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RESEARCH **Open Access**

Soil characterization and heavy metal pollution assessment in Orabi farms, El Obour, Egypt

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Abstract

Background: Soil pollution negatively impacts on food safety and human health. The main aim of this work is to determine the As, Cd, Cr, Cu, and Pb concentrations in Orabi farms, El Obour city, Egypt. The contamination of soil with these metals was assessed by contamination factors (CF), degree of contamination (DC), pollution load index (PLI), ecological risk factor (Er), potential ecological risk index (PRI), and index of geoaccumulation (I_{geo}). Eleven soil samples were collected from Orabi farms and analyzed for physicochemical characteristics.

Results: The results indicate that Orabi soils are considered alkaline (pH = 8.11), weakly calcareous ($CaCO_3$ = 3.6%), sandy (sand = 90.23%) soils, and non-saline to slightly saline (EC = 4840.68 μS/cm) in nature. In addition, it contains negligible organic matter percent (OM = 3.15%) and so it is classified as mineral soil. The average concentrations of As, Cd, Cr, Cu, and Pb were 147.46, 2.31, 44.50, 4.10, and 13.01 mg/kg, respectively.

Conclusion: The calculated I_{geo}, CF, and Er recorded that investigated soil samples are uncontaminated with Cr, Cu, and Pb, considerably contaminated with Cd, and highly contaminated with As. The calculated integrated pollution indices PRI, PLI, and DC showed that soil samples were contaminated with the studied heavy metals. The high CF values of As and Cd are the main contributor to soil high contamination. The application of fertilizers and other agricultural practice in the study area must be paid attention.

Keywords: Organic matter, Heavy metals, Contamination factor, Pollution load index, Orabi farms

Background

Soil pollution is often thought as a result of chemical contamination. The use of poor quality water and the application of excessive amounts of pesticides and fertilizers can result in soil contamination. As well as waterlogging can lead to soil degradation and yield reduction (Singh 2015; Abdel-Hafiz 2017; Zeid et al. 2018). The soil is classified as contaminated when metal concentrations in its bulk horizons exceed baseline values taken as higher limits for noncontaminated soils (Kabata-pendias and Pendias 2001; Proust et al. 2013). Polluted water and soil pose a serious threat to plants, affecting crops and thus causing health risks by entering the food chain. Soil pollution has negative effects on food safety as well as result in increased health risks (Suresh and Nagesh 2015; Yonglong et al. 2015; Salman et al. 2016a).

The texture as well as physicochemical properties of soils affect its heavy metal contents and control directly or indirectly the nature of reactions that occur on the surfaces of their constituting particles (Manahan 1994; He et al. 2005).

Pollution indices are a powerful tool for environmental quality assessment. The commonly used pollution indices for heavy metals in soils are classified into two types, single and integrated pollution index (Yuan et al. 2004, Qingjie et al. 2008; Hafizur Rahman et al. 2012). In the present study, three single indices, namely index of geoaccumulation (I_{geo}), contamination factor (CF) and ecological risk factor (Er), as well as three integrated indices; degree of contamination (DC), pollution load index (PLI), and potential ecological risk index (PRI) were used. Integrated pollution indices for the studied samples were determined to build a broad overview of

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the extent of contamination of the area by the various heavy metals. It is well known that most of metal and metalloid contamination in the surface environment is associated with all contaminant metals rather than one metal (Chon et al. 1997; Swapnil et al. 2011; Elnazer et al. 2015).

The scope of the present study is to determine the general characteristics of soil (pH, EC, PSDs, $CaCO_3$, and OM) and content of As, Cd, Cr, Cu, and Pb metals. As well as the calculation of different single (I_{geo}, CF, and Er) and integrated (DC, PLI, and PRI) pollution indices to assess soil quality.

Methods

Sampling and methods for physicochemical analysis

Orabi area represents the eastern part of El Obour city that is considered as one of the most important fruits and vegetable farms in Cairo and located on the eastern side of the Nile Delta. The area is bordered by the Cairo-Belbeis road in the west and northwest and the Cairo-Ismailia highway in the south.

Eleven surface soil samples were collected at depths 0–30 cm from different sites in Orabi farms (Fig. 1). The selected samples were collected from the vegetable fields (Fig. 2). Soil samples were transferred to the laboratory of geological sciences department, National Research Centre for analyses. After being air-dried, they were sieved through a 2 mm sieve. Soil pH was measured in 1:1 soil to water ratio. Soil salinity was determined by measuring the electrical conductivity of a solution extracted from a water-saturated soil paste (1:1) (Tam and Wong 1998; Zhang et al. 2003). Calcium carbonate ($CaCO_3$) was estimated by titrimetric method according to USDA (1996). The organic content was determined by Walkley-Black wet combustion method (Walkley 1947; USDA 1996). The hydrometer (ASTM 152H) method was applied for particle-size analysis (Bashour and Sayegh 2007).

For determination of heavy metal concentration, exactly 1 g of pulverized sample was digested with aqua regia ($1HNO_3$: 3HCl) and analyzed for As, Cd, Cr, Cu, and Pb using atomic absorption spectrometer (Perkin elmer 400).

