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INTEGRATED USE OF POLLUTION INDICES AND GEOMATICS TO ASSESS SOIL CONTAMINATION AND IDENTIFY SOIL POLLUTION SOURCE IN EL-MINIA GOVERNORATE, UPPER EGYPT

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Abstract

This paper assesses the concentrations of Heavy Metals (HMs) to evaluate their potential risk to soil pollution in a cultivation area in the Nile Valley (Minia Governorate) with decades of intensive farming. 159 soil profiles samples were analyzed for essential trace constituents (B, Fe, Cu, Zn and Mn) and toxic heavy elements (As, Cd, Cr, Co, Ni, Pb, and Se). The metal pollution index MPI was applied to assess the mobile forms and total content of HMs in all profiles' layers. Geostatistical models were applied to identify the sources and hotspots of accumulated HMs in the studied soil. The results revealed that the contamination by accumulated HMs is due to anthropogenic activities from industry and sewage irrigation, which indicated that the high content of HMs in the soil is not from geogenic sources. HMs concentrations are higher in the southern part of the area compared to the middle portion, while the northern part's soil had the lowest concentrations. Uncontrolled surface or flash irrigation is a likely cause of leaching of HMs to sublayers of soil. The compline GIS map of MPI indicated that highly effected portions are affected by El Moheet drainage water from the Abu Qurqas sugar factory. This work raises the need to develop strategies and policies to prevent widespread HMs soil contamination in the area. This study confirms the need to install filters and water purification systems on the openings of sugar factories in Minia and consequently, all the factories on the Nile River and all canals used for irrigation.

Keywords: Egypt, Heavy metals, HMs pollution sources, Minia governorate, Statistical analysis.

1. Introduction

Industrialization and rapid urbanization are key factors among many anthropogenic causes, which cause environmental degradation [1, 2]. All spheres whether biosphere, hydrosphere, atmosphere, lithosphere or pedosphere qualities are directly affected by environmental pollution [3, 4]. Weathering of parent rocks is the natural source of heavy metals, furthermore urban land use and industrial are point sources of heavy metals while economic and transportation set up are non-point sources of heavy metals [5]. The previous studies emphasized that urban soil, agricultural soil, and soil in mining areas are susceptible to contamination with HMs [6]. Assessment of HMs soil contamination has many different methods, and comparison of the results of these different methods were published [7-9].

Soil pollution is a series problem for agricultural purposes affected on food quality, drinking water, and air quality which threaten human health [10-15]. Helena and Jiří [16] stated based on the previous reviews and articles that the comprehensive geochemical assessment of HMs is mainly based on suitable indicators and indices use for assessment of pollution/contamination status. This comprehensive way of use such indices help to estimate soil quality, environmental risk and soil degradation due to long-term accumulation of heavy metals. Moreover, those indices help to determine whether the accumulation of heavy metals was due to natural processes or is the result of anthropogenic activities, and therefore, the indices of pollution can contribute also to human activity monitoring.

The concentration of HMs in agricultural soils is a major factor affecting human health, directly and indirectly, by affecting food chain quality [17-19]. In the terrestrial ecosystem, the most common sink of HMs pollutants is soils [10], which have caused problems worldwide [20]. Generally, HMs in soils mainly comes from two sources: natural and anthropogenic inputs. The latter includes agrochemicals and artificial fertilizers, mining activities, vehicle exhaust, sewage, and industrial sources [21]. The high concentrations of HMs in surface soils might negatively affect human health [22, 23]. Accumulation of HMs in deep soil can also cause groundwater contamination [24, 25]. The wastes produced by various industrial activities are major contributors of HMs into soils and the surrounding environment [26, 27], and consequently the pollution of groundwater by the percolated polluted soil water [28, 29]. This might highlight the needs of assessment of surface water and groundwater interaction using field measurements [30, 31], therefore indicating sources affecting groundwater quality [32, 33]. There is an interaction effect between surface and groundwater quality and soil quality [34], this interaction could be easily described using geostatistics, spatial model in Arc GIS, thus could figure out soil quality and land degradation indicators accurately [35-37].

Minia Governorate, Egypt is cultivated with sugarcane and sugar beet for Abu Qurqas sugar factory as one of the economic pillars of Egypt. Minia is also the highest producing governorate of wheat and maize in Egypt. Due to the importance of these strategic crops to Minia Governorate, it is important to follow the heavy metals contamination characteristics of the soil and to avoid its possible adverse impacts upon local people. The identification and characterization of soil pollution with HMs and their risks in Minia governorate might be useful for the monitoring and assessment of soils contamination in the investigated area. Previous studies are restricted on a single aspect of this, especially HMs concentration in soils and water [18, 19, 38-46].

