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Evaluation of heavy metal mobility in contaminated soils between Abu Qurqas and Dyer Mawas Area, El Minya Governorate, Upper Egypt

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Abstract

Background: Heavy metals have dangerous effect on the biota. So, this work aimed to determine the mobility and bioavailability of these metals through the application of pollution indices and geochemical fractionation technique. Thirty-one topsoil samples (20 cm) were collected from the area between Abu Qurqas and Dyer Mawas, El Minya Governorate, and subjected to chemical analysis.

Results: The results revealed that Cd and As are mainly associated with carbonate fraction while Cr, Pb, Ni, and Cu are more present in the residual fraction. The relative amounts of easily dissolved phase of heavy metals in the soils are in the order of As > Cd > Cr > Pb > Ni > Cu.

Conclusion: The results revealed that As, Cd, and Cr have high mobility and risks more than Pb, Ni, and Cu metals in the studied soils. As, Cd, and Cr were the heavy metals that caused pollutants in the soils of the studied area.

Keywords: Soil, Heavy metals, Pollution, Contaminants, Speciation, Sequential extraction, Mobility, Risk

Introduction

Metal contamination of soil is an important concern to human and environmental health worldwide. The potential toxicity of heavy metals in soil is a function of their mobility and bioavailability. Metal mobility is depending on the phase in which the metal occurs as well as physical and chemical processes that control transformations between phases. Some heavy metals cause damage to the nervous system and internal organs as well as carcinogenic effects (Lee et al. 2007; Maas et al. 2010). One of the most critical properties of these metals that distinguish them from other contaminants is their persistence and non-biodegradability in the environment (Ghaderi et al. 2012; Yang et al. 2012).

Heavy metals in soils are derived from natural sources such as weathering of rock, volcanoes, and forest fires as well as anthropogenic activities such as the industrial

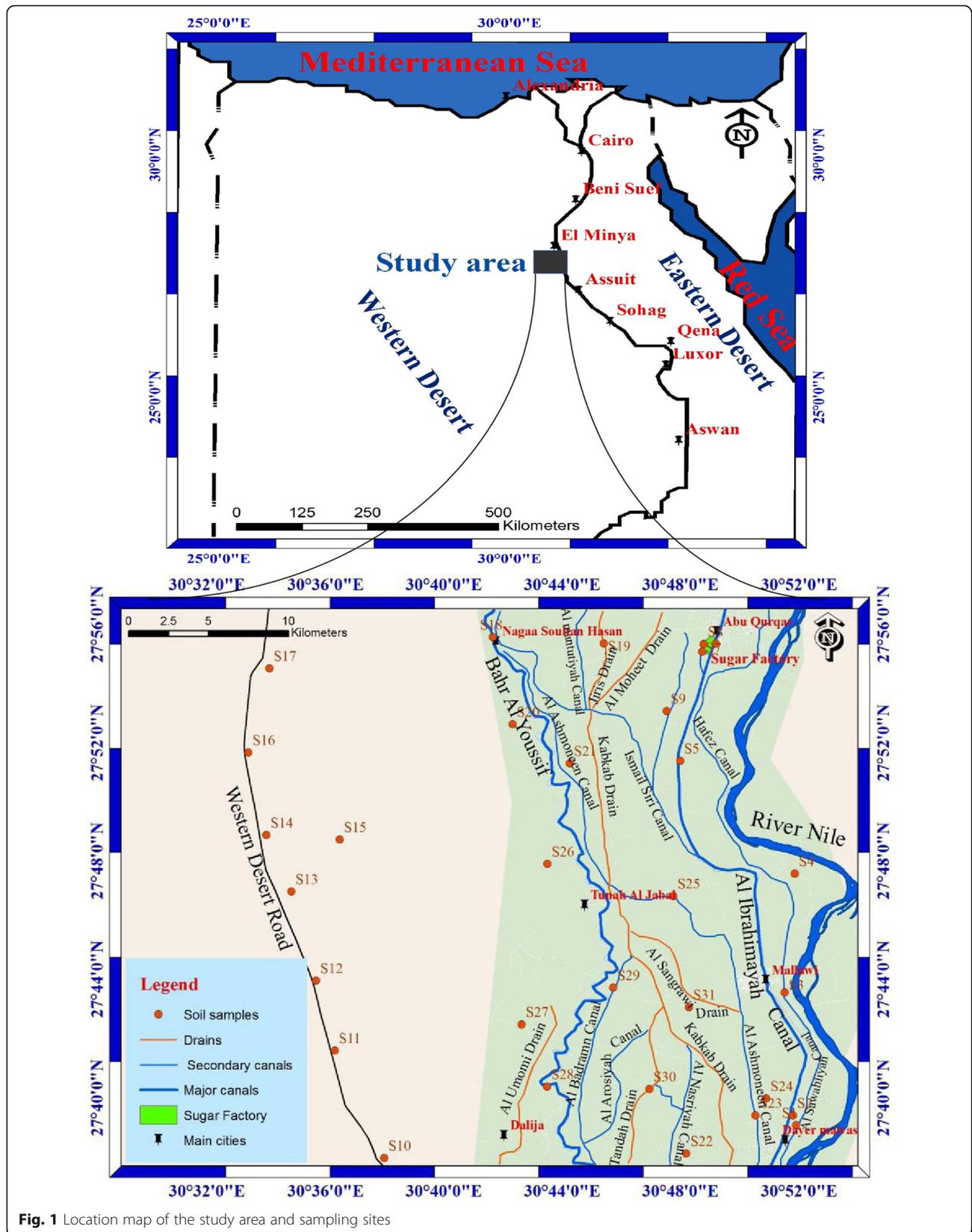
effluent, fertilizers, atmospheric deposition, traffic, agricultural drainage, and phosphate industry (Ghaderi et al. 2012; Wali et al. 2013).

