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Magnetic susceptibility as an indicator to heavy metal contaminationof the urban top soil in Port Said city and surroundings, Egypt

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Abstract: *Due to the rapid urbanization and industrialization in Port Said city and surroundingsover the last few decades, metals have been continuously emitted into the urban environment and introduced a serious threat to the human health. Accordingly, Magnetic susceptibility measurements and laboratory soil analyses have been conducted in some selected sites of possible potential risk in Port Said city and surroundings in order to evaluate the current status of heavy metals contamination and todetermine its potential sources. The magnetic susceptibility survey has been carried out using a systematic grid pattern intheindustrial area and the solid waste dump site of Port Said city. The soil samples have been collected from the sites showing high values of magnetic susceptibility.*

The concentrations of 10 heavy metals Fe, Cd, Mo, Mn, Ni, V, Cu, Pb, Zn and Co were determined in the soil samples.Also, the contamination factor and geochemical accumulation indices were calculated to assess for the heavy metals contamination in the studied sites.The interpretation of the obtained field measurements and the laboratory analyses indicated that. Cd, Zn and Pb providethe highest potential risk, while the other heavy metals are in the safe limits.

Keywords*: Environmental assessment, Environmental magnetism, Heavy metals contamination, Magnetic susceptibility, urban soil analysis,*

I. Introduction

The increase of automobile emissions, factory emissions and industrial wastewater is the result of the rapid pace of urbanization and industrializationprovides negative effects on the prevailing environment. Heavy metal contamination is considered as one of these negative effects[1]. Dust that accumulates on soils and roadsides in the urban and industrial areas is an indicator of the heavy metal contamination from atmospheric deposition [2].Heavy metals, which are a group name for metals and semimetals (metalloids) that have been associated withthe contamination and potential toxicity, receive increasing attention due to the better understanding of their toxicological importance in ecosystems and human health[3]. As a crucial component of the urban ecosystems, urban soils are subjected to a continuous accumulation of contaminants, especially toxic metals [4]. Because of the proximity to large populations, contaminated urban soils can pose significant risks to human health.

Soils may become contaminated by the accumulation of heavy metals and metalloids through emissions from the rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition[5,6].

The study of the spatial distribution of heavy metals in an urban environment is very important to identify hot-spot areas and to assess the potential sources of pollutants. The spatial distribution of heavy metal contamination can be studied based upon geostatistical technology.Geochemical maps enable the visualization and analysis of information in a geographic context in order to simulate and present future scenarios for the formulation of appropriate proactive measures [7].

Despite the most accurate method for heavy metal detection, geochemical analysis suffers from many problems such as the data gives only indication for the analyzed sample, it covers a small area of investigation, it is time consuming as it takes long time to collect; prepare and analyze the sample, and it is an expensive tool. Accordingly, the measurement of the magnetic susceptibility proved to be a general and accepted method to map pollution.Numerous studies have employed magnetic parameters, mainly the low field magnetic susceptibility (χlf) measurements, to provide a cost effective way to prospect for signs of industrial and traffic related atmospheric particulate pollution [2]. This is the main task of the present study.

The city of Port Said shows a tremendous urbanization and industrialization changes in the last decade.In this study an assessment of heavy metal contamination will be carried out using the magnetic susceptibility survey and confirmed by a geochemical analysis of soil samples which have been collected from the high signatures magnetic response.After that a quantitative analysis will be made and recommendations for the mitigation of possible contamination will be given.

II. Materials And Methods

2.1 Study area

Port Said city lies in the north-eastern part of Egypt, between latitudes 32^0 12' 59" to 32^0 19' 15" Eandlongitudes31^0 12' 4" to 31^0 17' 6"N. It has a triangular shape and surrounded by the Suez Canal to the east, the Mediterranean Sea to the north and the eastern part of Lake Manzala to the west (Fig. 1). Port Said area belongs to the far western part of the Sinai coastal plain. The area dates back to the Holocene Era, it is consisted of the Nile sediments which are represented by the Mit-Ghamerand Bilqasformations. Aeolian deposits cover most of the coastal area of Port Said city[8]