Interactions between chemical pollutants such as trace minerals and HM sources can be performed with the help of overlapping analysis of the spatial distribution of pollutants for geochemical mapping in different landscapes [47-51]. The quantitative and qualitative degree of HMs content in the investigated area were assessed by calculating soil contamination indices; and finally, HMs contents were present using a geostatistical approach.

This study aimed to assess soil pollutions through determining HMs concentration in surface soil and the distribution of HMs content in soil profiles. This was done to figure out the source of the pollution whether is from soil inherent and/or by anthropogenic activities.

2.Materials and Methods

2.1. Study area

The study area is a part of Nile Valley, old river sediments are clay and silts, located in Minia Governorate Fig. 1, with a total area of 3216.31 km^2 and more than 3.7 million inhabitants. It is characterized by an arid climate (coordinates 30° 40′ - 31° 00′ E, 27° 30′ - 28° 50′ N). AbdelRahman et al. [37] stated that evaporation rate in the area is 4897.91 mm/year, while the mean annual rainfall was ranged from 23.05 to 33.15 mm/year for the last 15 years. Korany et al. [47] and Korany [48] mentioned that the mean monthly relative humidity during daytime ranged from 62% in May to 29% in December, while the average temperatures in winter ranges from 5° to 20°c with the maximum one about 42°c in summer. The governorate has 9 administrative centers comprising 9 cities, 57 local village units, 346 villages, and 1430 towns and villages including the Minia new city. It is a heavily industrialized governorate, with this industry including cement factories, black and white cement factories, iron and steel quarries, sand quarries, marble quarries, limestone quarries, natural gas filling stations, soda water plants in Samalut center, oil factories, cotton processors, natural gas filling stations and soda water plants in Minia center, sugar factories in Abu Qurqas center, and tile factories. Minia Governorate also contains an estimated area of agricultural land of about 452 thousand acres, representing about 6.5% of the total area of agricultural land in Egypt. Its main crops include cotton, wheat, maize, potatoes, sugar cane and bananas. The agricultural lands are mostly irrigated from canal carrying Nile water, reusing wastewater from industrial drainage (El Moheet drain).

2.2. Soil sampling

A systematic sampling strategy was applied on January 2018, to collect soil samples in the old Nile valley of Minia Governorate; with sample locations recorded using a global positioning system (GPS) Fig. 1. 159 soil profiles were distributed based on semi detailed survey to well cover the study area, to investigate the impacts of anthropogenic activities on HMs concentrations in the soil. Soil samples were collected as disturbed mixed soil from different layers by systematic depth as follow (0-30, 30-60, 60-90, 90-120 cm).

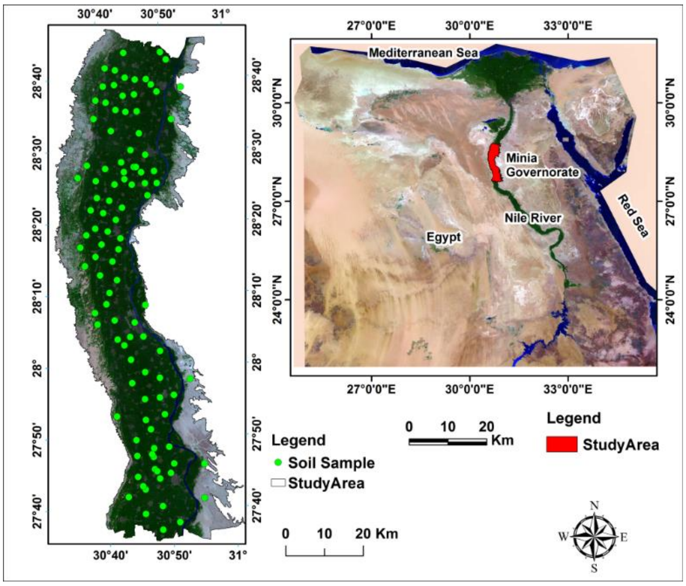


Fig. 1. Location map of soil profiles and study area.

2.3. Soil analysis

All samples were air-dried in shadow at room temperature and sieved to 2 mm; gravel-sized material and plant roots were removed. The sieved soil samples were then ground with a pestle and mortar until all particles passed through a 0.149 mm mesh.