Several studies have estimated the total metal contents in polluted and unpolluted soils (Vega et al. 2004; Covelo et al. 2007; Kierczak et al. 2008; Maas et al. 2010; Nemati et al. 2011; Wali et al. 2013, Mohamed et al. 2015, Elnazer et al. 2015; Salman et al. 2016; Salman et al. 2018; Said et al. 2019). However, the total contents of trace metals cannot give enough information about their various forms, mobility, bioavailability, or potential risks to the environment (Davutluoglu et al. 2011; Nemati et al. 2011). In contrast, the speciation analysis for metals in soil can give a good indicator of the ecosystem quality. Metals may be present in soil in several physico-chemical phases, including soluble or exchangeable, bound to amorphous material (Fe/Mn oxides), bound to organic matter, sulfides, and bound to mineral fractions (residual) (Rauret et al. 1999; Zemberyova et al. 2006; Perez-Lopez et al. 2010 and Nemati et al. 2011). The mobility and bioavailability of trace metals are highly

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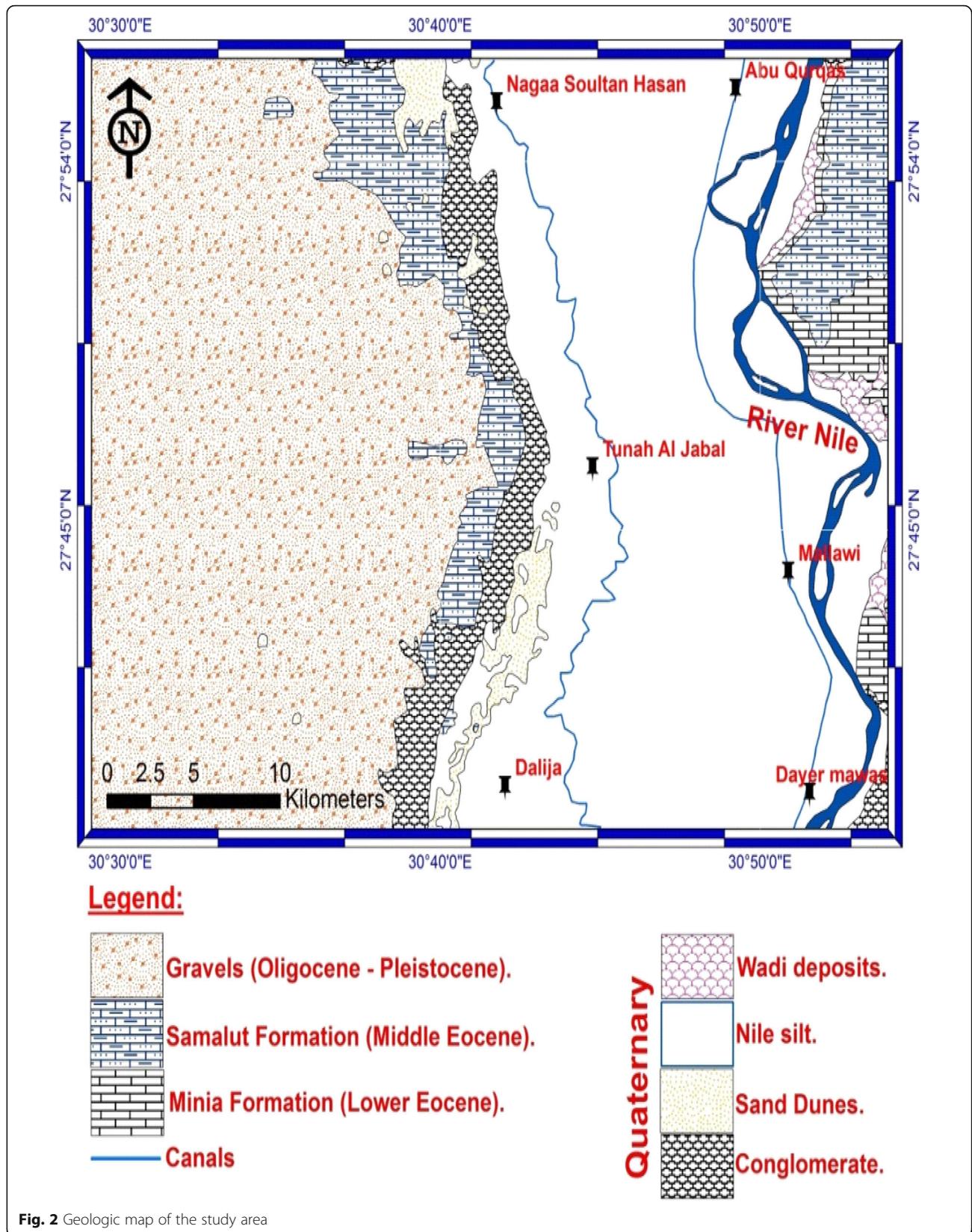


Fig. 2 Geologic map of the study area

dependent on their specific chemical forms or behavior of binding to each soil phase. Sequential extraction procedures have recently been developed to detect the speciation of heavy metals in soil matrix; these procedures provide more information on the origin, physicochemical availabilities, mobilization, and transport of trace metals in natural environments (Kierczak et al. 2008; Rao et al. 2010; Nemati et al. 2011; Aiju et al. 2012).

In case of plants, free metal ions in the soil solution may be more toxic than metals in the complex states (Gupta and Sinha 2006). Accordingly, only the labile metal species (soluble, exchangeable, and chelated) are available to plants. Thus, the detection of total concentrations must be complemented by evaluating available fractions of metals (Buccolieri et al. 2010). The specific objective of this work was the determination of the mobility and bioavailability of heavy metals (As, Cd, Cr, Pb, Ni, and Cu) through the application of pollution indices and geochemical fractionation technique.

Location

The study area occupied the middle part of the Nile Valley between longitudes 30° 29' and 30° 54' E and latitudes 27° 37' and 27° 56' N (Fig. 1) between Abu Qurqas and Dyer Mawas Area, El Minya Governorate. The stratigraphic succession in El Minya Area is represented by Tertiary and Quaternary sedimentary rocks. The distribution of the different rock units was indicated in Said (1981). The stratigraphic sequence is built up from base to top as follows: Middle Eocene limestone intercalated with shale (Samalut Formation); Pliocene undifferentiated sands, clays, and conglomerates; Plio-Pleistocene sand and gravel with clay and

Table 1 Classification of enrichment factor (EF) and geoaccumulation indices (I_{geo})

EF values	Class of EF	
< 2	Depletion to minimal enrichment	
2–5	Moderate enrichment	
5–20	Significant enrichment	
20–40	Very high enrichment	
> 40	Extremely high enrichment	
Grade	I_{geo} values	Soil quality
0	< 0	Practically unpolluted
1	0–1	Unpolluted to moderately polluted
2	1–2	Moderately polluted
3	2–3	Moderately polluted to heavily polluted
4	3–4	Heavily polluted
5	4–5	Heavily polluted to extremely polluted
6	> 5	Extremely polluted

