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ENVIRONMENTAL MAGNETISM AS PROXY TO HEAVY METAL CONTAMINATION OF INDUSTRIAL AND OPEN LANDFILL TOPSOILS IN PORT SAID CITY, EGYPT

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المغناطيسية البيئة كدليل علي وجود تلوث بالمعادن الثقيلة في مكبات النفايات الصناعية والعشوائية في مدينة بورسعيد، مصر

الخلاصة: تعتبر بورسعيد كمدينة حضارية والصناعية لديها نشاط سريع على مدى العقود القليلة الماضية، وكثير من هذه البيئات الحضارية لديها المعادن التي تنبعث باستمرار وبالتالي تشكل تهديدا خطيرا للبشرية. وقد أجريت قياسات القابلية المغناطيسية (MS) علي عينات من التربة من مواقع مختارة عالية المخاطر وكذلك المنخفضة منها، من أجل تحديد مصادر هذه المعادن الثقيلة الملوثة. تم مسح المنطقة الصناعية (مواقع A و B) ومكب النفايات الصلبة في مدينة بورسعيد (الموقع C) بطريقة القابلية المغناطيسية. واظهرت خرائط القابلية المغناطيسية وجود شاذات من القيم العالية التي تشير إلى ان هذه المواقع هي الأكثر تضررا جراء التلوث.
حسبت عشرة تركيزات من المعادن الثقيلة (الحديد، المنجنيز، المولبدنم، الكادميوم، النيكل، الفانديوم، الرصاص، النحاس، الكوبلت، والزنك) في العينات التي تم جمعها. وبالإضافة إلى ذلك، تم حساب معامل التلوث، والتراكم الجيوكيميائي، حمل التلوث ومؤشرات التلوث (Nemerow) لاختبار تلوث المواقع المختارة بالمعادن الثقيلة. مواقع (A & B) تعطي درجة عالية من التلوث بالكادميوم، الرصاص، النيكل والزنك حيث تقع الأنشطة الصناعية. أيضا، يظهر موقع A قيم معتدلة إلى منخفضة من التلوث بالمولبدنم والفانديوم والحديد والكوبلت والنحاس والمنجنيز في حين يظهر الموقع B أن التلوث نشأ أساسا من الصناعات الخاصة بتصنيع الحديد.

أيضا، يظهر مؤشر التلوث (Nemerow) أن موقع A يمثل مستوى أعلى من الموقع B الذي لديه مستوى معتدل من التلوث، في حين أن الموقع C يمثل خط التحذير من التلوث وهو ما يعني أن التعرض بالمعادن الثقيلة قد يكون له العديد من العواقب غير الآمنة. وأخيرا، أثبتت هذه الدراسة أن المغناطيسية البيئية استخدمت بنجاح كدليل للتلوث بالمعادن الثقيلة في مكبات النفايات الصناعية والعشوائية ومجالات مماثلة.

ABSTRACT: *Port Said is considerd as an urbanized and industrialized city which has a rapid activity over the last few decades, and many urban environments there have metals which continuously emit gases which are seriously threatening the humankind. Ground magnetic susceptibility (MS) was carried out and soil samples were collected from selected sites of possible high risk as well as low ones in order to determine the contamination sources of heavy metals. An MS survey was carried out in the industrial area (sites A and B) and the solid-waste dump site in Port Said city (site C). MS maps of the three sites show anomalies of high values which indicate that these sites mostly affected by contamination.*

Ten of heavy metals concentrations (Fe, Mn, Mo, Cd, Ni, V, Pb, Cu, Co, and Zn) were calculated in the collected samples. In addition, the factor of contamination, geochemical accumulation, pollution load and Nemerow pollution indices were calculated to test heavy metals contamination in the selected sites. Sites (A & B) give a higher degree of contaminated with Cd, Pb, Ni and Zn where the industrial activities are located. Also, site A shows a moderate to low contamination with Mo, V, Fe, Co, Cu, and Mn while site B shows that the contamination originated mainly from the iron processing industries.

Also, Nemerow pollution index shows that the site A represents a higher level of pollution than site B which has the moderate level of pollution, while site C represents the warning line of pollution which means that the heavy metal exposures have many consequences and is generally not safe. Finally, this study proves that the environmental magnetism used successfully as a proxy to heavy metal pollution in industry and topsoil of an open landfill and similar areas.

1. INTRODUCTION

Recently, the human impact adversely effect on the environment, increased and became a world concern. The type and intensity of human activity greatly impact on the environment. With increased urbanization, the urban environment threatened by various pollution sources released into it. This pollution ranged from an indiscriminate refuse dump, sewage disposal, industrial wastes, bush burning, and emissions from industries and automobile exhaust.Usually heavy metals and toxic elements from industrial, Vehicular and domestic emissions emitted into the air and combined with the environment and in the organism such as human, animals and vegetation. These released contaminants are rich with magnetic particles that enhance the magnetic property of the urban soils and sediments (Kanu et al., 2014).

There is a cyclic order in the heavy metal contamination that always follows an industry, air, soil, water, foods and human. Of course, the effect of toxicity of any contaminant on human health is a concentration function, but also it is known for all that continuous exposure to heavy metals, even if at relatively low levels can cause adverse effects (ATSDR 2008; Castro-Gonzalez & Méndez-Armenta 2008).