The atomic absorption spectrophotometry method was used to determine the content of HMs in accordance with procedure Abu Zied [39] and Awad [40]. To determine contents of As, Se, Cr, Cd, Pb, Ni, Co, and, Cu soil samples underwent acid digestion with a mixture of HNO_3-HF-$HClO_4$ followed by Inductively Coupled Plasma Atomic Emission Spectrometry and analyzed according to Benton [51].

2.4. Determining the hazard degree of HMs content in soil samples

The metal pollution index (*MPI*) was used to determine the hazard degree of HMs content in the collected samples [42] by Eq. (1):

$$MPI = (C1.\ C2\ .\ C3\ .\ \dots Cn)^{1/n} \tag{1}$$

where $C1 \cdot C2 \cdot C3 \cdot \dots Cn$ is the metal concentration $(\mathrm{As} \cdot \mathrm{Se} \cdot \mathrm{Cr} \cdot \mathrm{Cd}.\ \mathrm{Pb} \cdot \mathrm{Ni} \cdot \mathrm{Co} \cdot \mathrm{Cu} \cdot \mathrm{B} \cdot \mathrm{Fe} \cdot \mathrm{Zn} \cdot \mathrm{Mn})^{1/12}$.

The ordinary kriging geostatistical interpolation method [43] was used to create a map of HM contamination of the soil horizons.

2.5. Accuracy assessment and validation

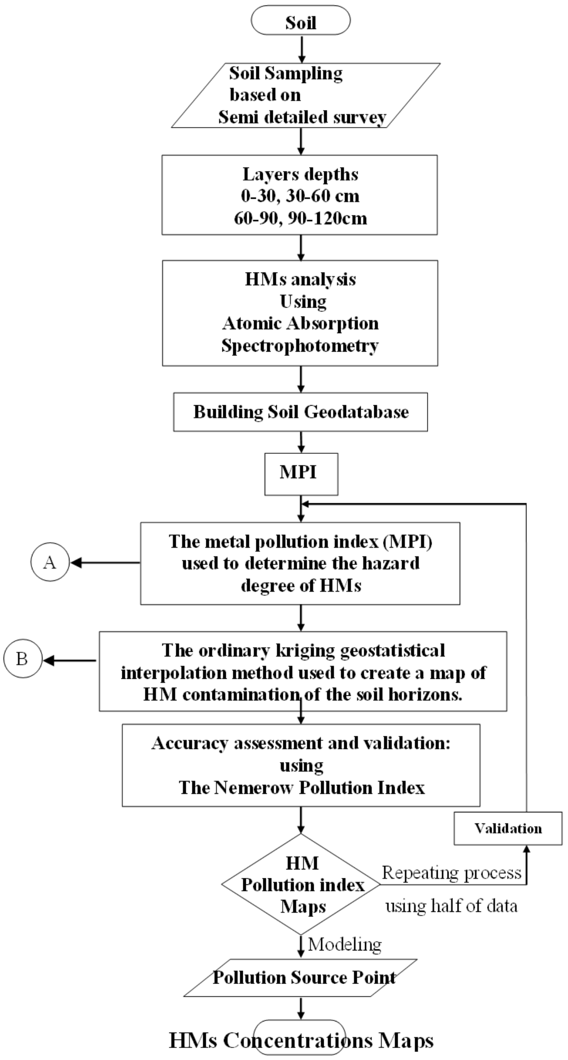
The Nemerow Pollution Index ($PI_{Nemerow}$), stated by Awad et al. [44] to be the most stringent of the pollution indices, and recommended for safety considerations. It was used as a validation index for the obtained results. According to Cheng et al. [52] a Nemerow Pollution Index ($PI_{Nemerow}$) has been widely applied to assess the quality of soil using the equation Eq. (2) of Zhang et al. [53]:

$$PI_{Nemerow} = \sqrt{\frac{(\frac{1}{m}\Sigma_{i=1}^{m} Pi)^2 + Pi2_{max}}{2}} \tag{2}$$

where Pi is the single pollution index of HM "i"; Pi_{max} is the maximum value of the single pollution indices of all the HMs and "m" is the count of the heavy metal species. The quality of the soil environment was classified into 5 grades from Nemerow Pollution Index:

$PI_{Nemerow} < 0.7$ - safety domain
$0.7 \leq PI_{Nemerow} < 1.0$ - precaution domain
$1.0 \leq PI_{Nemerow} < 2.0$ – slightly polluted domain
$2.0 \leq PI_{Nemerow} < 3.0$ – moderately polluted domain
$PI_{Nemerow} > 3.0$ – seriously polluted domain

The implemented methodology of this study is well shown as follow in Fig. 2.