2.2 Magnetic susceptibility survey

Magnetic susceptibility (MS) survey has been carried out in three sites in Port Said city (A, B and C) (Fig 1) in an attempt to figure out zones of high magnetic susceptibility anomalies.These sites were chosen according to their spatial relation with possible source of heavy metal, sites(A and B) are located adjacent to the industrial area of Port Said city, whereas site (C) is located adjacent to the Port Said's dump site. The survey was carried out using a KT+10 magnetic susceptibility meter (Terra plus instruments).This device utilizes a 10 kHz LC oscillator with an inductive coil to measure the magnetic susceptibility. The susceptibility is calculated from the frequency difference between that of the sample and the free air measurements. It also takes into account geometric corrections to determine the true susceptibility. The frequency of the oscillator is extremely sensitive to temperature deviations. Any temperature instability is propagated in frequency deviations and has a direct impact on maximum sensitivity. To minimize these effects, the KT-10 takes many measurements in free air before measurement of the sample and many after it as well. Then using a sophisticated algorithm, the negative impact of temperature shift is minimized [9].

The station locations were identified using a Garmin GPS model 71 champ, where the position of each station (latitude and longitude) is determined and then stored on the internal memory of the GPS. Then these data were dumped into the PC along with the magnetic susceptibility measurements of the KT-10.The both data sets were merged into one single sheet for each site, which is then used to produce the magnetic susceptibility contour map of each location.

2.3Soil samples (collection and preparation).

Twenty five top soil samples (from 0 to 15 cm deep) were collected from the locations of high magnetic susceptibility values in the three studied sites A, B and C. The samples were collected by scooping surface soils using a stainless steel hand trowel and stored in a nitric acid pretreated and dry polypropylene bags. Then they were manually sorted to eliminate pebbles and coarse materials, and air-dried under ambient conditions that are inside the laboratory for about a week to completely remove moisture. The dried soil samples were pulverized in a disc mill crusher. The resulting powdered samples were screened through a nylon sieve of 2 mm mesh size. Five grams of each soil sample was mixed and classified to quadrant in order to achieve a complete mixing of the sample.A weight of one gram portion of the fine ground sample was digested for complete dissociation with the acid mixture, (H2SO4, HCl, HNO3andHF). The resulting sample digests were filtered into 100 mL volumetric flasks and made up to 100 mL mark with distilled water and closed up to a measuring volume of 100 ml. The total concentrations of Mo, Co, Cu, V, Pb, Mn, Ni, Cd, Fe and Zn in filtrate were then determined using a flame atomic absorption spectrometer Unicam model 969.