Table 2 Heavy metal content in the studied soil samples (ppm)

Sample no.	Cd	As	Cr	Pb	Ni	Cu
Min.	0.35	ND	89	ND	18	35
Max.	2.60	140	260	300	170	140
Mean	1.19	27	182	54	111	92
MAC	1–5	1–10	50–200	20–300	20–60	60–150

ND not detected, MAC maximum allowable concentration (after Kabata-Pendias and Mukherjee 2007)

Table 3 Enrichment factor (EF) and geoaccumulation index (I_{geo}) of heavy metals in soil samples

Sample no.	EF					I_{geo}				
	As	Cr	Pb	Ni	Cu	As	Cr	Pb	Ni	Cu
S ₁	16.53	2.60	9.92	5.26	5.97	3.74	1.07	3.00	2.08	2.27
S ₂	0.00	3.76	0.00	4.26	5.20	–	1.68	–	1.86	2.15
S ₃	1.56	2.60	2.19	4.61	5.64	0.42	1.15	0.90	1.98	2.27
S ₄	0.85	3.01	1.60	4.71	3.86	–0.39	1.44	0.53	2.08	1.80
S ₅	1.12	2.75	0.97	4.26	4.16	–0.07	1.23	–0.27	1.86	1.83
S ₆	1.44	2.54	1.59	4.59	4.00	0.42	1.23	0.55	2.08	1.89
S ₇	5.51	2.97	3.53	5.11	6.24	2.19	1.30	1.55	2.08	2.37
S ₈	3.54	3.21	2.12	5.26	6.43	1.51	1.37	0.77	2.08	2.37
S ₉	3.46	2.75	2.47	5.32	4.34	1.56	1.23	1.07	2.18	1.89
S ₁₀	0.24	0.20	0.00	0.28	0.23	0.86	0.57	–	1.06	0.83
S ₁₁	0.32	0.16	0.13	0.18	0.22	1.82	0.79	0.50	0.98	1.31
S ₁₂	0.19	0.20	0.09	0.19	0.20	0.86	0.98	–0.14	0.89	0.95
S ₁₃	0.17	0.14	0.04	0.17	0.10	1.65	1.37	–0.42	1.60	0.89
S ₁₄	0.00	0.30	0.00	0.38	0.35	–	0.57	–	0.93	0.80
S ₁₅	0.14	0.13	0.09	0.12	0.12	1.07	0.98	0.42	0.91	0.92
S ₁₆	0.00	0.31	0.00	0.36	0.20	–	0.98	–	1.22	0.37
S ₁₇	0.43	0.24	0.26	0.30	0.36	1.31	0.44	0.58	0.79	1.03
S ₁₈	0.00	2.73	0.00	3.95	5.20	–	1.44	–	1.98	2.37
S ₁₉	1.95	2.68	0.96	4.74	4.46	0.70	1.15	–0.32	1.98	1.89
S ₂₀	3.79	2.75	2.97	4.61	4.12	1.70	1.23	1.34	1.98	1.81
S ₂₁	0.00	3.04	0.00	4.61	4.34	–	1.37	–	1.98	1.89
S ₂₂	2.36	2.75	0.93	4.51	5.97	0.93	1.15	–0.42	2.18	2.27
S ₂₃	3.44	2.97	1.99	5.47	4.91	1.51	1.30	0.73	2.08	2.03
S ₂₄	1.69	2.60	0.80	4.71	4.11	0.61	1.23	–0.47	2.36	1.89
S ₂₅	4.37	3.21	2.48	6.39	4.59	1.82	1.37	1.00	1.51	1.89
S ₂₆	0.08	0.11	0.08	0.12	0.07	0.93	1.44	0.86	1.74	0.83
S ₂₇	0.31	0.17	0.18	0.52	0.25	1.00	0.14	0.20	–0.87	0.70
S ₂₈	0.96	2.23	0.48	0.55	4.09	–0.07	1.15	–1.06	1.86	2.03
S ₂₉	0.00	2.95	0.00	4.14	3.80	–	1.37	–	1.86	1.74
S ₃₀	2.75	2.82	0.90	4.38	5.80	1.19	1.23	–0.42	2.08	2.27
S ₃₁	10.27	2.91	1.92	5.26	4.32	3.05	1.23	0.63	2.18	1.80
Average	2.18	1.99	1.25	3.20	3.34	–	–	–	–	–

Table 4 Cadmium fractionation results (ppm)

Samples	Ex	Ct	Ob	FM	Rd
S ₁	0.08	1.63	0.25	0.21	0.38
S ₇	0.08	0.96	0.32	0.28	0.36
S ₈	0.18	0.62	0.31	0.22	0.53
S ₉	0.05	0.69	0.14	0.09	0.19
S ₂₅	0.04	0.65	0.12	0.07	0.11
S ₃₁	0.03	0.45	0.19	ND	0.13
Mean	0.08	0.83	0.22	0.14	0.28

Ex exchangeable fraction, Ct carbonate-bound fraction, Ob organic matter-bound fraction, FM Fe-Mn oxide-bound fraction, Rd residual fraction

shale lenses; Pleistocene sand and gravel with clay lenses; and Holocene silt and clay (Fig. 2); the main economy of the study area is based on agricultural and agro-industrial activities. The cultivated areas are represented by two plains, the older alluvial plain (reclaimed land) and the younger alluvial plain (agriculture soil) which originated from the Ethiopian Plateau (Abd Elsanad 2010).

