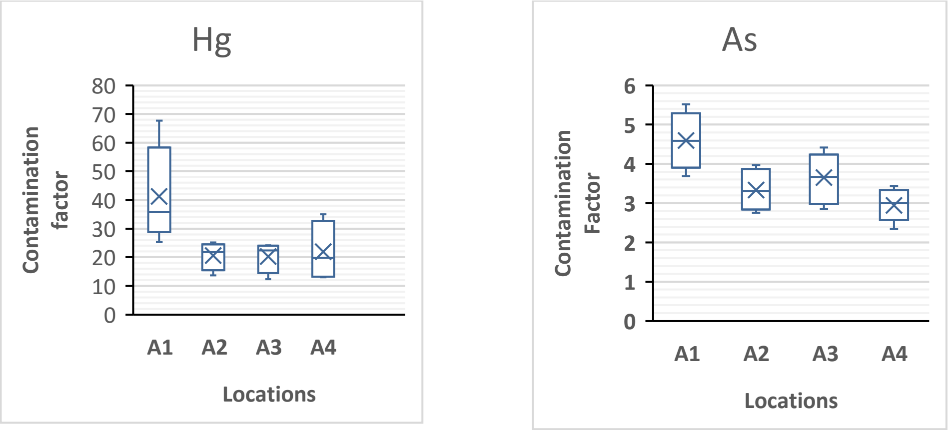

Figure (2) Box-plots of contamination factor for Mercury and Arsenic in (A1) EL Harra, (A2) Mendisha, (A3) Al Kaser and (A4) Al Bawiti ; the medians are represented by horizontal lines within the boxes. The bars denote the minimum and maximum numbers, and the crosslet represents the arithmetic mean.

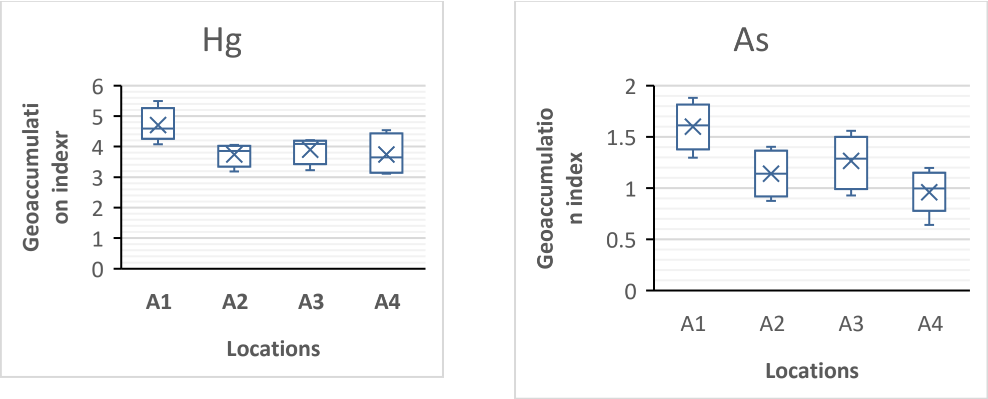

Figure (3) Box-plots of Geo-Accumulation index for Mercury and Arsenic in (A1) EL Harra, (A2) Mendisha, (A3) Al Kaser and (A4) Al Bawiti ; the medians are represented by horizontal lines within the boxes. The bars denote the minimum and maximum numbers, and the crosslet represents the arithmetic mean.