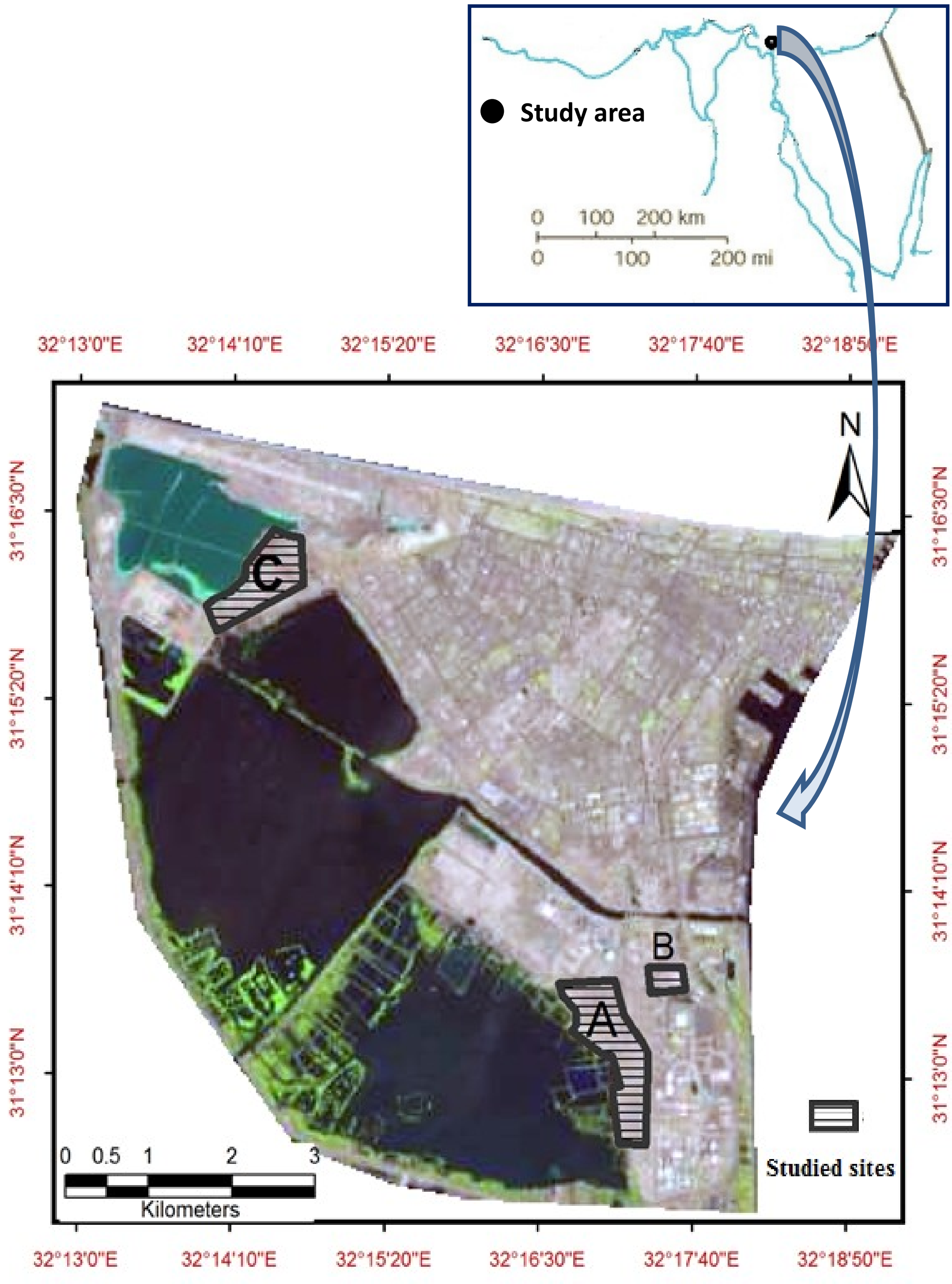

Fig 1: Study sites (A, B & C) in the Port Said city

III. Assessment of metal contamination

3.1 Determination of geo-accumulation index (Igeo) of sediment samples

An index of geo-accumulation (Igeo) was originally defined by Müller [10] in order to determine and define the metal contamination in sediments. The index actually enables the assessment of contamination by comparing the current concentrationswith the pre-industrial(background) concentrations in the sediments [11,12 & 13]. The method assesses the degree of metal pollution in terms of seven enrichment classes (Table 1) based on the increasing of numerical values of the index[12]. The (Igeo) is computed according to [11, 12] using equation (1):

$$I_{geo} = log_2 \frac{C_{sample}}{1.5 * C_{reference}} \qquad)$$

Where, C_{sample} is the metal concentration in the sample, $C_{reference}$ is the average value of the same metal in abackground level. The crustal abundance data in (Table 2) were used as background data.

The factor (1.5) is introduced in this equation to minimize the effect of possible variations in the background values which may be attributed to lithogenic variations in soils. The geo-accumulation index (Igeo) was distinguished into seven classes by Müller [12].

Table 1: Index of geo-accumulation (Igeo) for contamination levels in soil (Hasan et. al. 2013)

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

Table 2: Natural background concentration in earth's crust (ppm)

Metal	[14]	[15]	[16]
Mo			1.2
V			120
Cu	68		60
Fe		50500	
Cd	0.15		0.15
Pb	10		14
Co	30		25
Ni	90		84
Zn	79		70
Mn		900	950

3.2 Determination of Contamination factor (CF) of sediment samples

A contamination factor (CF) describes the contamination level of a given toxic substance in soil [12, 17].Itwassuggested by Håkanson[18]as follows:

$$\text{CF} = \frac{C_{sample}}{C_{reference}} \qquad (2)(1$$

The following terminologies are used to describe the contamination factor according [11]:

CF<1: low contamination factor;

1≤CF<3: moderate contamination factor;

3≤CF<6: considerable contamination factors and

CF≥6: very high contamination factor.