A: MPI calculated in ArcGIS model builder
B: HM maps were implemented in site deterring model in ArcGIS

Fig. 2. Flow chart of study.

3. Results and Discussion

From Table 1, the soils' physiochemical characteristics could be summarized as: the soil textures are clay, clay loam, and silty clay loam. The soil pH (1:2.5) ranged from 6.9 to 8.2, while EC (electrical conductivity) ranged between 198 and 704 µS/cm. $CaCO_3$ ranged between 0.25 and 6.50 %. The SAR (sodium absorption ratio) ranged between 0.20 and 128.00. The soils were fertile with moderate values of macro nutrients (Nitrogen N, Phosphorous P and Potassium K). The area is characterized by fertile alluvial fluvial soils with fine texture and high content of organic matter and minerals. The soil texture types were silt clay loam, clay loam and clay.

Table 1. Weighted average of Physico -chemical properties of soil.

	Particle-Size Distribution (%)			pH (1:2.5)	Ec µS/cm	$CaCo_3$ (%)	Soluble cations mg/L			
	Sand	Silt	Clay				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Max	29.40	60.10	71.34	8.30	731.00	9.60	102.0	35.70	51.00	19.10
Min	3.13	14.30	29.60	6.70	177.90	0.43	39.90	14.30	3.90	0.99
Mean	16.2	3.35	51.2	7.53	400.30	3.77	67.90	21.30	15.13	3.11

	SAR epm	Na%	Soluble anions mg/l			Nutrients concentration mg/L		
			HCO_3^-	$SO4^{2-}$	Cl^-	N	P	K
Max	197.30	129.00	323.11	125.11	55.91	128.11	40.11	1731.00
Min	0.53	7.33	9.99	0.19	6.32	9.57	0.13	75.99
Mean	29.11	25.17	179.18	60.78	22.18	60.25	10.12	470.45

HM soil contamination degree is mainly measured by the translocation hazard index. The metal pollution index (MPI) was used to assess the soil contamination depending on HMs mobile forms' content and their total content. Contamination hazard index degree was assessed using the total content and content of mobile forms of HMs. The results indicated that the maximum content of elements is concentrated in the upper soil layer as shown in Fig. 3. Their value decreases with depth through the profile layers by 2-3 times. On the whole, the total content of investigated elements was considerably higher than the maximum allowable concentration (MAC), with the exception of as Fig. 3.

The iron content was greatest in the clay soil, and high in the clay loam, with lower values of iron found in silty clay loam Fig. 3. These still exceeded its content in alluvial soil by 1.1-1.9 times and in alluvial Soddy soil by 2.3-3.9 times. On the whole, the iron content didn't exceed 23 g/kg, and its toxic effect on cultivated plants only manifests itself at a content exceeding 30 g/kg (Fig. 3).

The high concentrations of HMs contented in the surface layers rather than the subsurface layers of all soil profiles Fig. 3 could be due to high content of fine soil particles; clay and silts as shown in Table 1. Also this could be due to the high content of soil organic carbon in surface layers, which may be absent or disappear in the lower layers of all soil profiles.