Magnetism has become an important approach in environmental studies for several reasons, the most fundamental reason being that most substances show some form of magnetic behavior. And because iron, which characterized by its high magnetic susceptibility is one of the most important elements in the Earth's crust. Therefore, the magnetic susceptibility of polluted material can give a general view of the degree of pollution (Thomson and Oldfield 1986). Using of magnetism as a proxy to detect heavy metal contamination based on the fact that the origin of heavy metals and magnetic particles are genetically related. By monitoring the environmental and magnetic agents, the relationship between heavy metal amounts and magnetic properties is achieved by considering the lithological properties of soils (Schmidt et al. 2005). Use of the magnetic method becomes generally accepted as fast, relatively cost and non-invasive, besides it can mapping contamination of heavy metal in soils and sediments (Yang et al. 2007; Kapicka et al. 2008, Blundell et al. 2009; Rosowiecka and Nawrocki 2010; Canbay et al. 2010; Ayoubi et. al. 2011).

Soils of urban areas are full of varied atmospheric particles from industrial activities. Kapicka et al. (2003) stated that industrial pollution for sediments in the urban environment has four essential types: (1) ashes emitted from industrial production and fossil-fuel combustion, such as steel production and power generation; (2) particles from vehicles, such as exhaust particulates, brake lining dust, and erosion of bodywork; (3) exotic materials, such as metallic fragments, slag, road surface and building materials and (4) fertilizers and pesticides transported from agricultural soils and sewage sludge. The largest one is that resulted from steel production and power generation, such as, in environments with the highest load of industrial factories, the annual amount of deposit dust in the atmosphere reaches about several thousands of tons.

A rise of motors and factories emissions, abrasion of tires as well as industrial wastewater due to the rapid pace of industrialization and urbanization. These various emissions give negative effects on their environment. Heavy metal pollution is assumed as one of these negative effects (Gautam et al. 2005). Measuring environmental magnetism is a vital method used to map the lateral and vertical distributions of contamination and degree of industrial pollution around power plants, cement, and metallurgical industries (Petrovsky et al. 2000; Lecoanet et al. 2001).

Port Said as one of the most important ports on the major hub in the Mediterranean region is expected to be one of the largest national projects in years. Consequently, a tremendous urbanization and industrialization will take place in Port Said city. The aim of this work is to assess the heavy metal contamination using the magnetic susceptibility survey to merge data of the magnetic susceptibility of urban soils and show its correlation with the degree of heavy metal pollution, then a geochemical analysis of soil samples which are collected from areas of higher magnetic response in addition to the lower ones. Finally, a quantitative evaluation will be concluded and what ways to decrease possible contamination if there are.

2. MS FIELD WORK

Port Said is a coastal city which in the northern entrance of the Suez Canal and lies between latitudes 320 12' 59" to 320 19' 15" E and longitudes 310 12' 4" to 310 17' 6" N. It is surrounded from the east by the Suez Canal, the Mediterranean Sea from the north and Lake Manzala from the west (Fig. 1). Port Said is the extended area from the western part of the Sinai coastal plain. The area dates back to the Holocene Era that composed of the fluvial sediments of the river Nile (Mit Ghamer and Bilqas formations) and the coastal area, mostly covered by Aeolian deposits (Environmental Description of Port Said 2007).

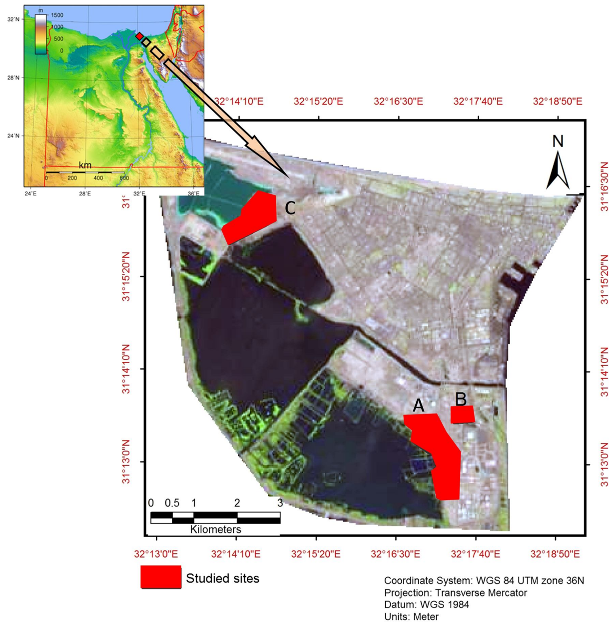

Fig. (1): Location map of the studied sites (A, B, and C) in Port Said city.

In the last decade, Port Said showed an increase of urbanization and industrialization activities. This helps in increasing the spread of random open landfill sites in Port Said city. Consequently, the city suffers from all types of pollution (air, water, and soil).

The obtained value in measuring magnetic susceptibility of the sediment would be nearly proportional to the mass of those minerals. Magnetic susceptibility values work efficiently as chemical measurements on sediment and soil samples for monitoring anthropogenic contamination. Here in the study area, two effective applications of susceptibility measurements of sediment were done: determination of contaminated areas and the specified mapping of these areas to discover the range of contaminants (Schibler et al. 2002).