IV. Results and Discussion

4.1 Magnetic susceptibility maps

The magnetic susceptibility (MS) map of site A (Fig 2) shows a range of susceptibility varying from (0.01 to 8.2) 10^{-3} SI unit.It is clear that the anomalous zones in this site are concentrated along the eastern side which is near to the asphaltic road and facing the industrial area.These anomalies have a localized and limited aerial extension, which give an indication of concentrated source that may result from dumping wastes. The rest of this site has MS values below 2.2 x 10^{-3} SI.There are about seven separated anomalies having values higher than 2.2 x 10^{-3} SI unit.

The magnetic susceptibility map of site B (Fig 3) shows a range of susceptibility varying from (0.5 to 9.64)10^{-3} SI unit. The anomalous zones in this site are located at the north western part, near the iron smelting plant.The wide spread of the MS anomaly in this site represent an atmospheric effect, knowing that the wind direction is N-W.Thismay conclude that the source of the high magnetic susceptibility in this site comes from the industrial dust of the steel plant, which is accumulated in this site.

The magnetic susceptibility map of site C (Fig 4) shows a range of susceptibility varying from (0.86 to 5.7) 10^{-3} SI unit.A number of about twelve separated anomalies having a small spatial distribution are mainly concentrated in the northern part of this site.These anomalies have MS values higher than 4.7 x 10^{-3} SI unit.They have limited aerial extension, which give an indication that the sources of these anomalies come from the dumping process as this site represents an open dump site.The rest of the site hasMS values below 4 x 10^{-3} SI units.

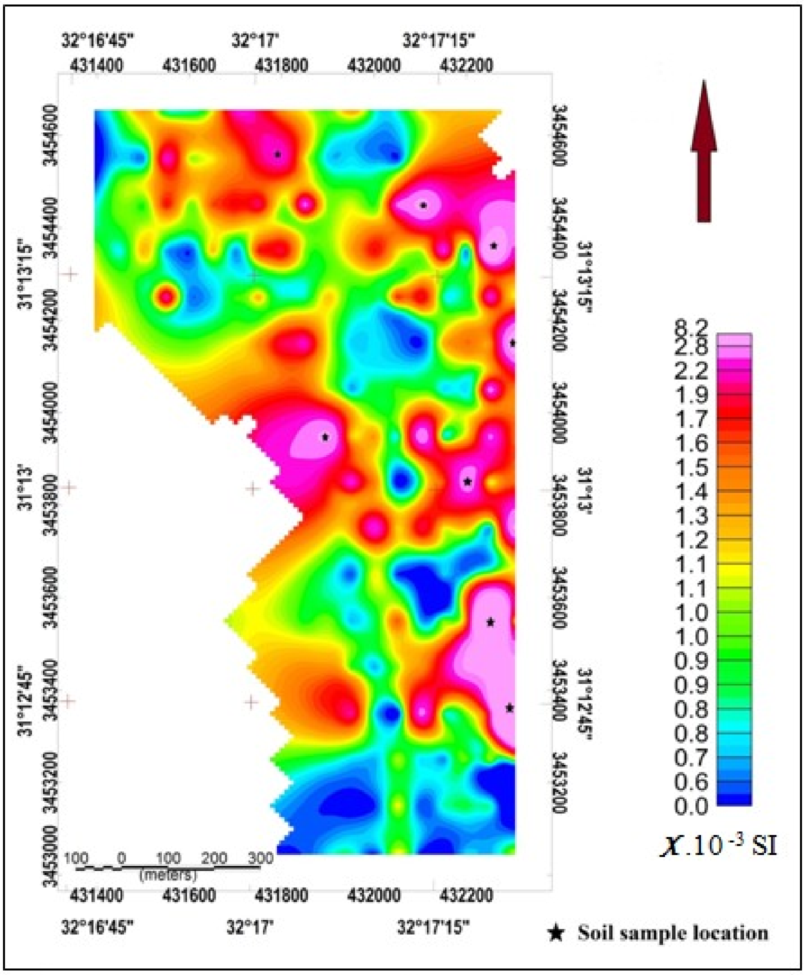

Fig (2): Magnetic susceptibility map in SI unit of site "A"