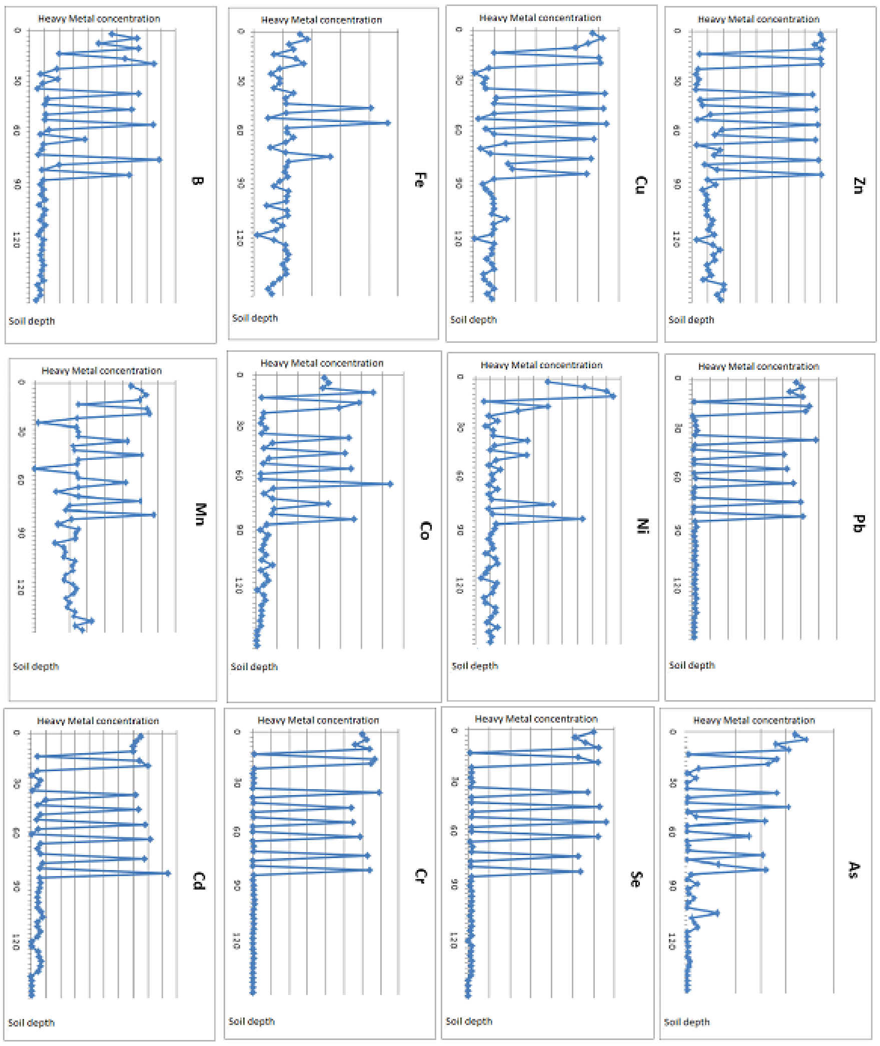


Fig. 3. Weighted average of mobile forms of heavy metals content in layers of soil profiles.

Surface irrigation is the common irrigation system in the investigated agriculture soils. This could explain the capacity of water for transporting mobile forms of HMs from surface layer to subsurface layer of the soil profiles as shown in Fig. 3. The deep soils contained small amounts of HM confirming that lethogetic factors did not cause any high concentration of accumulated HM, and that HMs in the area did not derive from parent rock materials.

Increasing the cation exchange capacity of clay granules increases the rate of adsorbed elements on the surface of the granules, which may lead to less movement of heavy elements to sub-surface layers in the soil profiles. Also the lack of movement of the element in the soil solution may be another reason for the lack of movement of elements from the surface layers to the subsurface layers through the soil profiles.

Comparisons to the maximum allowable concentration MAC were calculated for both essential trace constituents (B, Fe, Cu, Zn, Mn) and toxic heavy elements (Co, Ni, Pb, Cd, Cr, Se, As) in different soil layers. The obtained values were between 0.2 and 0.3 MAC for most of the soil profiles. All soil profiles within the southern part of the area were above 0.8-0.9 MAC. Soil profiles located in the north of the area recorded low values of MAC. The soil's pollution is mainly limited to southern parts of the old valley of Minia Governorate.

The mean contents of B, Cu, Zn, and Mn in the soils exceed the critical limits of the Egyptian soils guideline limits, while Fe was below the critical limit. The mean content of toxic heavy elements (Pb, Cd, and Se) were above 0.8-0.9 MAC. The elements Co, Ni, Cr and As were below 0.3-0.4 MAC, reflecting non-inherent soil pollution source and irrigation source might be behind it.

Statistical analysis results Table 2, revealed that the mean contents of Co, Pb, Cd and Se exceed the MAC while for Ni, Cr and As were below the MAC according to World Soils [54].

Table 2. Weighted average of heavy metals content of soil.