Magnetic susceptibility (MS) measurements applied in three selected sites A, B and C in Port Said city, (Fig. 1) to define localities of high MS anomalies. Where the surveyed profiles on the sites (A and B) directed to EW trend, while it directed NS trend in site C with a profile spacing of 50m and station spacing 20m in all sites. And the number of stations in the three sites A, B, and C was (370, 310 and 330 respectively). All sites were selected because of their spatial relationships with existing sources of heavy metal. Sites A and B located near to the industrial area of Port Said city, site A is a random landfill, close to the industrial zone of south Port Said and site B is close to the Steel plant and El Raswa highway (southern entrance of Port Said city). And site C is near to the Port Said's dump site which is close to El Gameel highway (western entrance of Port Said city) and it is considered the sewage treatment plant in Port Said city. Therefore, analyses of heavy metals in soils of the three different selected sites (A, B, and C) offer an ideal means to observe not only the contamination extent of sediments itself but also the type of cultured environment as reflected in its soil.

The ground magnetic susceptibility survey done using (KT+10) MS meter (Terra plus instruments). This instrument uses a 10 kHz LC oscillator with an inductive coil to measure the magnetic susceptibility. The susceptibility is the difference in frequency between the measured sample and the free air measurements. To reduce the effects of temperature instability, few measurements in the free air were taken before the measuring of the sample and few after it as well (KT- 10 user guide, Terraplus).

The geographic locations of stations (latitude and longitude) were recorded using a Garmin GPS model 71 champ, after determining the location of each station, they were stored on the internal memory of the GPS. Then GPS data was merged with magnetic susceptibility measurements of the KT-10 into one single sheet for each site on the PC. Finally, merged data is used to produce the MS contour map of each location.

2.1. MS contour maps:

MS contour map of site A (Fig. 2) gives a susceptibility values ranging from 0.01 to 8.2 x10^{-3}SI. Ten anomalies have the highest values (2.2 x10^{-3}SI). Most of the anomalous zones accumulated in the east of site A, close to the highway and face the industrial area. MS anomalies are restricted areas that indicate the dumping wastes from factories as a contaminated source.

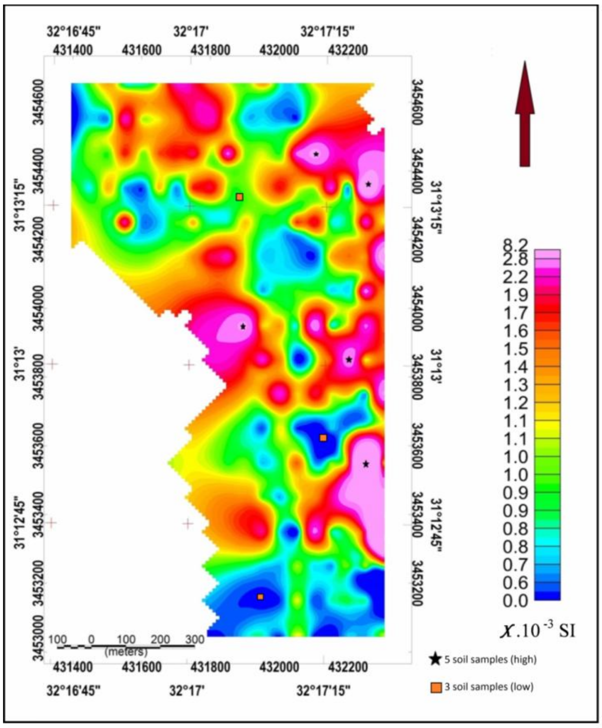

Fig. (2): Magnetic susceptibility map in SI unit of site "A".

Besides, automobile emissions are considered as much source of contaminants (dust). Dust and roadside soils near motorways are contaminated by heavy metal from automobiles (Imperato et al. 2003). Canbay et al. (2010) and Ordonez (2002) recorded high magnetic susceptibility values near the areas of industrial activities and the areas of combustion products of these facilities. Street dust deposited by two major anthropic activities: on-road transportation and industrial activities where, vehicles that commonly drive through the estate include container trucks, large trucks, buses and Lorries.

Heavy metal pollution of surface and underground water sources results in significant soil contamination (INECAR 2000). Marine life like fishes in Lake El Manzala (the longest boundary of the site A) is a vital source of food for population in Port Said (depends on 60% of fishes daily) that spawn in waters contaminated by heavy metal that also accumulate such metals in their tissues (Peplow 1999). Human beings are in turn Susceptible to heavy metals by consuming polluted plants and animals, and this has been known to result in various biochemical diseases. Shortly, all living organisms within a given ecosystem are variously contaminated along their cycles of the food chain. In addition to what Attia et al. (2014) detected at the same site (A) that the main reason of increase potassium concentration on this site is due to both, the dumping of fertilizer wastes of chemical factories and Paints Company that close to the landfill site, besides the accumulation of cut granite coming from stone refine factory. It is also noticed that the highest uranium anomaly may indicate buried artificial radioactive source rich in uranium. Finally, the dose rate grade map of site A showed values reached to 1.61 mSv/year (ICRP 2007). This value considered risky as it exceeds the safe limit (<1 mSv/year) stated by (IAEA 2005; Anonymous 2005).