Pollution risk assessment

Single pollution indices

The I_{geo} was computed using the following equation (Muller 1979):

$$I_{geo} = \log_2 \left({C_n} \Big/ {1.5 \times B_n} \right)$$

where C_n is the measured concentration of heavy metals in soil and B_n is the reference values expressed here as worldwide soils average; As = 5, Cd = 0.5, Cr = 54, Cu = 25, and Pb = 25 mg/kg (Kabata-pendias and Mukherjee 2007).

The constant 1.5 is used for the possible variations of the background data due to the lithogenic effects.

The CF is computed using the following equation (Hakanson 1980):

$$\mathrm{CF} = {C_s} \Big/ {C_0}$$

Where C_s is the concentration of metal in the studied sample and C_0 is baseline concentration (mean worldwide soils).

The Er of a given contaminant was suggested by Hakanson (1980) as follows:

$$Er = Tr \times CF$$

where CF is contamination factor and the Tr is "toxic-response" factor for a given metals; As = 10, Cd = 30, Cr = 2, Cu = 5, and Pb = 5 (Hakanson 1980).

Integrated pollution indices

The DC defined as the sum of all contamination factors (Hakanson 1980):

$$DC = \sum\nolimits_1^n CF$$

where CF is the single contamination factor and is the count of the elements present.

The PLI of a single site is the root of number (n) of multiplied together CF values. The formulas applied are as follows (Tomilson et al. 1980):

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots\ldots\ldots \times CF_n)^{1/n}$$

where n is the number of metals studied.

The PRI is defined as the sum of Er (Hakanson 1980):

$$PRI = \sum\nolimits_1^n Er$$

Each index was ranked into several classes as showed in (Table 1).

Results

The results of physicochemical characterization of soils (pH value, conductivity (EC), calcium carbonate content ($CaCO_3$), organic matter (OM)) and particle size distributions (PSDs) are illustrated in (Table 2). The values of international standard limits and summary of descriptive statistics for the elements As, Cd, Cr, Cu, and Pb concentrations in the studied soils are given in (Table 3). Cadmium, chromium, and copper in more than 82% of the samples as well as all lead contents in the studied soil are below the upper critical limit. The calculated

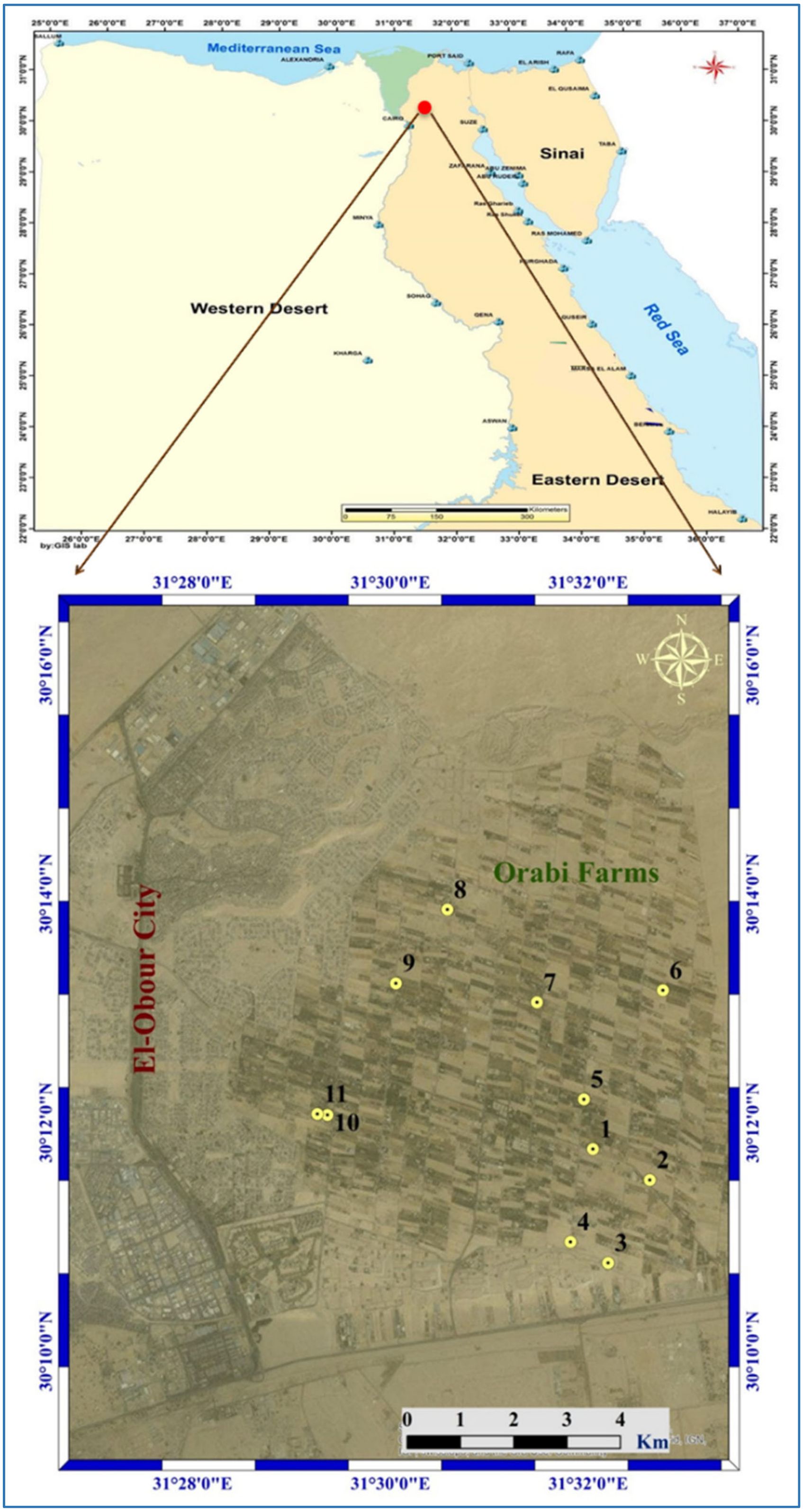

Fig. 1 Location map of the collected soil samples in the study area

Fig. 2 Photographs showing some cultivated vegetables and sandy nature of soil in Orabi farms