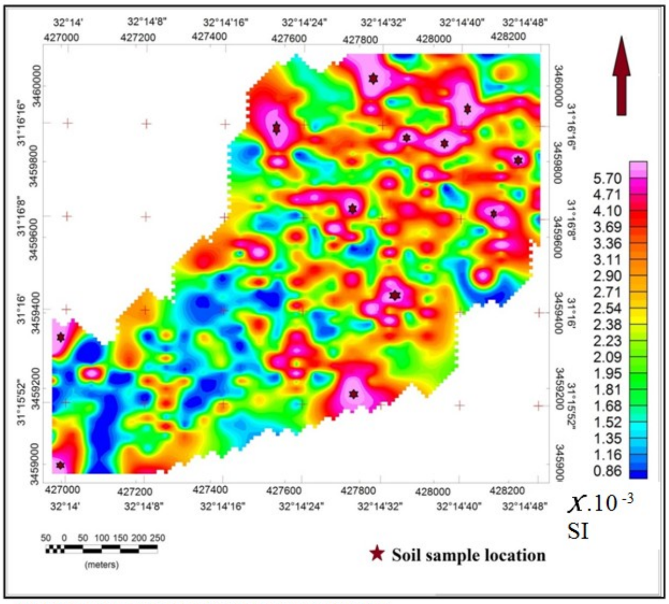

Fig (4): Magnetic susceptibility map in SI unit of site "C"

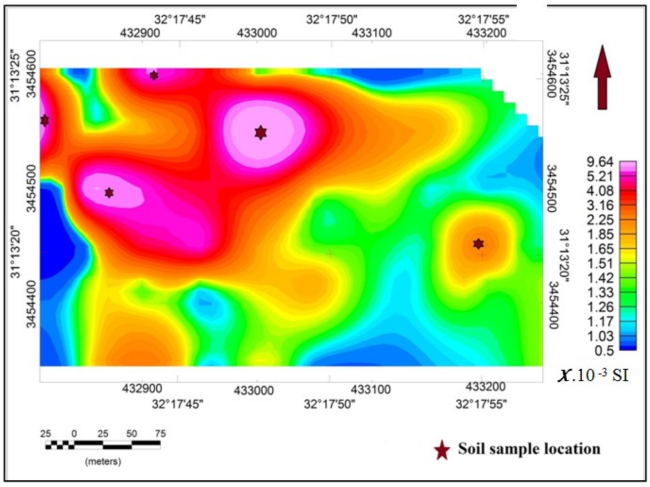

Fig (3): Magnetic susceptibility map in SI unit of site "B"

4.2 Heavy metals concentrations in soils

Heavy metals concentrations were calculated and presented in (Table 3). Molybdenum (Mo), Vanadium (V), Iron (Fe), Cadmium (Cd), Lead (Pb), Cobalt (Co), Nickel (Ni), Zinc (Zn), and Manganese (Mn), are recorded in all the analyzed soil samples from the studied sites (A, B & C). To know if these values are abnormal or not, the values in (Table 2) should be consulted.

4.3 Index of geo-accumulation (Igeo)

According to the geo-accumulation indices which are calculated by equation (1) and listed in (Table 4) and (Fig 5), site (A) is strongly to moderately contaminated with cadmium and lead; moderately contaminated with zinc and uncontaminated with molybdenum; iron; vanadium; copper; cobalt; nickel; or manganese. Site (B) is strongly to moderately contaminated with cadmium, moderately contaminated with lead, uncontaminated to moderately contaminated with zinc and uncontaminated with molybdenum; iron;vanadium; copper; cobalt;nickel; and manganese. Site (C) is moderately contaminated with cadmium, uncontaminated to moderately contaminate with lead, uncontaminated with molybdenum, iron, vanadium, copper, cobalt, nickel, zinc and manganese. The results of the geo-accumulation index also confirmed that the cadmium, lead and zinc have the highest contamination effects, while other metal have nearly no contamination effects.