MS map of site B (Fig. 3) has values of susceptibilities ranging from 0.5 to 9.64 x10^{-3}SI. There is one large MS anomaly occupying from middle to northwestern part of the area, which is close to the iron smelting plant at this site. The atmospheric effect is responsible for the wide-spread of this MS anomaly, owing to the known wind direction at that site (N-W). Consequently the dust of iron of the steel plant is the source of MS anomaly, which works in the dust accumulation in site B. As Kalliomäki et al. (1982) indicated that the blast furnace, reduction of hematite to metallic iron takes place with the aid of carbon monoxide and direct reaction between hematite and coke.

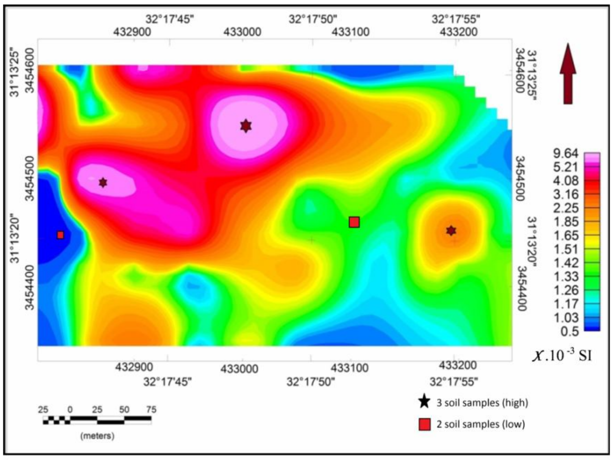

Fig. (3): Magnetic susceptibility map in SI unit of site "B".

In this case, airborne dust originates both from molten steel and partly congealed slag. Concentrations of iron in dust and fumes originating from steel production vary in the range of ten weight percent.

MS map of site C (Fig. 4) has values of susceptibility ranging from 0.86 to 5.7 x10^{-3}SI. Nearly about twelve separated and small anomalies occupy the northern part of this site. These MS anomalies (4.7 x10^{-3}SI) give an indication to dumping processes represented on this dump site. Also, the map shows that these higher anomalies concentrated on the north and northeastern edges of the site C are due to iron waste accumulations in El Gameel highway and internal roadsides. As indicated before that the radioactive anomalies in site C look like many limited and localized anomalies spread all over the area, which reflects the artificial soil (man-made soil) made by the random dump of wastes, because this site considers the solid waste dump and sewage treatment plant of Port Said city (Attia et al. 2014).

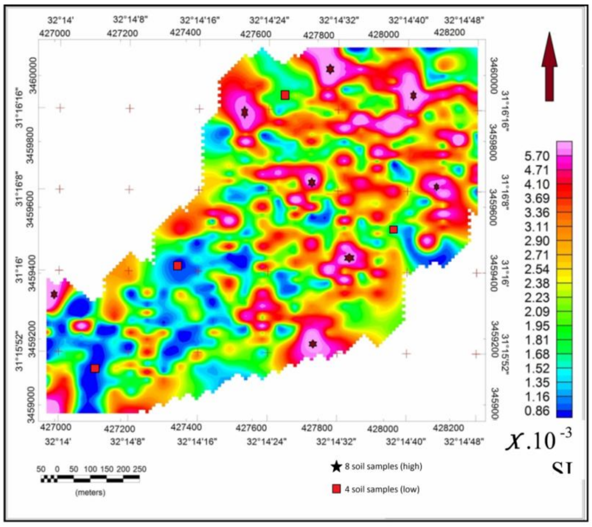

Fig. (4): Magnetic susceptibility map in SI unit of site "C".

The sites A and C are open random landfill sites found for a long period containing a mixture of quarry and metal wastes, fuel ash, rubble from heavy industries and contaminated industrial wastes, as well as spoil from building foundations. Accordingly, measuring of magnetism had also proved easier way to transport of contaminants by air or water (Petrovsky et al. 2000). Which is alert as hazardous areas, because this street dust stays in the surface soil, after accumulating for several years, it will remain in the local environment for a long time, and will then be transformed through dissolution, precipitation, REDOX, and adsorption processes (Wang 2013).

A positive and reliable relation of MS with the total content of heavy metals gives opportunity to perform a detailed survey of the three selected sites (A, B, and C), which are highlighting areas with increased soil contamination (Magiera et al. 2007; Stradina 2008).

3. SAMPLES COLLECTION AND ANALYSES

Twenty-five topsoil samples were collected in the three investigated sites A, B and C (from surface to 20cm deep), which collected from the locations: the highest magnetic susceptibilities (5, 3 and 8 from A, B and C sites respectively) and low susceptibilities (3, 2 and 4 from A, B and C sites respectively). The samples collected by scooping surface soils of the sampling locations using a stainless-steel trowel. These soil samples, then stored in a nitric acid and dry polypropylene bags and labeled.