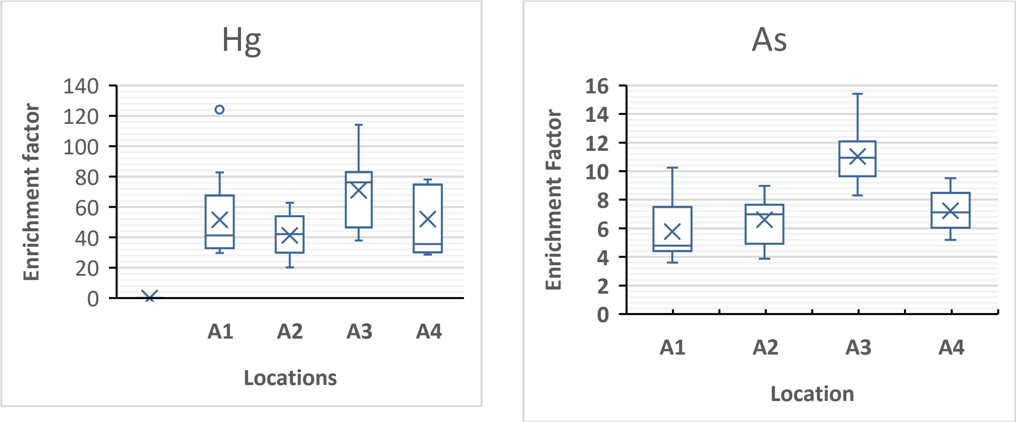

Figure (4) Box-plots of Enrichment factor for Mercury and Arsenic in (A1) EL Harra, (A2) Mendisha, (A3) Al Kaser and (A4) Al Bawiti ; the medians are represented by horizontal lines within the boxes. The bars denote the minimum and maximum numbers, and the crosslet represents the arithmetic mean.

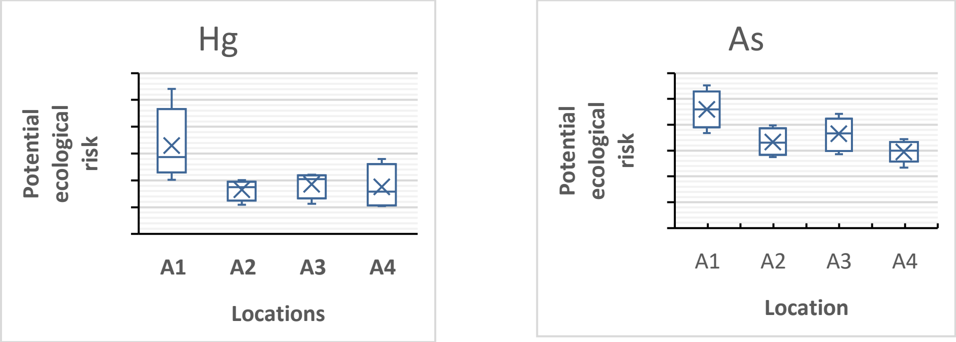

Figure (5) Box-plots of Potential ecological risk for Mercury and Arsenic in (A1) EL Harra, (A2) Mendisha, (A3) Al Kaser and (A4) Al Bawiti ; the medians are represented by horizontal lines within the boxes. The bars denote the minimum and maximum numbers, and the crosslet represents the arithmetic mean.

Fraction distribution of Mercury and Arsenic:

Fraction distribution of elements has direct effect on their mobility, toxicity and availability to plants in soil. For example, exchangeable fraction of heavy metals is easily mobile and more available to plants (Salem et al., 2021; Poschenrieder et al., 2001). Moreover, carbonate fraction can easily be in available and mobile form (Singh, 1999). In contrast, fractions bound to oxides and organic matter are relatively stable while residual fraction is the most stable fraction.

Therefore, fractions of elements provide realistic estimation of the environmental effect.