Table 1 I_{geo}, CF, Er, DC, PLI, and PRI classes

Index type		Value	Environmental risk grade	Reference
Single indices	I_{geo}	$I_{geo} \leq 0$	Practically uncontaminated	(Muller 1979)
		$0 < I_{geo} \leq 1$	Uncontaminated to moderately contaminated	
		$1 < I_{geo} \leq 2$	Moderately contaminated	
		$2 < I_{geo} \leq 3$	Moderately to heavily contaminated	
		$3 < I_{geo} \leq 4$	Heavily contaminated	
		$4 < I_{geo} \leq 5$	Heavily to extremely contaminated	
		$I_{geo} > 5$	Extremely contaminated	
	CF	$CF < 1$	Low contamination	(Hakanson 1980)
		$1 \leq CF < 3$	Moderate contamination	
		$3 \leq CF < 6$	Considerable contamination	
		$CF \geq 6$	High contamination	
	Er	$Er < 40$	Low potential ecological risk	(Hakanson 1980)
		$40 \leq Er < 80$	Moderate potential ecological risk	
		$80 \leq Er < 160$	Considerable potential ecological risk	
		$160 \leq Er < 320$	High potential ecological risk	
		$Er \geq 320$	Very high ecological risk	
Integrated indices	DC	$DC < 5$	Low contamination	(El-Bady and Samy 2014)
		$5 \leq DC < 10$	Moderate contamination	
		$10 \leq DC < 20$	Considerable contamination	
		$DC \geq 20$	High contamination	
	PLI	$PLI < 1$	Not polluted	(Tomilson et al. 1980)
		$PLI = 1$	Baseline levels of pollutants	
		$PLI > 1$	Polluted	
	PRI	$PRI < 150$	Low contamination	(Hakanson 1980)
		$150 \leq PRI < 300$	Moderate contamination	
		$300 \leq PRI < 600$	Considerable contamination	
		$PRI \geq 600$	High contamination	

Table 2 Summary statistics of physicochemical parameters of soil samples in Orabi area

Parameter	$pH_{1:1}$	EC_{25} µS/cm	$CaCO_3$%	OM%	Grain size analysis		
					Sand%	Silt%	Clay%
Mean	8.11	4840.68	3.6	0.76	90.23	1.35	8.42
Median	8.15	2098.80	3.15	0.50	91.40	0.50	8.10
Mode	8.18	ND	2.25	0.00	91.50	0.50	8.00
SD	0.28	10,382.76	2.25	0.77	5.00	1.31	4.06
Range	1.11	35,550.64	7.65	1.95	14.70	3.70	13.50
Min	7.58	464.4	0.45	BDL	83.50	0.50	1.30
Max	8.69	36,015	8.10	1.95	98.20	4.20	14.80
Q_1	8.02	902.57	2.25	0.09	85.85	0.50	6.75
Q_3	8.20	2744.20	4.50	1.51	92.75	1.50	11.45

SD standard deviation, *Min* minimum, *Max* maximum, *Q1* 1st quartile, *Q3* 3rd quartile, *BDL* below detection limit, *ND* not detected, *OM* organic matter

single and integrated pollution indices are shown in (Table 4).

Discussion

Physiochemical characteristics of soil

The measured pH values for the studied soils vary from 7.58 to 8.69 (Table 2), indicating the alkaline nature of the soil, which may be attributed to carbonate hydrolysis or lack of rainfall environment (Foth 1990). Geologically, the study area is rich in carbonate rock deposits of Marine Miocene deposits (RIGW 1980; Abdel-Hafiz 2017). The studied soil extracts exhibit a wide variation of electric conductivity (salinity), ranging from 464.4 to 36,015 µS/cm.

Richards (1954) has described the general relationship between EC and plant growth (Table 5). Accordingly, the majority investigated soil samples in the study area ranged from non-saline to slightly saline soil. There is one abnormal sample (11) that shows extremely saline soil. The farm owner complained about the lack of soil fertility compared to the adjacent soil (Fig. 3).

Table 3 Summary statistics of heavy metals (mg/kg) compared with the average of worldwide soil

Parameter	As	Cd	Cr	Cu	Pb
Mean	147.46	2.31	44.50	4.10	13.01
Median	147.8	1.9	44.5	4.55	10.8
SD	21.60	1.48	11.89	1.55	4.57
Min.	117.5	1.5	29.05	2	8.65
Max.	182.8	6.75	67.25	6.45	22.5
Q_1	134.5	1.8	36.35	2.825	9.55
Q_3	156.2	2	49.375	5.05	14.95
WSA	5	0.5	54	25	25

WSA world soil average (after Kabata-Pendias and Mukherjee 2007)

According to the UNCCD (2005), the process of soil salinization is due to:

- Excessive utilization of irrigation water.
- Inadequate salt leaching practices.
- Inefficient or impaired drainage conditions.
- Evaporation from the water table, especially when it is within 2 m (waterlogging), significantly contribute to root-zone salinity.