The total concentration of each element (Mo, Cu, Co, V, Mn, Pb, Cd, Ni, Zn and Fe) was determined using a flame atomic absorption spectrometer Unicam model 969. The collected soil samples were manually sorted to eliminate pebbles and coarse materials, and then dried in air under ambient conditions that are inside the laboratory for about a week to completely remove the moisture. The dried samples pulverized in a disc mill crusher. The resulting powdered samples screened through a nylon sieve of 2 mm mesh size. Each 5g of soil sample were mixed and classified to the quadrant in order to make a complete mixing of the sample. Weight 1g portion of the fine ground sample was digested for complete dissociation with the acid mixture, (H2SO4, HCl, HNO_3 and HF). 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 digested sample solutions of soil in 100 mL volumetric flasks were quantified for the heavy metals Cd, Cr, Mn, Ni, Cu, Zn, Pb, Co, Fe and V by use of flame atomic absorption spectrometry (FAAS) by aspirations the samples into flame of Unicam 969 atomic absorption spectrometer (at the Nuclear Material Authority of Egypt) fitted with deuterium lamp, over a 2mm burner using pre-mix fuel (i.e. air/acetylene mixture). The concentrations of these metals in ppm are illustrated in (Table 1).

Flame atomic absorption spectrometry (FAAS) is the analytical technique estimates, metal ions in their solutions. It is based on absorption of radiation emitted from the light source by free atoms found in the atomic cloud. This technique is of high sensitivity and minimal interfering effects when estimating trace amounts of metal ion, regardless of other metal ions and the nature of the solution media.

4. HEAVY METALS POLLUTION ASSESSMENT

Environmental heavy metal pollution has become increasingly known for more than 40 years as an important issue in public health. Anthropogenic areas were enriched in poisonous heavy metals (Pb, Fe, Zn, Mn, Ba, Cr and Cd) and, almost stationary, magnetic particles (Maher 2009). The mutual relation between MS concentration and heavy metals content discovered a causative relation between the ferrimagnetic oxide and heavy metals in urban sediments. This relationship could be, due to fact that heavy metal elements

Table 1: 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	MS
1	A	1.04	110	33	54821	n.d.	34.18	0.59	21	264	106.4	3.2
2		1.34	191	55	86667	0.04	74	41	56	400	562	6.2
3		1.41	154	7	20717	2.9	87	n.d.	16	1.15	85	7
4		1.26	131.5	74	80000	2.5	36	9	96	455	587	7.32
5		1.12	176	67.2	66348	2.3	28.7	n.d.	43	346.22	217	3.7
6		0.91	122.7	74.5	37128	1.47	32.84	4.11	30	294.67	188.42	3.4
7		1.13	198.16	72.72	43026	1.82	30	n.d.	87.26	575.7	454.5	7.06
8		1.06	118.5	21.75	67000	n.d.	30	0.75	36	228	162.75	8
9	B	1.08	131	9.36	34625	2.1	47	n.d.	12	3.46	124	3.1
10		1.54	185	47	93230	n.d.	27	29	55	566.67	405	9.3
11		1.34	195.5	7	64000	2	17	25	47	730	325	6.4
12		0.74	192	41	60280	n.d.	65	17	33	127.81	226	2.8
13		1.38	154	33	53333	3.6	53	5	49	238.33	290	7.4
14	C	0.7	78.8	14.46	44555	n.d.	19.95	0.5	23.94	151.62	108.23	4.2
15		0.87	95.04	4.32	12785	1.79	53.69	n.d.	9.87	1.94	52.46	6.3
16		0.81	97.13	24.68	48946	n.d.	14.18	15.23	28.88	297.5	212.63	3.8
17		0.78	85.53	3.89	11507	1.61	48.32	n.d.	8.89	1.74	47.21	5.2
18		0.64	70.07	6.28	9426	1.32	39.59	n.d.	7.28	0.52	38.68	4.5
19		0.54	66.04	3.82	10654	1.06	20.9	n.d.	5.01	0.63	27.62	1.1
20		0.67	98.53	3.53	32256	1.01	8.57	12.6	23.69	367.92	163.8	4.6
21		0.67	74.38	15.94	25760	n.d.	25.6	2.42	23.67	115.12	140.07	3.6
22		0.67	72.7	3.3	9781	1.37	41.07	n.d.	7.55	423	40.13	4.21
23		0.47	118.67	22.61	34061	n.d.	15.06	10.8	13.64	144.6	12.62	1.5
24		0.51	103.44	3.1	22605	0.98	8.21	4.15	12.94	107.95	34.8	1.2
25		0.46	109.27	15.04	30845	n.d.	17.66	7.09	17.06	137.02	62.99	0.9
n.d.: Not detected	MIN	0.46	66.04	3.1	9426	0.04	8.21	0.5	5.01	0.52	12.62	0.9
Samples of high MS (blue)	MAX	1.54	198.16	74.5	93230	3.6	87	41	96	730	587	9.3
Samples of low MS (yellow)	Mean	0.92	125.15	26.54	42174.24	1.74	34.98	11.51	30.54	239.22	186.97	4.63

incorporated into the lattice structure of the ferrimagnetic during combustion process or adsorbed onto surface of pre-present the ferrimagnetic in the environments (Kapicka et al. 2003; Vodyanitskii 2010). It was reported worldwide that the Pb emission from automobile exhaust that deposited close to roads and highways, besides that the roadside soils contained by the heavy metal at a higher level than soils further away. Results from the present research and other studies support the finding that heavy metal emitted from gasoline combustion, especially roadside soils are important inputs to the environment (Gautam et al. 2005).