Figure (6) showed the percentage of different fractions of Hg and As in 4 sites. For Hg, data showed that carbonate and exchangeable fraction were the predominant fractions. While carbonate plus exchangeable fractions represented around 45%, 60%, 50%, and 55% in A1, A2, A3, and A4 respectively. Occurrence of mercury in carbonate fraction might be attributed to the presence of carbonate mineral in these soils as mentioned by (Baghdady et al., 2018; Elnaggar, 2017). Exchangeable and Carbonate fractions represented by Hg could be adsorbed by soil through weak electrostatic bond or co-precipitated with carbonates. These fractions can easily release to soil solution by ion exchange process and species that could be co-precipitated with carbonates (Reis et al., 2016). Carbonate and exchangeable fraction followed by organic and oxides fractions and the residual fraction represented the least fraction. As well, as carbonate and exchangeable fractions represented high percentage of total As. These results were in agreement with (Asmoay et al., 2019) who reported that As is associated mainly with carbonate fraction in El Minya Governorate - Egypt. Furthermore, (Salman et al., 2018) reported the same result for As fractions in soil at Southwest Giza, Egypt. However, (Salman et al., 2021) stated that As bio-accessible fraction represented around 70.7% of total As in Governorate of Assiut, Egypt and they contended that this was due to high levels of As contamination in the soil. According to (Perin et al., 1985; Kwaja et al., 2001) Risk Assessment Code (RAC) demonstrated that if the soil contains carbonate and exchangeable fractions less than 1%, it is regarded environmentally safe. It is considered low risk if the sum of these fractions is between 1 and 10%. The medium risk category accounts for 11-30% of these fractions. 31 – 50% of these fractions means high-risk category while very high-risk category is reported if the sum of these fractions is more than 50%.

RAC was calculated for Hg, it was around 45.05% of total Hg in A1, 59.91% in A2, 50.62 % in A3 and 56.20% in A4. According to RAC, soil in this study fell in high risk and very high risk categories. Metals detected in these categories are possibly bioavailable and might easily enter the food chain that, might interpret the high concentration of Hg in plants' Table (7). For As RAC values were 35.91, 43.64, 36. 29, and 38.08 in A1, A2, A3 and A4 respectively which indicated that the soil fell in high-risk category (Perin et al., 1985; Kwaja et al., 2001). It is also noteworthy that the nature of soil effect on the fractionation of metals such as the decrease of clay fractions, which is responsible for trapping the elements between layers of clay minerals, decrease of organic matter content, elevated of $CaCO_3$ content in addition to that agricultural soil is adjacent to point source of pollution .