Material and methods

In November 2014, 31 surface soil samples (20 cm) have been collected from the study area (Fig. 1); the samples were air-dried, crushed, passed through a 2-mm sieve, and stored at ambient temperature. Afterwards, the coning and quartering method was used to obtain representative sub-samples; each quarter was thoroughly homogenized, and about 50 g was milled to a diameter of < 0.01 mm and another 50 g to a diameter of < 63 μm for further analysis. Afterwards, 1 g of soil was digested with aqua regia (3:1 HCl:HNO₃) and analyzed for heavy metals. Enrichment factor (EF) was used to assess the accumulation or leaching processes of heavy metals in soils for the detection of their behaviors. It may be determined by comparing concentrations of certain heavy metal with a reference element (Kabata-Pendias and Pendias 2001). This factor has been calculated from the following equation according to Buat-Menerd and Chesselt (1979). According to the equation, $EF = (E_s/E_{background}) / (R_s/R_{background})$, where E_s is the content of the element in the soil, $E_{background}$ is the content of the same element in soils worldwide, R_s

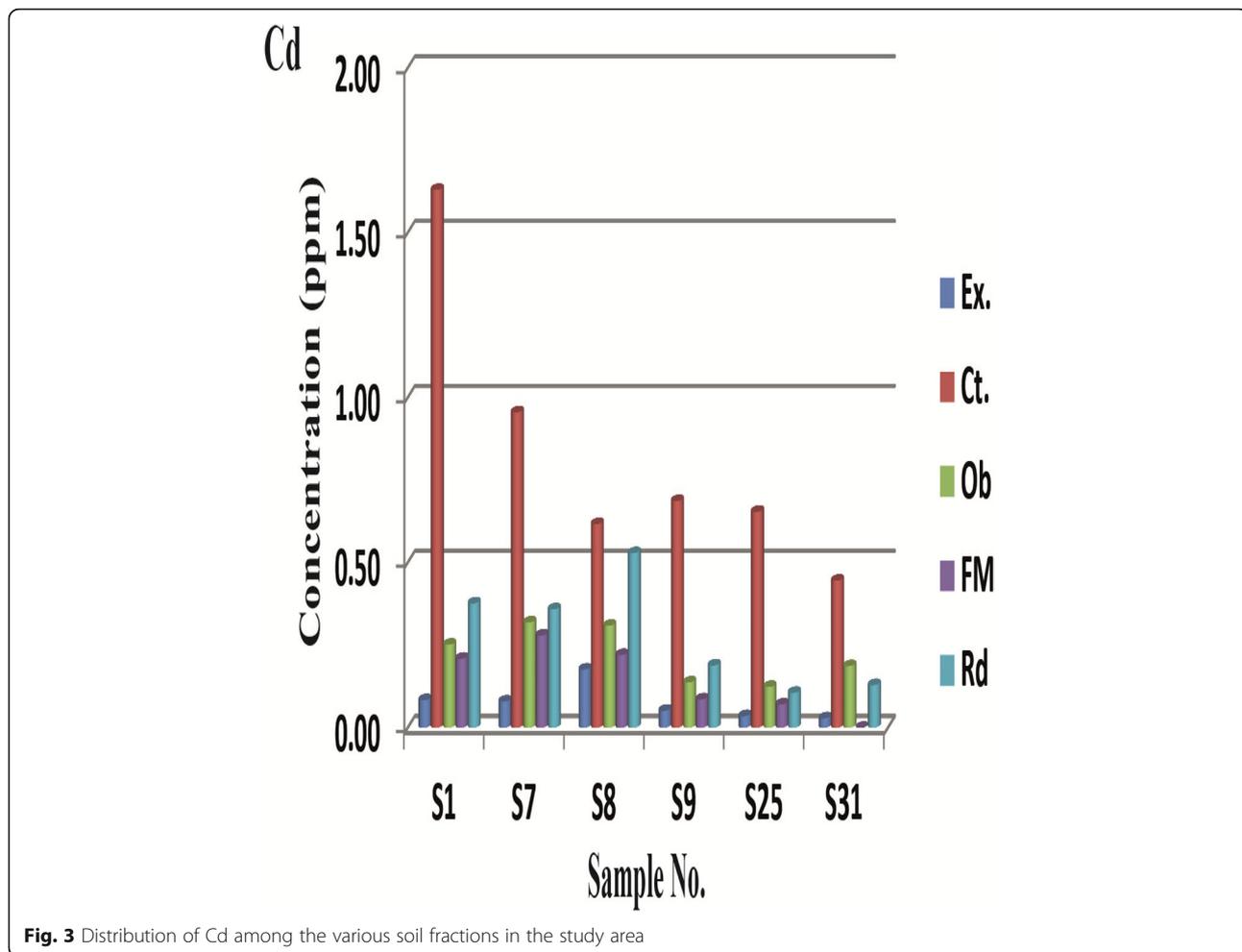


Fig. 3 Distribution of Cd among the various soil fractions in the study area

Table 5 Arsenic fractionation results (ppm)

Samples	Ex	Ct	Ob	FM	Rd
S ₁	ND	126	ND	ND	ND
S ₇	ND	43.20	ND	ND	ND
S ₈	ND	27	ND	ND	ND
S ₉	ND	27.90	ND	ND	ND
S ₂₅	ND	33.30	ND	ND	ND
S ₃₁	ND	78.30	ND	ND	ND
Mean	ND	55.95	ND	ND	ND

is the content of the reference metal in the soil, and $R_{background}$ is the content of the same reference element in soils worldwide.

Geoaccumulation (I_{geo}) index was applied to assess the pollution of metals in the soil. The geoaccumulation index (I_{geo}) is defined by the equation of Muller (1979): $I_{geo} = \text{Log}_2 (C_n/1.5B_n)$, where C_n is the measured concentration in soil sample and B_n is the background concentration of the metals in soils worldwide (Kabata-Pendias and Pendias 2001). The classes of soils according to EF and I_{geo} are illustrated in Table 1.

The contaminated soils were subjected to sequential extraction method which was described previously by Tessier et al. (1979) and modified after by Phuong (2008); this method is based on the partitioning of particular metal traces of 1 g of soil which was