Cadmium (Cd), lead (Pb), arsenic (As) and mercury (Hg) spread widely in the different soils. Mentioned elements have no useful meaning in humans, and there is no known homeostasis mechanism for them (Draghici et al. 2010; Vieira et al. 2011). They are generally considered the most toxic to humans and animals; the adverse human health effects associated with exposure to them, even at low concentrations are diverse, but are not limited to neurotoxic and carcinogenic actions (ATSDR 2008; Castro-Gonzalez & Méndez-Armenta 2008; Jomova and Valko 2010; Tokar et al. 2011).

Heavy metal concentrations (Iron (Fe), copper (Cu), Vanadium (V), Lead (Pb), Cadmium (Cd), Cobalt (Co), Zinc (Zn), Nickel (Ni), Manganese (Mn) and Molybdenum (Mo)) in the studied sites (A, B & C) are estimated and listed in (Table 1).

4.1. Geo-accumulation index (I_{geo}):

Geo-accumulation index (I_{geo}) was first applied by Muller in 1969 to calculate and quantify the metal pollution in soils. Actually, the I_{geo} provide the opportunity to assess the pollution by emulation the present concentrations with earlier concentrations of anthropogenic activity (background) in the sediments (Rahman et al. 2012; Hasan et al. 2013; Mmolawa et al. 2011). The way to assess the degree of metal contamination in terms of seven classes of enrichment based on the raising of numerical values of the index; $I_{geo} \leq 0$: Uncontaminated, $0 < I_{geo} < 1$: Uncontaminated/moderately contaminated, $1 < I_{geo} < 2$: Moderately contaminated, $2 < I_{geo} < 3$: Moderately/strongly contaminated, $3 < I_{geo} < 4$: Strongly contaminated, $4 < I_{geo} < 5$: Strongly/extremely contaminated and $5 < I_{geo}$: Extremely contaminated (Hasan et al. 2013). I_{geo} is computed by using the following equation:

$$I_{geo} = log_2 \frac{C_{sample}}{1.5 \times C_{reference}} \qquad (1)$$

Where, C_{sample} is the metal concentration in the sample, $C_{reference}$ is the average value of the same metal at a background level. The crustal abundance used as background data for different metals (Jefferson Laboratory Report 2007). The factor 1.5 is to reduce the effect of possible background variations due to lithogenic variations in this equation values. The sediment contamination was examined through following concentration of the studied heavy metals such as Mn, Fe, Zn, Pb, V, Ni, Cd, Cu, Mo, and Co.

According to calculations of the I_{geo} mentioned in (Table 2) and showed by (Fig. 5), sites (A, B, and C) are extremely contaminant with Fe and Extremely to strongly contaminated with Mn, Zn and moderately contaminated with Pb, Co, Ni, Cu, V, and uncontaminated with Mo and Cd. The results of the I_{geo} also confirmed that the Fe has the highest contamination effects; Mn and Zn have the higher contamination effects, while other metals have from moderate to not contamination effects.

Table (2): Geo-accumulation indices of the measured heavy metals in the three sites A, B, and C.

Site	I_{geo}									
	Mo	**V**	**Cu**	**Fe**	**Cd**	**Pb**	**Co**	**Ni**	**Zn**	**Mn**
A	-0.26	3.99	2.82	6.86	0.01	2.49	1.43	2.55	3.90	4.50
B	-0.25	4.05	2.53	6.91	0.06	2.46	2.07	2.49	3.79	4.53
C	-0.52	3.76	2.08	6.46	-0.21	2.23	1.56	2.07	3.19	3.89

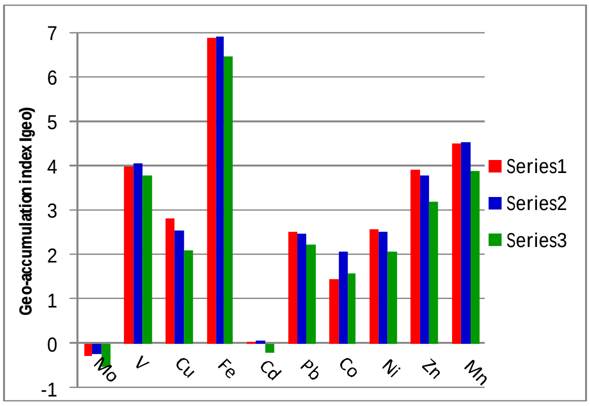

Fig. (5): Average geo-accumulation index of the measured heavy metals in the three sites A, B, and C.

4.2. Contamination factor

The contamination level of a given toxic substance in soil estimated by applying a contamination factor (CF) formula (Qingjie et al. 2008, Hasan et al. 2013). It was suggested by Hakanson (1980) as follows:

$$CF = \frac{C_{Sample}}{C_{reference}} \qquad (2)$$

The expressions used to depict the contamination factor according to Rahman et al. (2012) are CF<1: low contamination factor; 1≤CF<3: moderate contamination factor; 3≤CF<6: considerable contamination factors and CF≥6: very high contamination factor.

The average of contamination factors presented in (Table ٣) and illustrated in (Fig. 6) show that site (A) has a considerable contamination factor for Zn, Pb, Ni and Cd moderate contamination factor for Cu, Mo, V and Mn and low contamination factor for Co. And the site (B) has a considerable contamination factor for Zn, Pb, Cd and moderate contamination factor for Ni, Mo, V, Cu, Co, and Mn. While the site (C) has moderate contamination factor for Cd, Pb, Zn and Ni and low contamination factor for V, Cu, Co, Mo, and Mn. Accordingly, Pb, Zn, Cd, and Ni represent the highest potential risk; while Co, Cu, Mo, V and Mn represent a low potential risk in the sites (A, B and C).