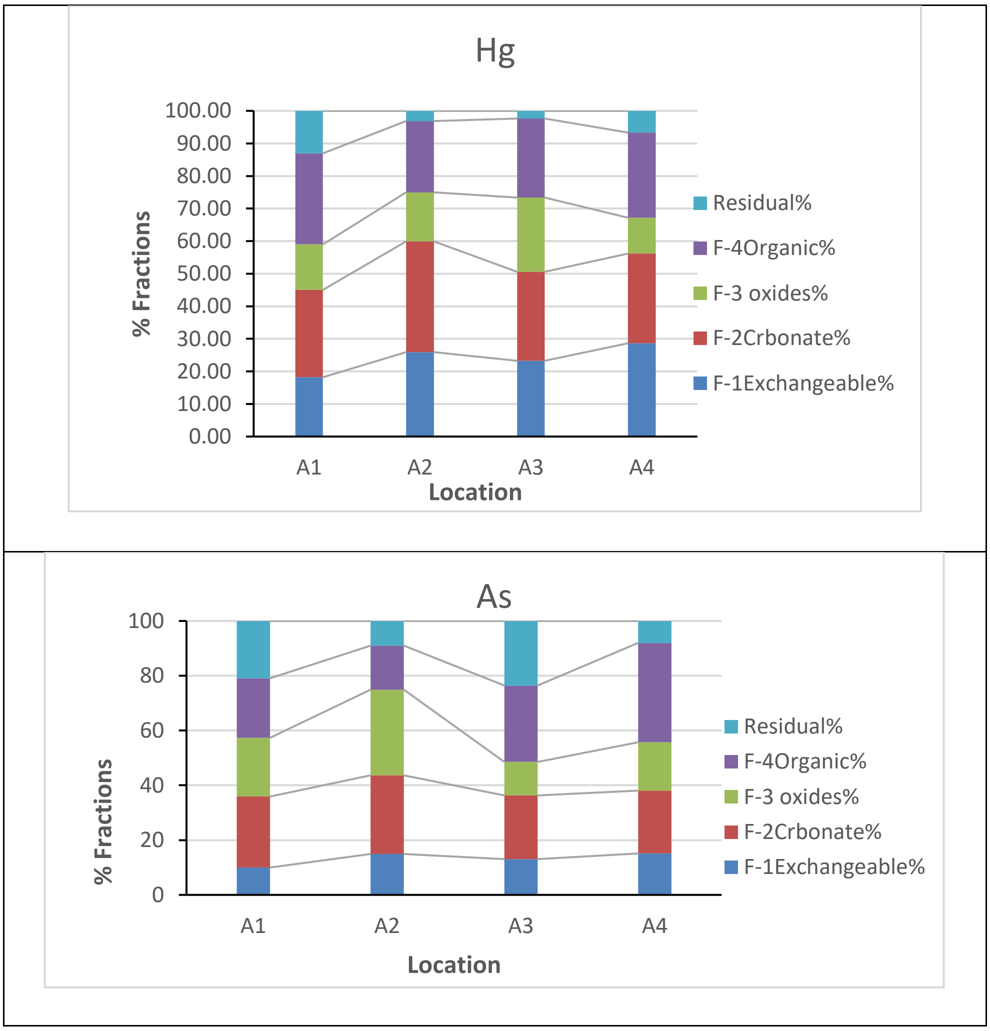

Figure (6) fractions of Mercury and Arsenic in studied locations A1) EL Harra, (A2) Mendisha, (A3) Al Kaser and (A4) Al Bawiti

Biological Absorption Coefficient (BAC):

The biological absorption coefficient (BAC) assesses plant uptake of elements from soil. According to (Nagaraju and Karimulla, 2002) table (5) and based on calculated BAC in Table (7) plants exhibited different accumulating capacity for Hg and As. For Hg, cantaloupe **(***Cucumis* ***melo varfor),*** **olive** *(Olea* ***europaea,***) and bean ***(Phaseolus)*** exhibited strong absorption degree of Hg (BCA ranged from1-10), While water melon ***(Citrullus lanatus)*** exhibited intermediate degree of adsorption in A1. In A2 plants that showed high adsorption degree of Hg were purslane **(*Portulaca oleracea*),** okra **(*Abelmoschus esculentus*),** cantaloupe **(*Cucumis melo var*),** and watermelon **(*Citrullus lanatus*),** while eggplant **(*Solanummelongena)*** showed intermediate degree of adsorption. In A3 peanut **(*Arachis hypogaea*)**, mango **(*Mangifera indica*),** okra **(*Abelmoschus esculentus*),** and fodder plant exhibited strong adsorption of Hg but grape **(*Vitis vinifera*)** displayed intermediate absorption of Hg. In A4 all plants showed strong degree of Hg absorption. For As, most plants showed intermediate absorption degree in four location except okra **(*Abelmoschus esculentus*)** and cantaloupe **(*Cucumis melo var*)** in A2. As well, mango **(*Mangifera indica*)** in A3. The data displayed that the difference in the degree of absorption between plants might be due to the bioavailability of elements in each area. According to fractionation results Figure (6), the bioavailability of Hg was higher than As in all locations, so most plants exhibited strong degree of absorption compared to plants in the case of As.

Correlation analysis:

Pearson correlation between some soil parameters and concentration of Hg and as in four different locations were stated in Table (8). There was high significant positive correlation between pH, CEC, Hg, CaCO$_3$%, and AS content. High positive correlations were observed between the Hg and As. Significant positive correlation ($p < 0.05$ or 0.01) were observed among pH, CEC, CaCO$_3$, and AS. The Hg is positively correlated with CEC, CaCO$_3$ and clay %. These results indicated that these soil parameters impacted occurrence and behavior of Hg and As in this study. As observed by (Ahmed and Pandey, 2020), high correlation between mercury and arsenic revealed that these elements might be sourced of the same origin and exhibited the same geochemical behaviors. These results were in agreement with (Zhuang et al., 2018) who stated that correlations between elements might imply a common source and comparable geochemical tendencies. If there was no correlation, the metals were not regulated by a single mechanism.