Table 3: Heavy metals concentration in ppm in the soil samples. These analysis have been done in the labs of Nuclear Materials Authority , Cairo)

Sample no.	Site	Mo	V	Cu	Fe	Cd	Pb	Co	Ni	Zn	Mn	$X.10^{-3}$ SI
1	A	1.41	158.00	29.00	89333.00	n.d.	40.00	1.00	48.00	304.00	217.00	5.6
2		1.34	191.00	55.00	86667.00	0.04	74.00	41.00	56.00	400.00	562.00	6.20
3		1.41	154.00	7.00	20717.00	2.90	87.00	n.d.	16.00	1.15	85.00	7.00
4		1.26	131.50	74.00	80000.00	2.50	36.00	9.00	96.00	455.00	587.00	7.32
5		1.25	218.00	80.00	47333.00	2.00	33.00	n.d.	96.00	633.33	500.00	5.40
6		1.08	113.09	63.64	68800.00	2.15	30.96	7.74	82.56	391.30	504.82	6.05
7		1.13	198.16	72.72	43026.00	1.82	30.00	n.d.	87.26	575.70	454.50	7.06
8		1.06	118.50	21.75	67000.00	0.00	30.00	0.75	36.00	228.00	162.75	8.00
9	B	1.55	169.71	7.71	22831.00	3.20	95.87	n.d.	17.63	3.46	93.67	5.3
10		1.54	185.00	47.00	93230.00	n.d.	27.00	29.00	55.00	566.67	405.00	9.3
11		1.34	195.50	7.00	64000.00	2.00	17.00	25.00	47.00	730.00	325.00	6.4
12		1.21	194.00	44.00	81640.00	n.d.	105.00	35.00	59.00	611.67	465.00	5.00
13		1.38	154.00	33.00	53333.00	3.60	53.00	5.00	49.00	238.33	290.00	7.4
14	C	0.70	78.80	14.46	44555.00	0.00	19.95	0.50	23.94	151.62	108.23	4.20
15		0.87	95.04	4.32	12785.00	1.79	53.69	n.d.	9.87	1.94	52.46	6.3
16		0.81	97.13	24.68	48946.00	n.d.	14.18	15.23	28.88	297.50	212.63	3.8
17		0.78	85.53	3.89	11507.00	1.61	48.32	n.d.	8.89	1.74	47.21	5.2
18		0.64	70.07	3.19	9426.00	1.32	39.59	n.d.	7.28	0.52	38.68	4.5
19		0.77	84.08	3.82	11312.00	1.58	47.50	n.d.	8.74	0.63	46.41	2.91
20		0.67	98.53	3.53	32256.00	1.01	8.57	12.60	23.69	367.92	163.80	4.6
21		0.67	74.38	15.94	25760.00	n.d.	25.60	2.42	23.67	115.12	140.07	3.6
22		0.67	72.70	3.30	9781.00	1.37	41.07	n.d.	7.55	1.48	40.13	4.21
23		0.96	114.30	36.19	64484.00	n.d.	20.79	22.33	42.35	436.33	311.85	3.07
24		0.77	113.31	4.06	37094.00	1.16	9.85	14.49	27.24	423.11	188.37	2.96
25		0.74	89.36	22.70	45030.00	n.d.	13.04	14.01	26.57	273.70	195.62	3.10
	MIN	0.64	70.07	3.19	9426.00	0.04	8.57	0.50	7.28	0.52	38.68	
	MAX	1.55	218.00	80.00	93230.00	3.60	105.00	41.00	96.00	730.00	587.00	

n.d.: Not detected

Table 4: Average geo-accumulation index of each metal in the three studied sites (A, B and C)

Site	A	B	C
Mo	-0.54	-0.37	-1.26
V	-0.20	-0.01	-1.03
Cu	-1.17	-2.13	-3.54
Fe	-0.40	-0.41	-1.68
Cd	1.76	2.20	1.53
Pb	1.46	1.67	0.67
Co	-1.88	-0.79	-1.38
Ni	-1.16	-1.58	-2.91
Zn	0.89	0.81	-1.95
Mn	-2.07	-2.28	-3.75