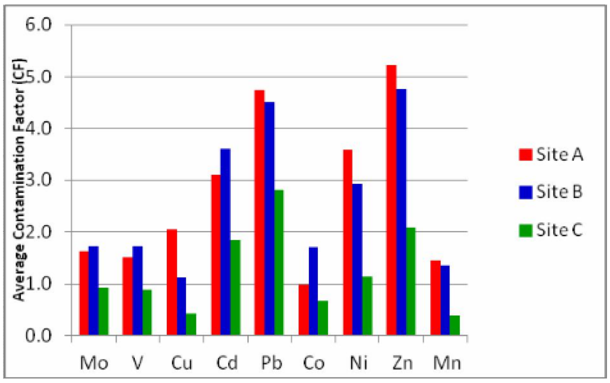

Fig. 6: Average contamination factors of the measured heavy metals in the three sites A, B, and C.

For centuries, lead was mined and used in industry and in household products. Recently, manufacturing with the entering of lead in the huge production of plumbing, paint, the material used in most cans, ceramics, and countless other products resulted in a marked rise in population exposures in the 20th century (EPA 1986). Furthermore, Children exposed to Pb via soil and dust polluted by precipitation from the atmosphere, water, and other sources. Lead negatively affects the nervous system, slowing down nerve response (European Commission 2002). And all the previously mentioned sources of Pb are available in the three sites.

In addition, the filter dust from steel reclamation as in site B may be processed for recovery of the metal content. Apart from the heavy metals mentioned here, the filter dust has significant amounts of Zn, the main economic incentive for the recovery. Pb and Cd are to some extent also recovered by the processes. As the result, these three heavy metals (Zn, Pb, and Cd) record the highest contamination factors in the site B rather than sites (A and C) as shown in (Table 3).

Table (3): Contamination Factor (CF) of the measured heavy metals in the three sites A, B, and C.

Site	Average Contamination Factor (CF)								
	Mo	**V**	**Cu**	**Cd**	**Pb**	**Co**	**Ni**	**Zn**	**Mn**
Site A	1.632	1.502	2.059	3.096	4.741	0.990	3.594	5.232	1.448
Site B	1.713	1.715	1.117	3.615	4.495	1.696	2.925	4.761	1.343
Site C	0.914	0.891	0.410	1.839	2.803	0.673	1.134	2.083	0.384

4.3. Pollution Load and Nemerow indices:

The most popular pollution evaluation methods of heavy metal contamination in industrial and landfill sites are the Pollution Load Index and Nemerow Index (Tomlinson et al. 1980; Angulo 1996).

In respect of assessing the integrative impact of anthropogenic activity related to heavy metals, the Tomlinson pollution load index (PLI) estimated based on the metal concentrations in the urban topsoil and sediment samples (Fe, Mn, Co, Cd, Cu, Pb, Ni, Zn and V) to prove its correlation with magnetic parameters. PLI infer how much a sample overtake the heavy metal concentrations in normal environments and give a valuation of the overall poisoning status for a sample (Angulo 1996). The PLI index defined as the n^{th} root of the multiplication of the concentration factors (CF):

$$PLI = n\sqrt{CF_1 \times CF_2 \times CF_3 \times \cdots CF_n} \quad (3)$$

Where CF is contamination factor of every heavy metal with reference to the background value in the sediment (Angulo 1996; Usero et al. 2000) and n is the number of metals (n=10 metals). According to Singh et al. (2003), the PLI classified as: 0 < PLI ≤ 1 unpolluted; 1 < PLI ≤ 2 moderately to unpolluted; 2 < PLI ≤ 3 moderately polluted; 3 < PLI ≤ 4 moderately to highly polluted; 4 < PLI ≤ 5 highly polluted; PLI > 5 very highly polluted.

The average PLI presented in (Table 4) and illustrated in (Fig. 7) shows that site (A) has very high polluted load and site (B) has moderately polluted load and site (C) has the unpolluted load. PLI reflects the combined action of many heavy metals; while Nemerow integrated pollution Index (NIPI) emphasizes the importance of high concentrations of heavy metals and formulated as follows (Yang et al. 2010):

$$NIPI = \left\{\frac{[(PI_{ave}{}^2) + (PI_{max}{}^2)]}{2}\right\}^{\frac{1}{2}} \quad (4)$$

Where PI_{ave} is the average of the total of the single pollution index, and PI_{max} is the maximum value of the single pollution index. The NIPI is classified as non-pollution (NIPI≤0.7), warning line of pollution (0.7<NIPI≤1), low level of pollution (1<NIPI≤2), moderate level of pollution (2<NIPI≤3) and high level of pollution (NIPI>3) (Yang et al., 2011).

Table (4): Pollution load index (PLI) of the measured heavy metals in the three sites A, B, and C.