Table (8) Pearson correlation between some soil properties and concentration of Hg and As

Soil properties	**CEC**	**Hg**	**$CaCO_3$ %**
Hg	0.98^{**}		
$CaCO_3$%	0.89^{**}	0.79^{**}	
AS	0.76^{**}	0.61^{*}	0.95^{**}

*** Statistically significant at the 0.05 level**

**** Statistically significant at the 0.01 level**

Principle Component Analysis

The correlations between the soil parameters in the four different places were interpreted using the principal component analysis (Figure 7). Based on the data from the four locations, PCA1 and PCA2 explained 91.99% of the total variance of soil properties. For the majority of the variables under investigation, positive loadings were seen in PCA1 and PCA2. PCA2, PCA1 had more soil properties across all locations. PCA1 accounts for 62.85% of the entire variation in the soil properties at all locations. PCA1 had a high positive correlation between pH, CEC, Hg, $CaCO_3$ %, sand, and AS variable with a sharp angle, indicating a positive association between these properties. In terms of PCA2, it had a strong positive correlation with EC, clay percentage, and silt percentage and explains 29.14% of the total variance of the variables. Therefore, PCA1 and PCA2 can be used as a basis for evaluating the correlation among the soil properties across locations. Hg has a positive correlation with clay percentage and silt percentage. The positive correlation between Hg and As indicated that two elements were mainly derived from the same sources. In addition, high positive correlation observed between Hg, As and $CaCO_3$ percentage. This result was assured by fractionation experiment in this study.

Based on PCA1 and PCA2, the soil properties in the study areas were primarily distributed and divided into three groups, as seen in Figure (4). The first group included pH, CEC, Hg, $CaCO_3$%, sand%, and AS variables, which were located in the first and fourth quarters with A-1 and A-2 locations. The other soil variables formed the second group and are located in the second and third quarters, with A-3 and A-4 locations. These results indicated that the soil properties inside each group introduced high values in the associated location for them.

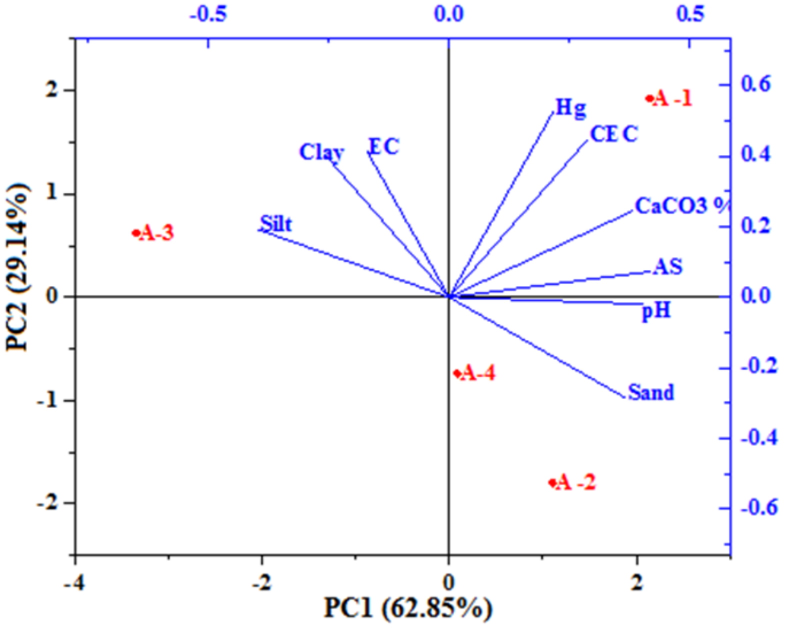

Figure (7) principal component analysis for soil parameters in four different places A1) EL Harra, (A2) Mendisha, (A3) Al Kaser and (A4) Al Bawiti