The distribution and amount of carbonates influence soil fertility. The $CaCO_3$ in the studied soil samples varies from 0.45 to 8.1% with an average of 3.6% (Table 2). This indicates that all samples can be considered as weakly calcareous soil except samples (1 and 2) considered as moderately calcareous soil (NSSCC 1965).

Organic matter flocculated between BDL and 1.95% with an average content of 0.76% (Table 2). This low content of OM is referred to the desert nature of the study area and the lake of organic additives into soil.

The result of grain size analysis of soil samples shows that sand is averaging 90.23%, silt averaging 1.35%, and clay averaging 8.42% (Table 2). According to Folk (1974) triangle chart (Fig. 4a), the studied soil samples can be texturally classified as two groups, namely, sand (seven samples) and clayey sand (four samples). On the other hand, it divides into three main groups based on USDA system Soil Survey Staff (1993); sandy loam (one sample), loamy sand (three samples), and sand (seven samples) (Fig. 4b).

Heavy metals

The soil may be contaminated by the accumulation of toxic metals through emissions from the industrial activities, land application of fertilizers, pesticides, spillage of

Table 4 Summary statistics of I_{geo}, CF, Er, DC, PLI, and PRI for the determined elements

Parameter	Single indices															Integrated indices		
	I_{geo}					CF					Er							
	As	Cd	Cr	Cu	Pb	As	Cd	Cr	Cu	Pb	As	Cd	Cr	Cu	Pb	DC	PLI	PRI
Mean	4.28	1.48	− 0.9	− 3.3	− 1.6	29.5	4.6	0.8	0.2	0.5	295	139	1.6	0.8	2.6	35.6	1.52	438.5
Median	4.30	1.34	− 0.9	− 3.0	− 1.8	29.6	3.8	0.8	0.2	0.4	296	114	1.6	0.9	2.2	34.8	1.40	406.6
SD	0.21	0.58	0.4	0.6	0.5	4.3	3.0	0.2	0.1	0.2	43	89	0.4	0.3	0.9	6.6	0.33	118.8
Range	0.64	2.17	1.2	1.7	1.4	13.1	10.5	0.7	0.2	0.6	131	315	1.4	0.9	2.8	24.0	1.15	447.7
Min	3.97	1.00	− 1.5	− 4.2	− 2.1	23.5	3.0	0.5	0.1	0.3	235	90	1.1	0.4	1.7	28.0	1.25	330.1
Max	4.61	3.17	− 0.3	− 2.5	− 0.7	36.6	13.5	1.2	0.3	0.9	366	405	2.5	1.3	4.5	52.0	2.40	777.8
Q_1	4.16	1.26	− 1.2	− 3.7	− 2.0	26.9	3.6	0.7	0.1	0.4	269	108	1.3	0.6	1.9	32.1	1.32	388.9
Q_3	4.38	1.41	− 0.7	− 2.9	− 1.3	31.2	4.0	0.9	0.2	0.6	312	120	1.8	1.0	3.0	36.5	1.60	428.4

petrochemicals, wastewater irrigation, and atmospheric deposition (Khan et al. 2008; Zhang et al. 2010). Increasing levels of soil contamination with heavy metals may be transformed and transported to plant and from plants pass into animals and human (Atayese et al. 2010).

Arsenic is widely distributed in the environment. The studied soil samples contain a significant content of As ranging from 117.5 to 182.8 mg/kg with an average of 147.46 mg/kg (Table 3). This content is higher than the world soil As content (5 mg/kg, Kabata-Pendias and Mukherjee 2007).

Arsenic was known for its toxic effects on plants and animals. When plants were exposed to excess arsenic either in soil or in solution culture, they exhibited toxicity symptoms such as inhibition of seed germination, decrease in plant height, depress in tillering, reduction in root growth, decrease in shoot growth, lower fruit and grain yield, and sometimes leads to death (Marin et al. 1992; Carbonell-Barrachina et al. 1995; Kang et al. 1996; Abedin et al. 2002; Jahan et al. 2003; Rahman et al. 2004). Arsenic becomes part of the human solid food chain when products and fodder become contaminated. The most prominent chronic arsenic manifestations involve the skin, lungs, liver, and blood systems (Saha et al. 1999). The significant difference between Q1 and Q3 (Fig. 5) suggests that its content is controlled by several intermixed processes, including the natural and anthropogenic, probably due to the special planting methods (Abdel-Hafiz 2017), because the sample with the high arsenic concentration was collected from an orchard farm. The application of pesticides and herbicides in orchard soils is intended to hinder insect pests and defoliation. This use increases the arsenic concentrations in the soil (De Gregori et al. 2003). Furthermore, As perhaps came from the rocks in the Eastern Desert during soil transportation and formation, where some serpentine rocks contain up to 75 mg/kg of As (Sadek et al. 2015).