Site	PLI			
	Max	Min	Mean	classified as
A	24.556	0.0003	6.3171	very highly polluted
B	8.5475	0.0008	2.2966	moderately polluted
C	1.1661	8.93E-08	0.0002	unpolluted

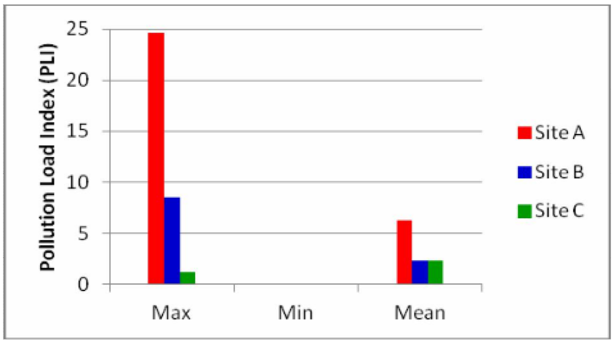

Fig. 7: Pollution load index of the measured heavy metals in the three sites A, B, and C.

The Nemerow integrated pollution index listed in (Table 5) and illustrated in (Fig. 8). The site A shows the high level of pollution and site B shows the moderate level of pollution, where site C has warning line of pollution. This is because site (A) is close to the area of industrial, South Port Said city and site (B) is near to the steel plant and El Raswa highway. These results show that the areas, which are strongly affected by human activities such as population; industry and vehicles; are facing serious pollution problems. Besides confirmation of Pb, Zn, Ni and Cd as polluted heavy metal in the studied sites as estimated by geo-accumulation index and contamination factor.

Table (5): Nemerow index (PN) of the measured heavy metals in the three sites A, B, and C.

Site	Nemerow Index (PN)	
A	3.173	High level of pollution
B	2.284	Moderate level polluted
C	0.653	warning line of pollution

5. MS AND HEAVY METALS

Pearson's correlation coefficients between the MS (**X**) and heavy metal concentrations are showen in (Table 6). The considerable correlation between magnetic susceptibility and heavy metal concentration (p <0.01) observed for Mo, Ni, Fe and V, while the considerable correlation between MS and heavy metal concentration (p <0.05) observed for Cd, Cu, Zn, and Pb.

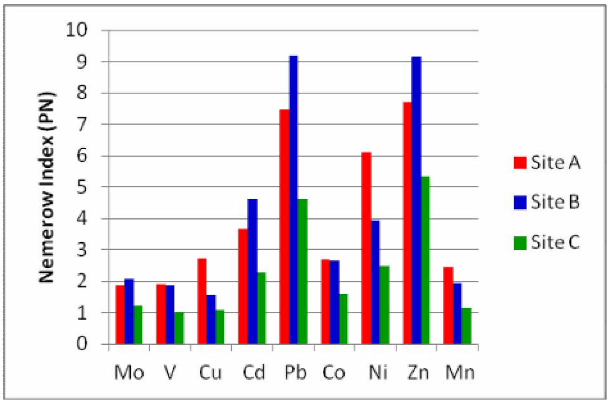

Fig. 8: Nemerow integrated pollution index (PN) of the measured heavy metals in the three sites A, B, and C.

The two confidence items confirm a good positive correlation with the MS measurements and heavy metals. This positive correlation between MS and heavy metal concentration in sediment, that authorizes MS to use as a proxy of pollutants and their distribution.

Table (6): Pearson's correlation coefficients between heavy metal concentrations and χ.

	Fe	Mo	V	Cd	Pb	Zn	Cu	Ni	Mn	Co
χ	0.48**	0.80**	0.44**	0.47	0.37	0.46	0.28*	0.59**	0.60*	0.36

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

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

6. CONCLUSION

A magnetic susceptibility survey is an important tool for mapping the heavy metal contamination and supplies non-invasive, fast and inexpensive tool.

The magnetic susceptibility measurements give high values at some localities in the studied sites, which are polluted with heavy metals (A, B, and C). The MS map of site A shows a localized, limited aerial extension anomalous zones, that accumulated along the eastern part and near to the asphalt road and the industrial free zone, which indicates the source of contamination from factories and automobile emissions. While the MS map of site B (near the iron smelting plant) shows larger anomalous zones, concluding that the industrial dust of the steel plant is responsible for the high magnetic susceptibility anomalies. Finally, the MS map of site C shows a number of about twelve individual and limited anomalies, which are focused mainly in the north of site B. This indicates that the processes of dumping waste in El Gameel highway and internal roads are the main sources of these anomalies.

Besides the heavy metal analysis of the sediment samples, the heavy metal pollution is also evaluated using the geo-accumulation, contamination factor, pollution load and Nemerow pollution indices. The results prove that sites A and B are highly contaminated with Pb, Cd, Zn and Ni, where the industrial activities were located, while site C is less contaminated. Also, site A and B showed a moderate to low contamination with V, Mo, Co, Fe, Mn and Cu, which give insight that the industrial activities in the two sites, especially the iron plant are the main contaminant in sites A and B.

Where, Nemerow pollution index shows also that the site A represents the higher level of pollution than site B which has the moderate level of pollution, while site C represents the warning line of pollution which means that the heavy metal exposures have considerable consequence and is generally not safe.

Finally, according to correlation analysis of soil samples; the heavy metal (which was analyzed) shows a strong to medium positive correlations with MS. The high linear correlation between MS and heavy metal content in soils allows environmental magnetism to use as a proxy to detect heavy metal contamination from industry and the topsoil of landfill in Port Said city and similar localities.

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