	Essential trace constituents					Toxic heavy elements (mg/l)						
	B	Fe	Cu	Zn	Mn	Co	Ni	Pb	Cd	Cr	Se	As
	mg/L * I					mg/Kg soil 2						
Limits	2	6	1	2	5	-	25	15	0.4	50	0.4	11.3
Max	10.11	27.31	7.11	7.87	15.22	8.10	6.12	144.00	6.02	142.00	13.01	0.91
Min	0.61	0.81	0.01	0.39	0.41	0.03	0.23	2.39	0.02	0.02	0.02	0.02
Mean	2.45	5.90	2.10	2.87	7.11	1.49	1.17	29.91	1.08	27.16	3.43	0.21

The obtained results confirm contamination of the topsoil layer (0-30 cm) in all contaminated soil sectors, where contamination in the subsurface (30-60cm) layer is reduced gradually, and here are no pollutant elements in the lower layers of all profiles. This could be due to the high cation exchange capacity which absorbs the metal on the clay minerals' surface. This action could led to impede the movements of HMs to subsurface through the soil profiles

3.1. Assessment of topsoil pollution in the study area

The spatial distribution of the HMs content in the topsoil Figs. 4 and 5 showed, the southern parts of the area have the highest level of contamination while, the northern parts are clear of toxic levels of both essential trace constituents and toxic heavy elements. A spatial model-builder was built up to determine the highly affected areas as well as the pollution source. The model was built based on the concept of geostatistical techniques which work with the idea that two nearby points are highly affected and correlated to one other more than two faraway points [37].

Based on the critical values limits for each HM and its toxic effect, the results shown in Figs. 6 and 7 indicated that the most affected parts are soils in southern part of the old Nile valley. Moreover, soils near of El Moheet drain in the middle of the south part of the valley have high HMs content.

Descriptive statistics of HMs contents and selected topsoil properties Table 2 showed, the ascending order using the cluster analysis is As < Cd < Ni < Co < Cu < Zn < B < Se < Mn < Fe < Pb < Cr. The elements which exceeded their background values are as follows: B = 8.874 > 2 mg/kg, Fe = 23.13 > 6 mg/kg, Cu = 6.40 > 1 mg/kg, Zn = 8.10 > 2 mg/kg, Mn = 13.53 > 5 mg/kg, Cd = 4.68 > 0.4mg/kg, Cr = 139 > 50mg/kg and Se = 13.22 > 0.4 mg/kg. Those elements that did not exceed their background values were as follows: Co = 6.384 < 25 mg/kg, Ni = 4.75 < 25 mg/kg, Pb = 137 < 15 mg/kg and As = 9.8 >11.3 mg/kg. This result may indicated that further monitoring of these HMs is required; according to Chen et al. [55], the prevention of additional enrichment of HMs in soils requires regular protection measures.