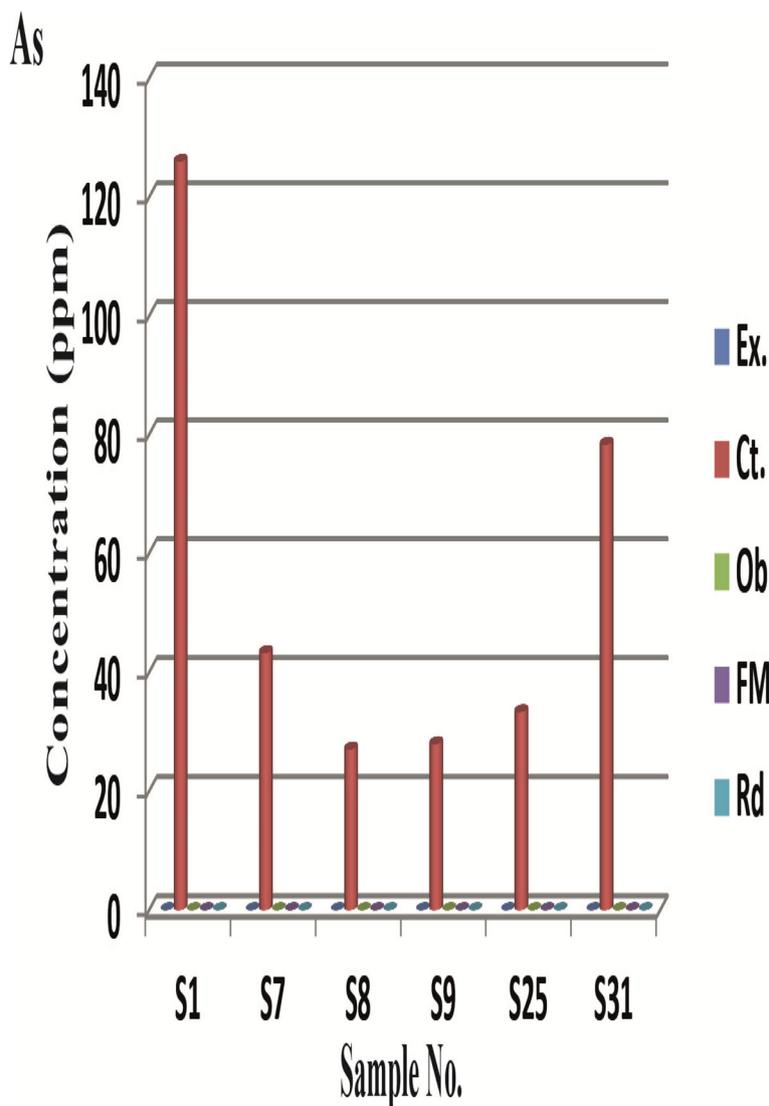


Fig. 4 Relative distribution of As among the various soil fractions in the study area

attacked by 25 mL of 1 M $\text{CH}_3\text{COONH}_4$ at a pH of 7 in 50 mL centrifugation tubes in order to liberate exchangeable fractions; metals associated and bound to carbonate phases have been solubilized using 25 mL of 1 M CH_3COONa adjusted to 5 pH with CH_3COOH ; the previous residue has been added to 25 mL of 30% H_2O_2 adjusted to 2 pH with HNO_3 which was added to liberate the metals associated with the bound to organic matter phases; the previous residue has been extracted with 25 mL of 0.2 M NH_4 -oxalate acidified 3.25 pH with oxalic acid solution in order to release the metals associated with the bound to Fe-Mn oxide phases. Finally, the contaminants have been released by a mixture of strong acid 15 mL of HCl and 5 mL of concentrated HNO_3 . The extracts were analyzed by using atomic absorption spectrometer instrument (model: Perkin Elmer 400) in the National Research Centre laboratories in order to assess the metal (Cd, As, Cr, Pb, Ni, and Cu) concentrations.

The risk assessment code (RAC) was applied for evaluating the availability of metals in soils. According to Perin et al. (1985), RAC was calculated from the equation $\text{RAC} = (100 \times F_1 + F_2)/(F_1 + F_2 + F_3 + F_4 + F_5)$, where F_1 is the water-soluble and exchangeable fraction (Ex), F_2 is the carbonate-bound fraction (Ct), F_3 is the organic matter-bound fraction (Ob), F_4 is the Fe-Mn oxide-bound fraction (FM), and F_5 is the residual fraction (Rd).

Results

The concentration range of Cd, As, Cr, Pb, Ni, and Cu was 0.35–2.6, bdl–140, 89–260, bdl–300, 18–170, and 35–140 ppm, respectively (Table 2). The obtained values of EF and I_{geo} were presented in Table 3. Cadmium fractionation data is recorded in Table 4 and demonstrated in Fig. 3. Carbonate fractions of As vary from 205 to 943 ppm with an average 608.41 ppm in the selected sample soils (Table 5 and Fig. 4). Chromium, lead, nickel, and copper fractionation data is tabulated in Tables 6, 7, 8, and 9 and explained in Figs. 5, 6, 7, and 8. According to Perin et al. (1985), values of risk assessment code of heavy metals in the selected soils are listed in Table 10. The risk assessment

Table 6 Chromium fractionation results (ppm)

Samples	Ex	Ct	Ob	FM	Rd
S ₁	ND	77.62	ND	ND	75.38
S ₇	ND	76.45	ND	ND	103.55
S ₈	ND	52.08	ND	ND	136.92
S ₉	ND	86.13	ND	ND	84.87
S ₂₅	ND	114.67	ND	ND	74.33
S ₃₁	ND	95.33	ND	ND	75.67
Mean	ND	83.71	ND	ND	91.79

Table 7 Lead fractionation results (ppm)

Samples	Ex	Ct	Ob	FM	Rd
S ₁	13.21	50.69	41.30	54.33	110.46
S ₇	5.58	12.41	19.32	23.29	38.39
S ₈	6.04	8.49	10.58	10.48	22.01
S ₉	8.12	15.26	11.42	13.08	23.22
S ₂₅	7.62	14.90	13.06	12.34	19.59
S ₃₁	6.51	11.32	10.05	9.18	15.14
Mean	7.85	18.85	17.62	20.45	38.13

code had been classified into five categories according to Perin et al. (1985) as summarized in Table 11.

Discussion

The concentrations of As, Cr, and Ni exceed the maximum allowable concentration (MAC) set by Kabata-Pendias and Mukherjee (2007), while Cd, Pb, and Cu were within MAC. Based on the EF values, it is noticed that the samples which have a value exceeding 5 are considered rich in heavy metals according to the EF classification (Table 1). Also, the I_{geo} values of the studied samples which have a value over 2 represented polluted according to the EF classification (Table 1).