The studied soil samples contain a significant content of Cadmium ranging from 1.5 to 6.75 mg/kg with an average of 2.31 mg/kg (Table 3). This content exceeds the average world soil (0.5 mg/kg, Kabata-Pendias and Mukherjee 2007). The close difference between Q1 and Q3 (Fig. 5) points to the uniform source and distribution of Cd in soil; this may be attributed to the application of P-fertilizers

Table 5 Salinity ratings for soil based on electric conductivity

Rating	EC (μS/cm)	Effect on plants
Non-saline	0–2000	Salinity effects are mostly negligible
Slightly saline	2000–4000	Yields of very sensitive crops may be restricted
Moderately saline	4000–8000	Yields of many crops restricted
Highly saline	8000–16,000	Only tolerant crops yield satisfactory
Extremely saline	> 16,000	Only a few very salt-tolerant crops yield satisfactory

Fig. 3 Location of high salinity soil (S. No. 11)

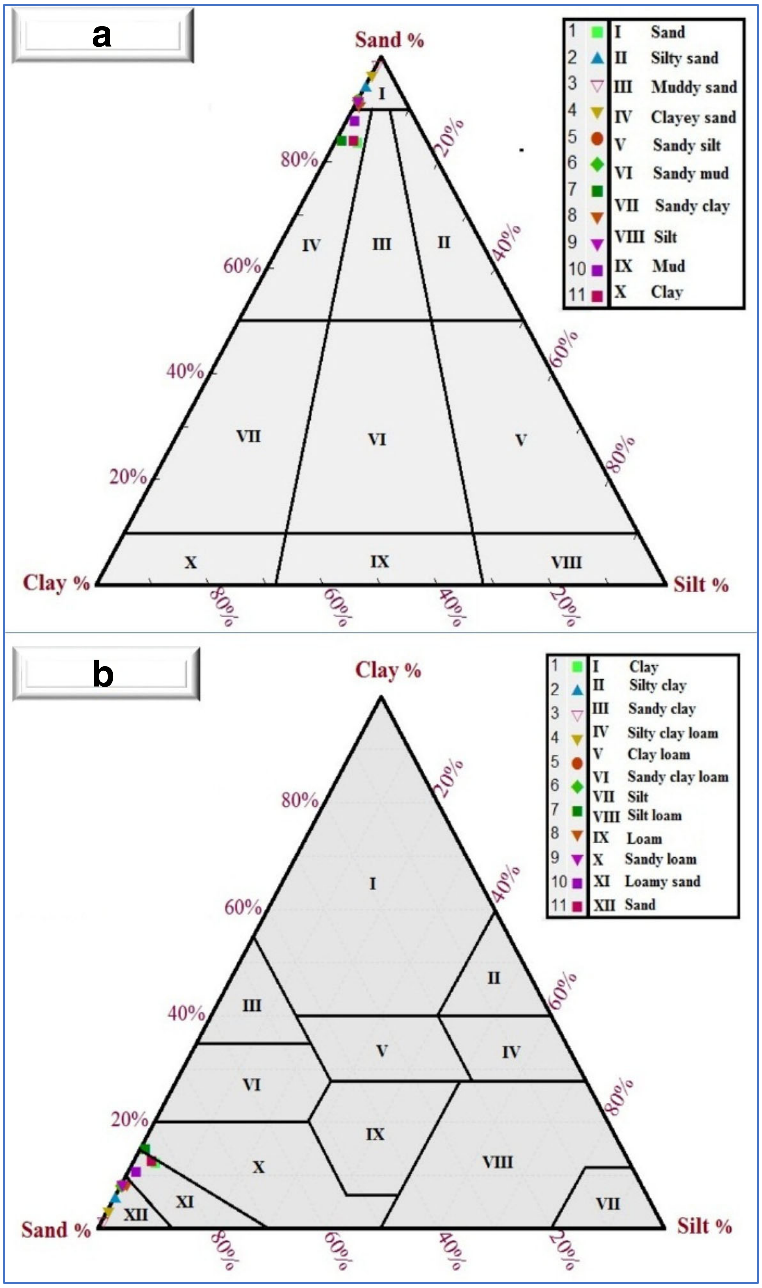

Fig. 4 Folk (**a**) and USDA (**b**) triangle diagrams of soil classification

which contains a considerable concentration of Cd, about 12.45 mg/kg (Kabata-Pendias and Mukherjee 2007; Salman et al. 2016b). In addition, the adjacent ways may be contributed greatly to the pollution of soil with Cd (Elnazer et al. 2015).

Chromium is one of the known environmental toxic pollutants in the world. The measured Cr content in soil ranges from 29.05 to 67.25 mg/kg with an average value of 44.5 mg/kg (Table 3). Of all analyzed samples, 81.8% contain chromium level below the reported worldwide in surface soils of 54 mg/kg (Kabata-Pendias and Pendias 2001). The relatively close difference between Q1 and Q3 (Fig. 5) implies that the anthropogenic process is the main controlling factors in its distribution.