Summary:

This study has indicated that agricultural soil in EL Harra (A1), Mendisha (A2), Al Kaser (A3) and Al Bawiti (A4) are polluted with mercury and arsenic according to WHO limits (0.2 and 0.08 mgkg^{-1}) for As and Hg respectively. Moreover, agricultural soil in EL Harra is the most polluted area compared to other three locations. The study attributed that to the anthropogenic activities especially mining activity in El Harra. These results were assured by soil pollution indices. For CF and EF values, the soil has very high contamination factor and is considered extremely polluted by Hg, while it is considered significantly contaminated and with significant level of enrichment by As. Igeo value and PER of soil indicated strongly polluted conditions and a very high ecological risk in the case of mercury while they indicated moderate contamination as well as moderate ecological risk in the case of As. Sequential extraction experiments demonstrated that carbonate-bound and exchangeable fraction were the predominant fraction for both elements. Therefore, these elements could be easy absorbed by plants and increase phyto-accumulation of Hg and As in plants grown in these locations and then move to human body. Therefore, these soils should be remediated as soon as possible from Hg and As. Moreover, a green belt must be planted around agricultural fields to separate them from mining areas. More researches are needed on edible parts of plants and on additional possible pollutants in this area.

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تقييم المخاطر البيئية للزئبق والزرنيخ في بعض أراضي - الواحات البحرية – مصر

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قسم كيمياء وطبيعة الاراضي– شعبة مصادر المياة والاراضي الصحراوية – مركز بحوث الصحراء – المطرية – القاهرة – مصر

الملخص العربي

نظرا لعدم الاهتمام بتواجد وتقييم المخاطر البيئية للزئبق والزرنيخ في الواحات البحرية؛ بالرغم من احتوائها على العديد من المناطق الزراعية؛ تهدف هذه الدراسة إلى تقييم المخاطر البيئية للزئبق والزرنيخ في بعض الأراضي الزراعية، في الجزء الشمالي من الواحات البحرية، بالقرب من منطقة التعدين؛ حيث تم جمع أربعة وستين عينة من التربة السطحية (0-30 سم) واثنين وثلاثين عينة نباتية من أربعة مواقع مختلفة: (الحارة، منديشة، القصر، الباويطي) وتم تقدير تركيز عنصري الزئبق والزرنيخ بالإضافة لتجربة الفراكشنيشن لمعرفة الصور المختلفة المتواجد عليها العنصرين في التربة، وقد استخدمت بعض مؤشرات التلوث مثل عامل التلوث – عامل التخصيب – مؤشر التراكم الجغرافي- مؤشر المخاطر البيئية المحتملة، لتقييم مدى التلوث بالعنصرين.

وقد أظهرت النتائج أن تركيز الزئبق والزرنيخ كان أعلى من التركيز الشائع في القشرة الأرضية وأعلى من حدود منظمة الصحة العالمية في التربة والنبات؛ لذلك فان التربة تعتبر شديدة التلوث من الزئبق، ولها مخاطر بيئية عالية، بينما كانت أقل تلوثا بالزرنيخ، وأقل خطرا. على الجانب الآخر أظهرت النتائج أن صور العناصر المرتبطة بالكربونات والمتبادلة كانت هي الجزء السائد للزئبق والزرنيخ، والميسر للنباتات، وقد تكون الأنشطة البشرية هي المصدر الأكثر مسؤولية للتلوث؛ وخاصة أنشطة التعدين، تليها المصادر الطبيعية؛ ومن ثم يجب السيطرة على التلوث في هذه المنطقة.

الكلمات المفتاحية: المعادن الثقيلة- التعدين- دلائل التلوث.