Sequential extraction

The most contaminated samples with As, Cr, Pb, Ni, and Cu are chosen based on the high enrichment factor and geoaccumulation index of these metals (Tables 1 and 3). The high contaminated samples are S₁, S₇, S₈, S₉, S₂₅, and S₃₁. So, these samples were subjected to sequential extraction methods. The metal forms have been obtained from the sequential extraction schemes which will be discussed as the following:

Cadmium

Cadmium has no essential biological function, but it tends to accumulate in plants and aquatic biota with consequent problems of toxicity. It is toxic to humans through the inhalation of dust causing lung damage and

Table 8 Nickel fractionation results (ppm)

Samples	Ex	Ct	Ob	FM	Rd
S ₁	6.03	22.27	11.31	9.39	77.01
S ₇	5.65	18.47	13.61	9.20	79.08
S ₈	6.53	24.15	10.30	7.81	77.21
S ₉	6.72	26.27	9.63	7.76	84.62
S ₂₅	9.76	41.80	17.74	9.87	73.84
S ₃₁	8.97	31.77	14.93	8.24	62.08
Mean	7.28	27.45	12.92	8.71	75.64

Table 9 Copper fractionation results (ppm)

Samples	Ex	Ct	Ob	FM	Rd
S ₁	2.71	6.72	16.54	33.49	57.55
S ₇	1.78	4.95	26.05	31.60	61.61
S ₈	2.40	3.78	23.35	33.65	62.83
S ₉	1.25	6.90	9.01	16.58	56.26
S ₂₅	1.64	9.72	14.77	14.64	49.23
S ₃₁	1.21	7.12	11.84	10.74	53.70
Mean	1.83	6.53	16.93	23.45	56.86

may cause cancer from long-range exposure (WHO 1996). According to mean levels, the comparative mobility and bioavailability of Cd in the studied soils were decreased in the following order: Ct > Rd > Ob > FM > Ex (Table 4 and Fig. 3). It is well known that Cd associated with the exchangeable fraction is really available,

whereas that associated with both of carbonate, oxides, and organic matter is less available to biota. The residual fraction of Cd is actually unavailable to every plants or microorganism (Abollino et al. 2011; Wuana et al. 2012).

Arsenic

Anthropogenic activity has resulted in the widespread atmospheric deposition of arsenic from the burning of coal and the smelting of non-ferrous metals and phosphate fertilizers; the hazards resulting from geogenic load are generally regarded as lower than from anthropogenic contamination (Skala et al. 2011), and they clear that As is only associated with the non-residual carbonate fraction (Table 5 and Fig. 4), referring that As may be adsorbed, precipitated, or co-precipitated with carbonates (Smith and Naidu 2009). Then, the non-residual carbonate fraction of As is potentially available to plants or microorganism.

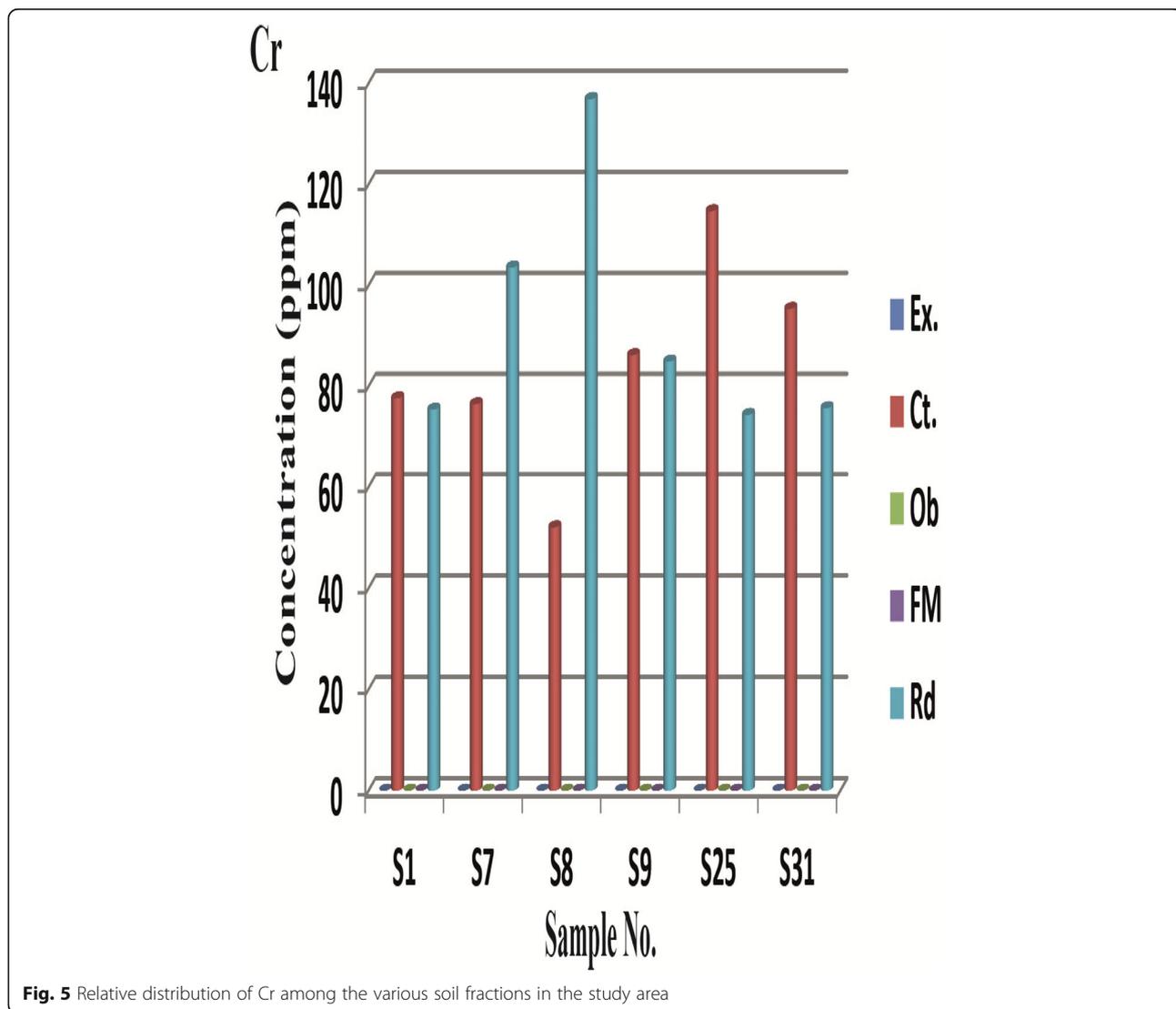


Fig. 5 Relative distribution of Cr among the various soil fractions in the study area