Copper is an essential micronutrient to nearly all higher plants and animals; in addition, it is an essential metal for crop plants. Total copper content in the examined soil ranges from 2 to 6.45 mg/kg with an

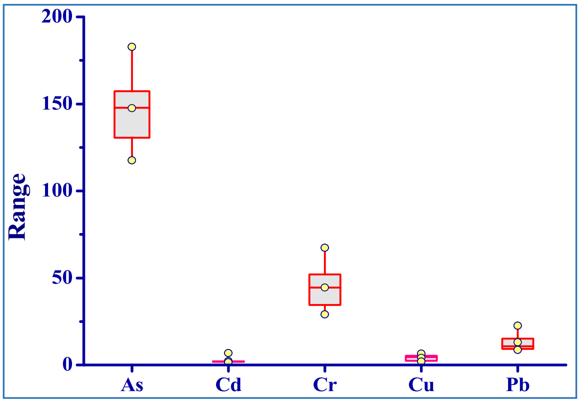

Fig. 5 Box-whisker graph showing soil heavy metals

average 4.1 mg/kg. All the investigated samples recorded Cu values are below maximum allowable concentration of 25 mg/kg (Kabata-Pendias and Mukherjee 2007) (Table 3).

The measured lead content in soil ranges from 8.65 to 22.5 mg/kg with an average value of 13.01 mg/kg. All the samples analyzed contain lead level lower than MAC.

The distribution patterns for heavy metals in the studied soil samples (for example Cd and As) show the highest concentration at the southeastern part (appears in sample 1) (Fig. 6) as a result of replacing the top 1.5 m of original soil in this location with other soil.

Pollution risk assessment

Single pollution indices

The calculated geoaccumulation index for the studied samples is illustrated in (Table 4 and Fig. 7a). The I_{geo} of Cr, Cu, and Pb showed no pollution. While the majority of soil samples (nine samples) are moderately contaminated with Cd. Moreover, the obtained I_{geo} revealed that most of the samples (nine samples) considers heavily to extremely contaminated with As.

The calculated contamination factor (Table 4 and Fig. 7b) indicates that all the soil samples are highly polluted with As ($CF > 6$). The CF of Cd showed considerable contamination in all samples except one sample considered high contamination. The CF of Cu and Pb in all samples showed low contaminated. Furthermore, the CF of Cr showed the majority of samples (eight samples) are low contamination, while it is moderately contaminated in three samples.

The calculated ecological risk (Table 4 and Fig. 7c) indicates that nearly all the soil samples have a high ecological risk with respect to As except samples (1 and 3) represented as very high ecological risk. In addition, the Er of Cd of indicates that nearly all samples are at considerable ecological risk except one sample has a very high ecological risk. Like I_{geo}, the Er of Cr, Cu, and Pb indicates that the samples are at low ecological risk.

Integrated pollution indices

According to the DC values (Table 4 and Fig. 8), all samples are at high contamination degree. High values of CF for As and Cd reported from soil samples are the main reason for the wide band of high contamination category in the study area.

PLI is presented in (Table 4 and Fig. 8). The results of pollution load index were found to be high ($PLI > 1$) in all the investigated samples. This indicates the high load of heavy metals in the studied soil samples. The PLI values for all samples are less than 1 indicating the role of external discrete sources, vehicle exhaust, and agricultural activities of soil pollution (Elnazer et al. 2015). These results indicate probable environmental pollution especially with hazards As and Cd.

PRI calculation results of samples (Table 4 and Fig. 8) showed considerable ecological risk except one sample no. (1) which showed very high ecological risk. The ecological risk comes mainly from soil pollution with As and Cd. These two metals have the adverse impact on both the plants and human health and much attention must be paid to the study area quality.

Conclusion

As a result of this study, it was found that the studied soils are of alkaline nature, non-saline to slightly saline, and weakly calcareous soils. Regarding the textural characteristics, the Orabi soils are sand and clayey sand according to folk system, whereas based on the USDA system, it is sand, sandy loam, and loamy sand. Concentrations of arsenic and cadmium are above maximum allowable limits. While Pb, Cr, and Cu in more than 82% are below the upper critical limit. For single pollution indices, investigated soil samples were uncontaminated with Cr, Cu, and Pb; moreover, considerably contaminated with Cd and highly contaminated with As. The calculated integrated pollution indices showed that investigated soil samples were varied from considerable contamination according to potential ecological risk index (PRI) values to high contaminated pattern according to pollution load index (PLI) and contamination degree (DC) results.

These results play an important role in order to determine soil quality and it can help the local authorities to take an action in term of remediation purposes. High values of CF for arsenic and cadmium reported from soil samples are mainly responsible for the wide band of high contamination category in the study area. Thus, increased contents of arsenic in agricultural soils have become a real problem.