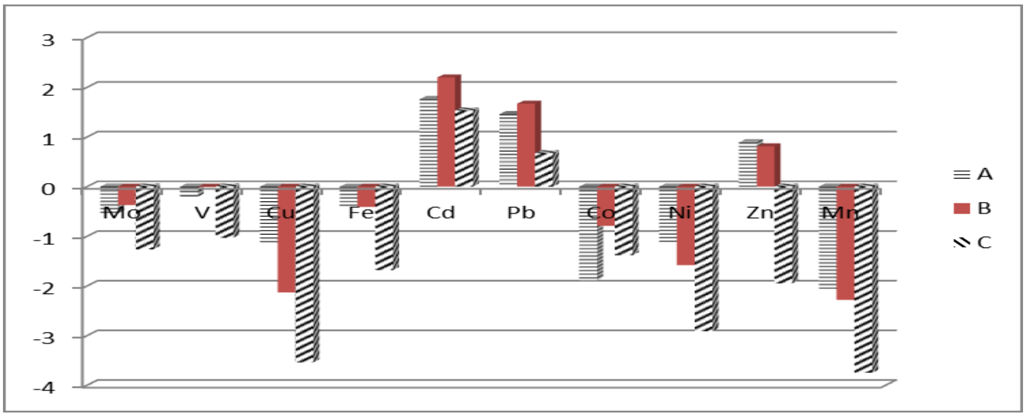

Fig5: Average geo-accumulation index of the measured heavy metals in the three sites A, B, and C

4.4 Contamination factor

The average contamination factors which are calculated by equation (2)and listed in (Table 5) and (Fig6) show that site (A) has a very high contamination factor for cadmium, considerable contamination factor for lead and zinc, moderate contamination factor for molybdenum , iron and vanadium, and low contamination factor for copper , cobalt, nickel, and manganese. Site (B) has a very high contamination factor for cadmium and zinc, considerable contamination factor for lead, moderate contamination factor for molybdenum, iron and vanadium, and low contamination factor for copper, cobalt, nickel and ,manganese. Site (C) has a considerable contamination factor for cadmium, moderate contamination factor for lead and zinc, and low contamination factor for molybdenum, iron, vanadium, copper, cobalt, nickel and manganese. Accordingly, cadmium, lead and zinc represent the highly potential risk; while molybdenum, vanadium and iron represent a low potential risk in the study area. Whereas, the other metals don't have potential risk.

Table 5: Average Contamination factor of each metal in the three studied sites (A, B and C)

Site	A	B	C
Mo	1.04	1.17	0.63
V	1.34	1.50	0.75
Cu	0.84	0.46	0.19
Fe	1.24	1.25	0.58
Cd	9.51	11.73	5.47
Pb	4.51	5.96	2.85
Co	0.30	0.75	0.27
Ni	0.77	0.54	0.24
Zn	5.34	6.14	2.47
Mn	0.43	0.35	0.14

Table 6: Person's correlation (r) matrix between Fe, Cd, Zn, Pb, Mo, and V

	Fe	Cd	Zn	Pb	Mo	V
Fe	1					
Cd	-.124-	1				
Zn	.778**	.031	1			
Pb	.163	.468*	-.002-	1		
Mo	.654**	.446*	.498**	.582**	1	
V	.645**	.343	.740**	.494**	.874**	1

**** Correlation is significant at the 0.01 level (2-tailed).**
*** Correlation is significant at the 0.05 level (2-tailed).**