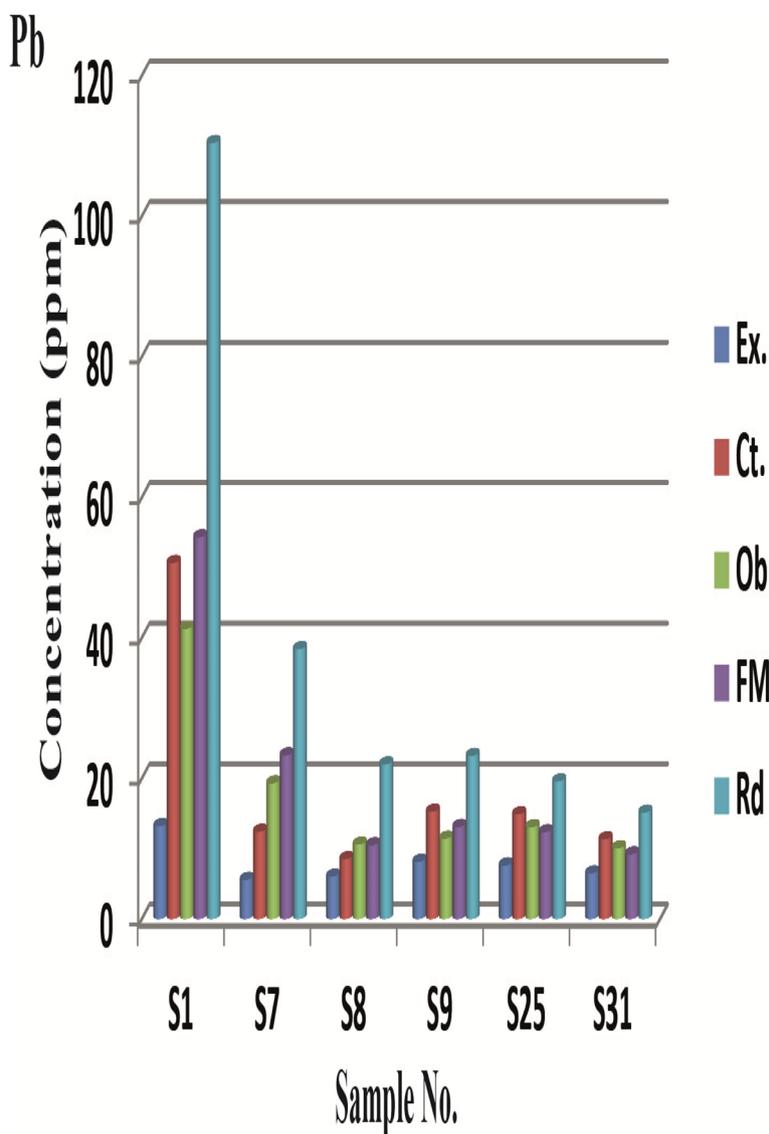


Fig. 6 Relative distribution of Pb among the various soil fractions in the study area

Chromium

The human body needed a small amount of Cr for insulin action and the metabolism of proteins and carbohydrates (Frausto da Silva and Williams 1991). Chromium has a varying toxicity depending on speciation in the environment. It is highly toxic, causing liver and kidney damage and acting as a carcinogen (WHO 1996). According to average values, the comparative mobility and bioavailability of Cr in the studied soil samples were decreased in the following order: Rd > Ct (Table 6 and Fig. 5). This point to the authentic Cr was primarily concentrated in the clay minerals or incorporated in the lattice structure in the studied soils (Rao et al. 2007; Hseu 2006). Therefore, the non-residual carbonate fraction of Cr is likely available to

plants or microorganism. The residual fraction of Cr is actually unavailable to biota.

Lead

Lead has unknown biological role in plants or animals and is highly toxic to mammals and aquatic life; it can cause mental impairment in young children, causes neuropathy and hypertension in adults, and may be lethal at high levels, e.g., over 25 µg kg⁻¹ of body weight (WHO 1996). According to mean contents, the comparative mobility and bioavailability of Pb in the examined soil samples cleared a decrease in the following order: Rd > FM > Ct > Ob > Ex (Table 7 and Fig. 6). This indicates that the native Pb was mainly fixed in the lattice structure in the studied soils (Rao et al. 2007;

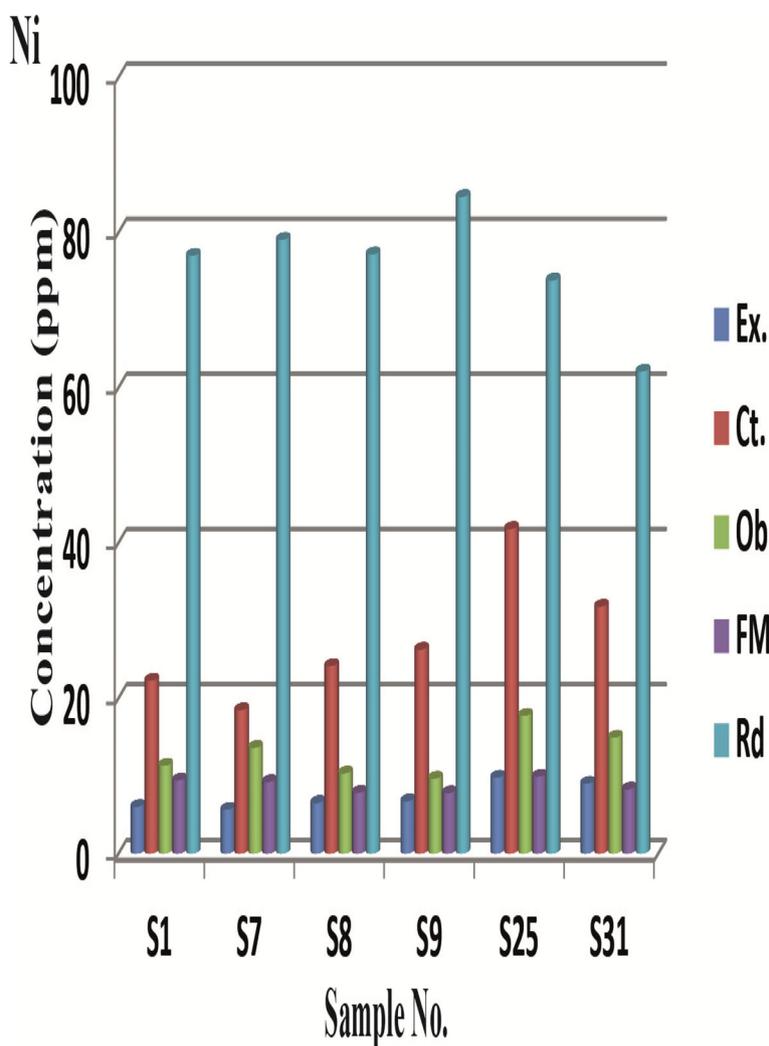


Fig. 7 Relative distribution of Ni among the various soil fractions in the study area

Hseu 2006; Sarkar et al. 2014). The residual fraction of Pb is indeed unavailable for biota.