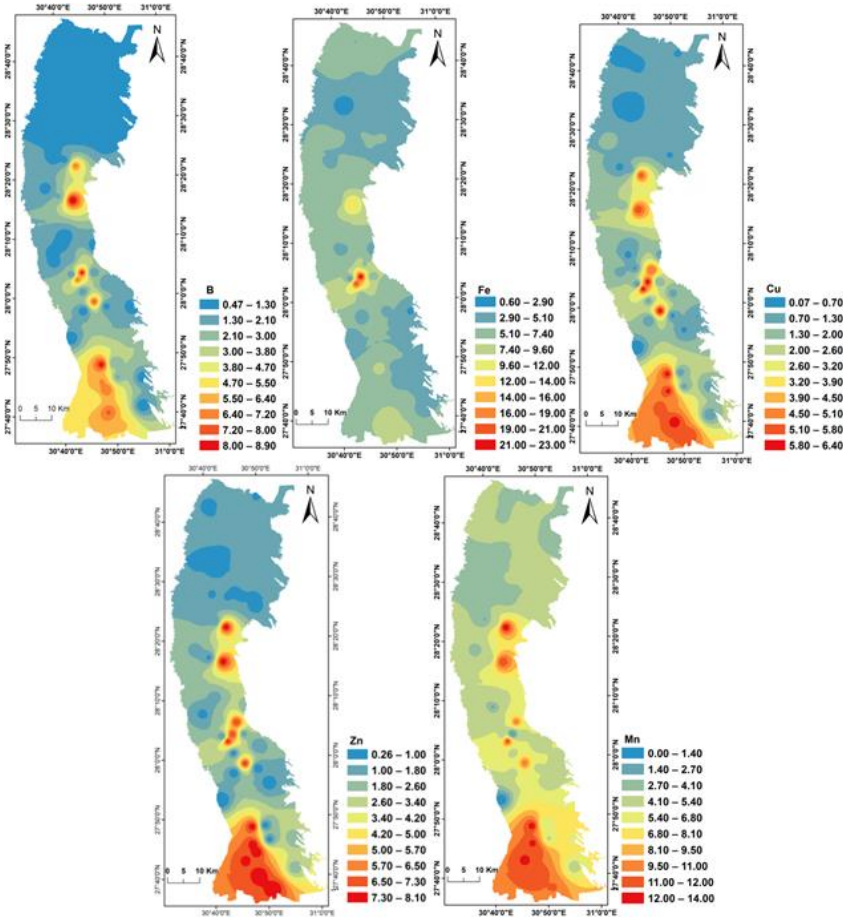


**Fig. 4. Essential traces constituents
(B, Fe, Cu, Zn and Mn) content in upper soil layer.**

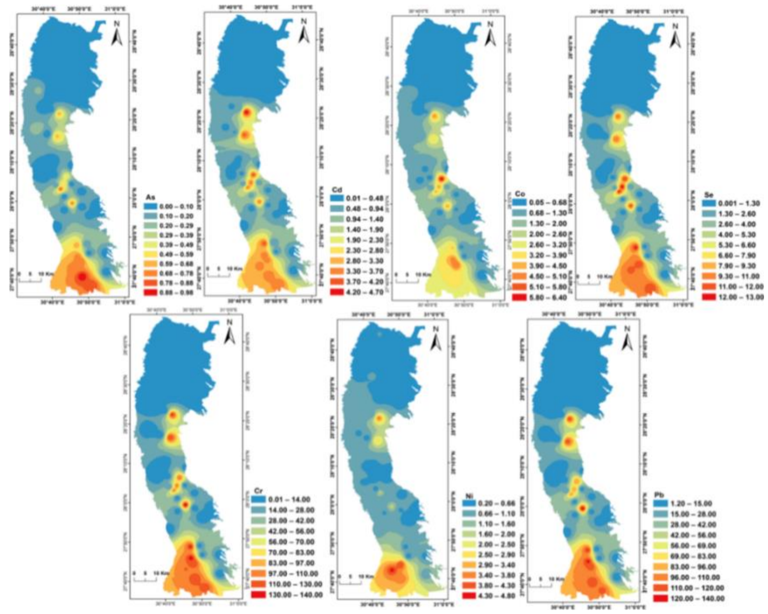


Fig. 5. Toxic heavy elements (As, Cd, Co, Cr, Ni, Pb, Se) content in upper soil layer.

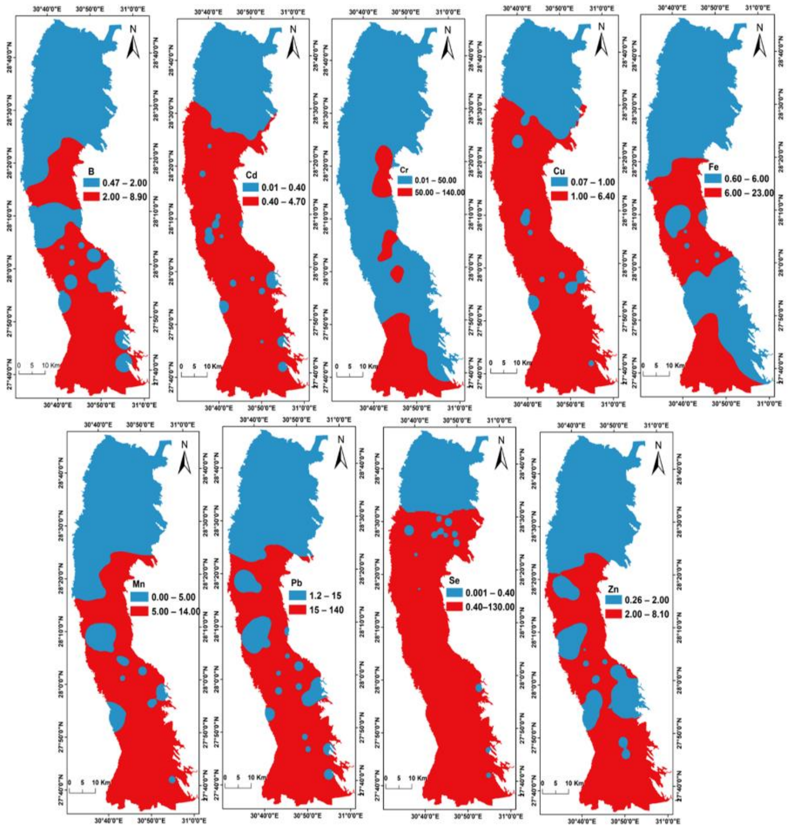


Fig. 6. Map of the toxic heavy metal pollution indices.