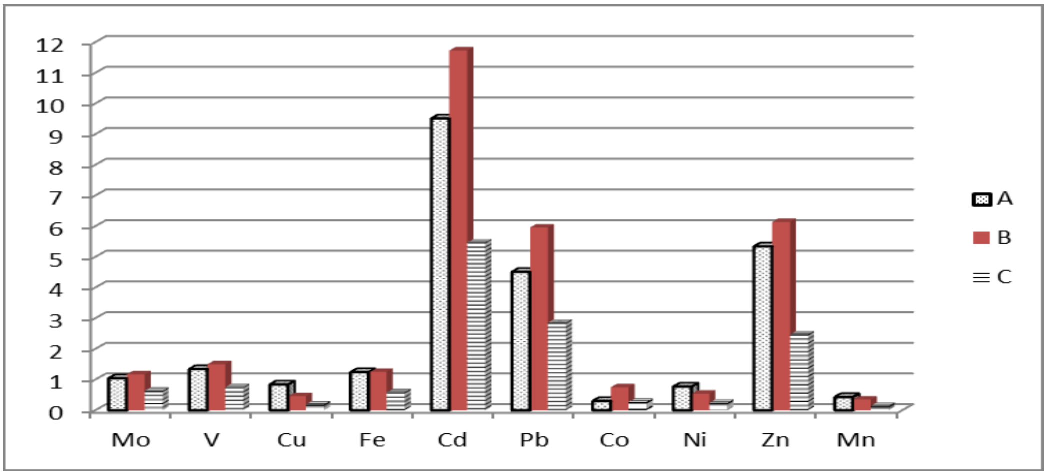

Fig6: Average contamination factors of the measured heavy metals in the three sites A, B, and C

4.5 Correlation between heavy metals

Pearson's correlation (r) analysis[19] was performed between Fe, Cd, Zn, Pb, Mo and V. The level of significance ($p \leq 0.05$ and $p \leq 0.01$) of multi-element correlation for soil samples was determined and the results are listed in (Table 6). The listed (r) values indicated a high degree of positive correlations and significant linear relation between various pairs of metals reflecting their simultaneous release and identical source, transport and accumulation in soil. The inter-metallic correlation coefficients in the soil samples with $p < 0.01$are Fe-Zn, Fe-Mo, Fe-V, Zn-Mo, Zn-V, Pb-Mo and Pb-V, where the correlation coefficients in the soil samples with $p < 0.05$ are Cd-Pb and Cd-Mo. The significant correlations indicate that they may have originated from common sources, presumably from other industrial (chemicals, paints) activities. These metals may be derived from anthropogenic sources, especially the steel and metal industry, paint industry and municipal sewage system in the study area.

4.6 Magnetic susceptibility and heavy metals

Pearson's coefficients for the correlation between heavy metal concentrations and the magnetic susceptibility (**X**)are listed in (Table 7). Significant correlation between magnetic susceptibility and heavy metal concentration with $p < 0.01$ is noticed for Fe, Mo, V and Ni, while Significant correlation between magnetic susceptibility and heavy metal concentration with $p < 0.05$ is noticed for Cu. Cd, Pb and Zn which prove a good positive correlation with the magnetic susceptibility measurements.

Table 7: Pearson's correlation coefficients between heavy metal concentrations and Magnetic susceptibilityχ

	Fe	Mo	V	Cd	Pb	Zn	Cu	Ni	Mn
χ	.518**	.732**	.599**	.263	.198	.339	.461*	.512**	.471*

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

V. Conclusion

The use of the magnetic susceptibility (MS) survey as a preliminary step for mapping the heavy metal contaminationproved its usefulness as it provides a rapid, non-destructive and inexpensive tool.The present study has been carried out in Port Said city and surroundings in order to evaluate the contamination levels with heavy metals due to the manufacturing activities in the area and to confirm the usefulness of using MS surveying in this kind of studies. Magnetic susceptibility (MS) survey along with laboratory soil analyses have been done in the study area. Three sites (A, B and C) surrounding Port Said city were anticipated to carry out the present study as these site are mostly affected by contamination.

The MS field measurements gave high values at sporadic points in the studied sites (A, B, and C) which are believed to be due to contamination with heavy metals.

The heavy metal analysis of the soil samples, which have been collected from the points of high MS values, showed that thesepointshavehigh levels of cadmium (Cd), lead (Pb) and zinc (Zn) in both sites(A) and (B) where the industrial activitiesare located.

The heavy metal contamination was also assessed using the contamination factor index.The results showed that sites(A) and (B) are highly contaminated with Cd, Pb and Zn, while site (C) is less contaminated.Also, site(A) and (B) showed a considerable contamination with Mo, V and Fe which are originated mainly from the industrial activities in the study area, especially the iron processing industries.

It is highly recommended carrying out a remediation action in Port Said city and surroundings using suitable techniques in order to remove the contamination effects and to safe the human health.

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