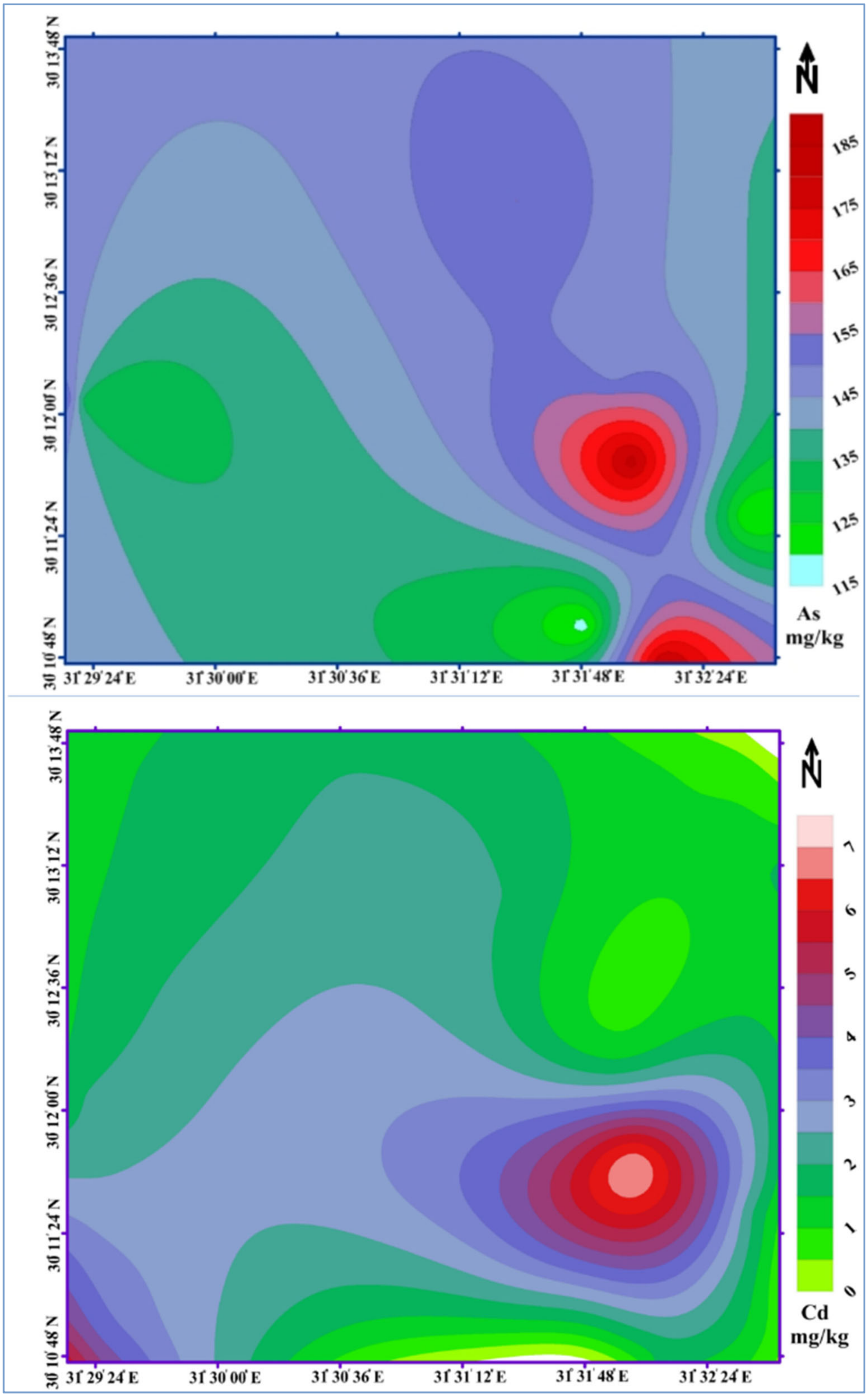

Fig. 6 Spatial distribution of cadmium and lead contents in Orabi soil

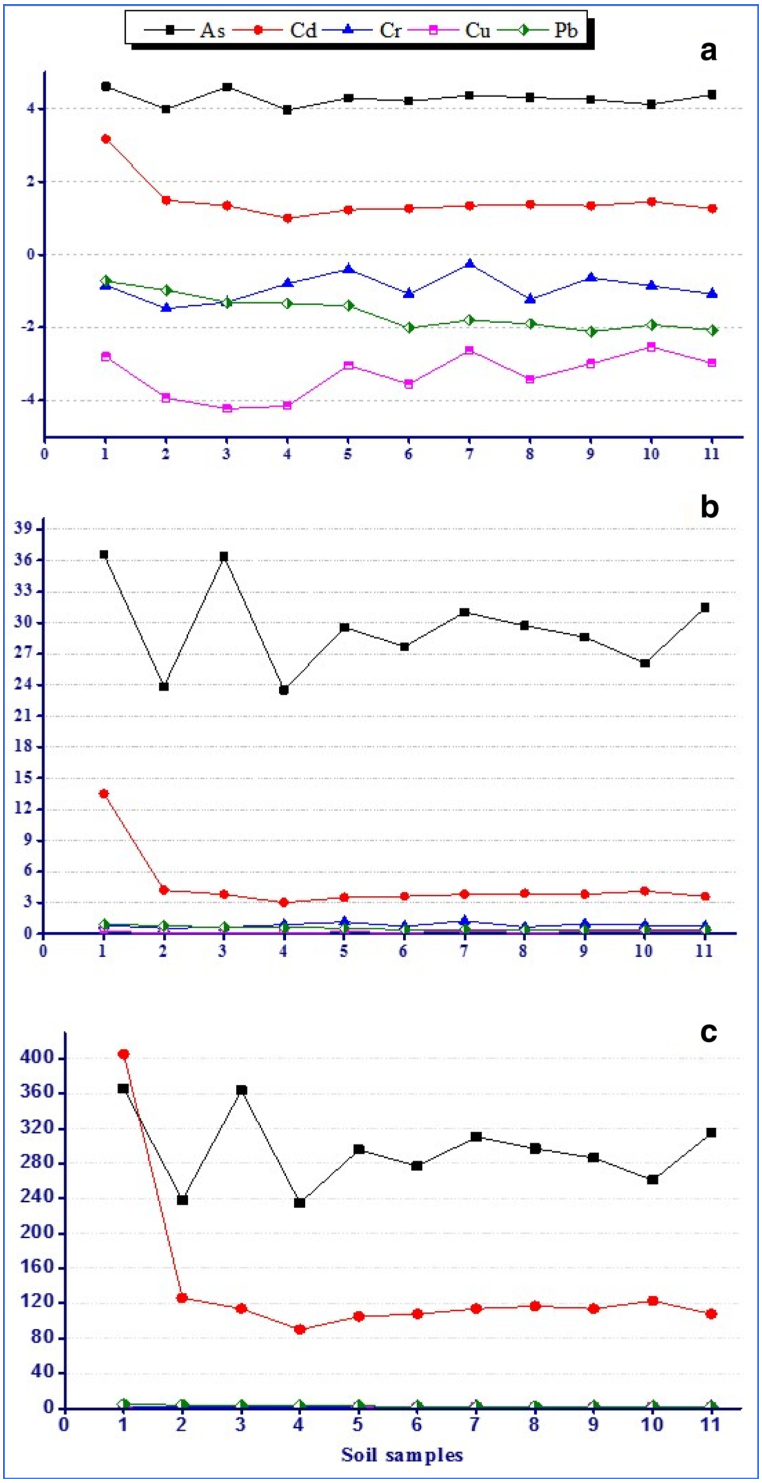

Fig. 7 Variation of As, Cd, Cr, Cu, and Pb