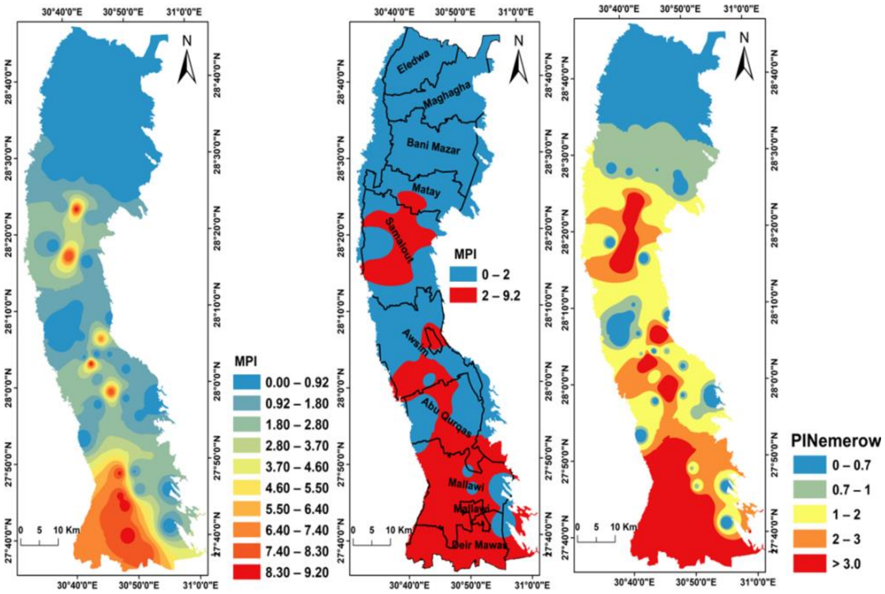


Fig. 7. Map of heavy metal pollution index indicating expected pollution source areas for toxic heavy metal pollution.

The result indicated that concentration of average HMs in the northern farmland were below the background values, which is in agreements with Mohamed et al. [56] and Zaki et al. [57]. All previous studies [56, 57] indicated that mean HMs contents were almost all above the background value. The MPI calculation indicates that the pollutions in the area is not inherent and comes mainly from an outside source, especially flash irrigation and industrial activities. Because of that the high concentrations of HMs content were observed only in the surface soil in all soil profiles.

4. Conclusions

The studied HM spatial distributions were determined with an assessed risk order as follows: Cr > Pb > Fe > Mn > Se > B > Zn > Cu > Co > Ni > Cd > As. This finding are important to whom are concerning with soil treatment of pollutants, in which method should be selected for the treatments processes. Hotspots of contamination were found along the El Moheet drain and in the southern portions of the area. Results of the $PI_{Nemerow}$ equation emphasized the outputs of the MPI equation with a significant correlation, reflecting the impacts of anthropogenic especially farming practices and industrial activities. The obtained model confirms that high concentrations HMs are not derived from parent rock materials (geogenic sources). The identified HMs pollution characteristics through the soil profiles showed a significant decrease in HMs contents with depth confirming the anthropogenic activities in the area. The most affected soils are near the El Moheet drain, therefore more attention and scientific precautions should be taken regarding the flow of the drainage water from Abu Qurqas sugar factory. The results emphasize that investigation of HMs surface soils might be better used for establishing environmental quality to identify the pollution source and to minimize or reduce soil contamination in the study area. This study confirms the need to install filters and water purification systems on the openings of sugar factories in Minia and consequently all the factories on the Nile River and all canals used for irrigation.

Nomenclatures

As	Arsenic
B	Boron
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Cuprum
EC	Electric conductivity, ppm
Fe	Iron
HMs	Heavy metals
K	Potassium
MAC	Maximum allowable concentration
Mn	Magnesium
MPI	Metal pollution index
N	Nitrogen
Ni	Nickel
P	Phosphorous
Pb	Lead
$PI_{Nemerow}$	Nemerow pollution index
SAR	Sodium adsorption ratio, meq/l
Se	Selenium
Zn	Zinc

Abbreviations

GIS	Geographic Information System
GPS	Global Positioning System
WHO	World Health Organization

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