I_{geo} (**a**), CF (**b**), and Er (**c**) in Orabi farms

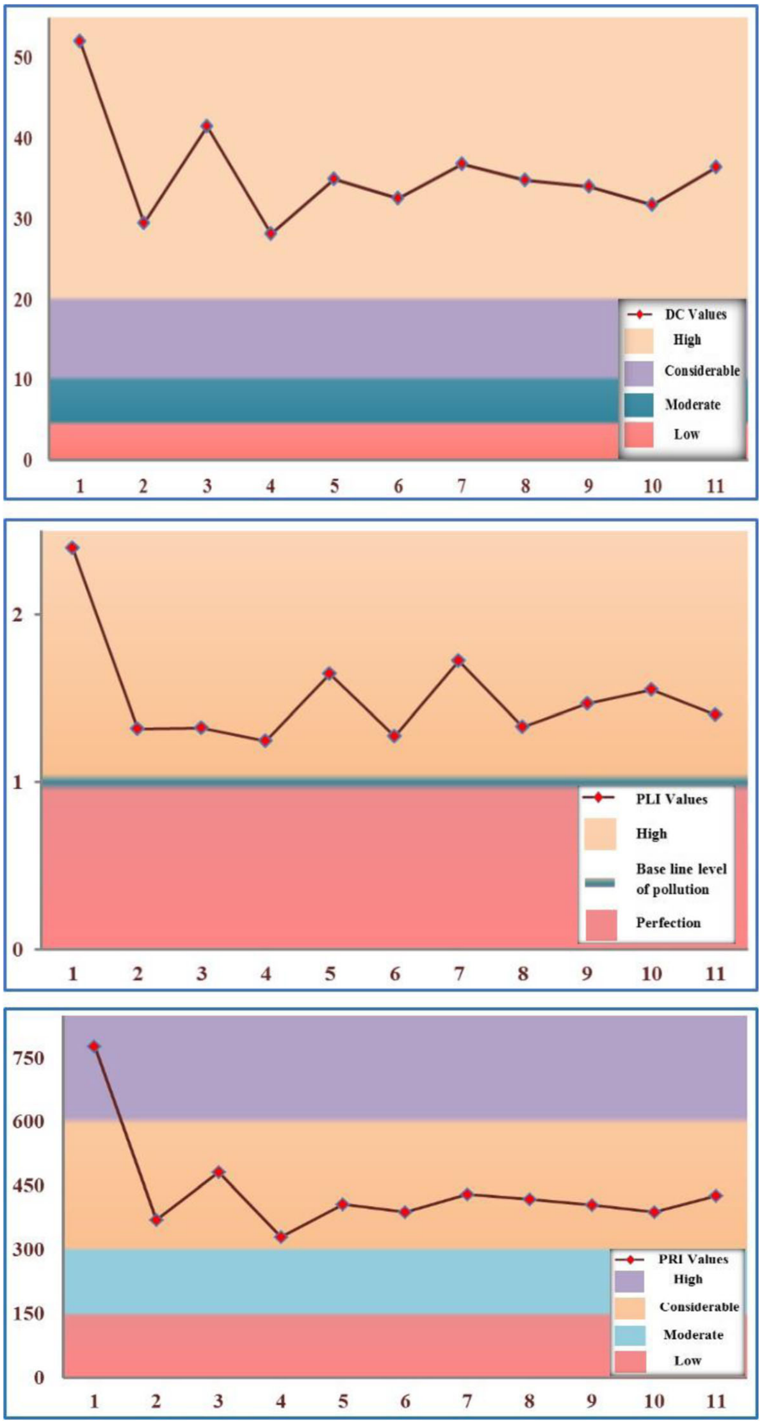

Fig. 8 DC, PLI, and PRI variations in Orabi farms

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