Nickel

Nickel has been shown to be fundamental for microorganisms and having an essential role in human metabolism (McGrath 1995); most Ni compounds are comparatively non-toxic, but some compounds are highly toxic, and extreme excesses of Ni are both toxic, causing dermatitis and gastric irritation and carcinogenic illnesses (WHO 1996). According to average concentrations, the comparative mobility and bioavailability of Ni in the investigated soil samples were reduced in the following order: Rd > Ct > Ob > FM > Ex (Table 8 and Fig. 7); this refers that the primary Ni was mostly concentrated in the clay fraction or may be incorporated in the lattice structure in the studied soils (Rao et al. 2007; Hseu 2006; Ayodele and Mohammed 2011). The total bulk of Ni in soil is really unavailable for biota.

Copper

Copper is an essential trace element for all organisms and humans which can bear levels up to 12 mg per day, although the element can be toxic at extremely high levels (WHO 1996). Reimann and de Caritat (2005) report examples of kidney failure in small children resulting from drinking water polluted with copper in low pH environments containing high concentrations of Cu up to about 1 ppm. According to mean values, the comparative mobility and bioavailability of Cu in the studied soil samples were decrease in the following order: Rd > FM > Ob > Ct > Ex (Table 9 and Fig. 8). This refers that the authentic Cu was largely concentrated in the clay fraction of the studied soils or may be integrated in the lattice structures in soils (Rao et al. 2007; Hseu 2006; Rutkowska et al. 2013). The bulk of total Cu in soil is rightly unavailable to every plants and microorganism.

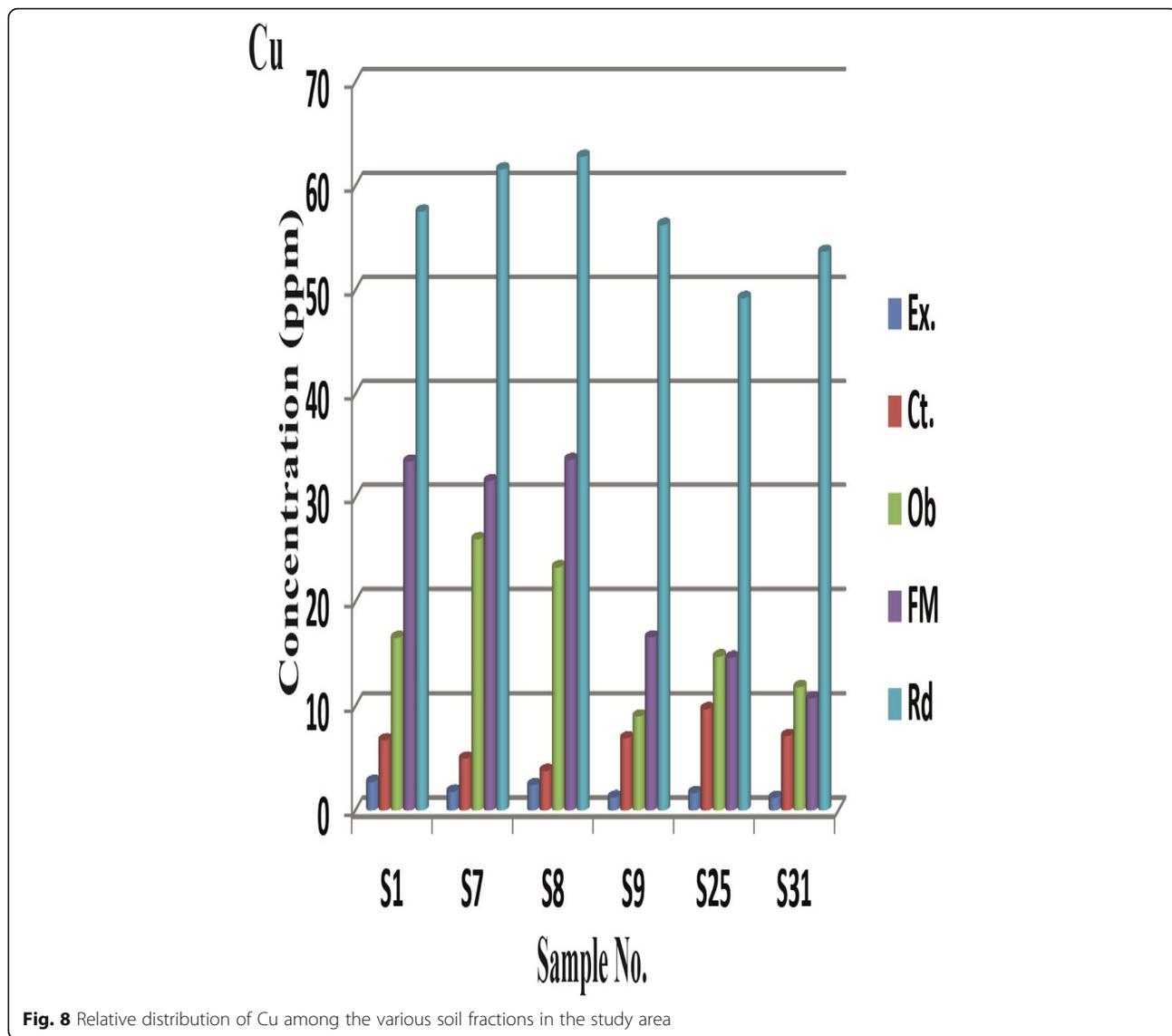


Fig. 8 Relative distribution of Cu among the various soil fractions in the study area

Risk assessment code

The risk assessment code (RAC) mainly compares the sum of the exchangeable and carbonate fractions with the total extracted for evaluating the availability of metals in soils. These fractions are considered to be

Table 10 Heavy metals risk assessment code (RAC%) in selected soils

Samples	Cd%	As%	Cr%	Pb%	Ni%	Cu%
S ₁	67.21	100	50.73	23.67	22.46	8.05
S ₇	52.00	100	42.47	18.18	19.14	5.35
S ₈	42.86	100	27.56	25.23	24.35	4.90
S ₉	64.18	100	50.37	32.89	24.44	9.05
S ₂₅	69.64	100	60.67	33.35	33.70	12.62
S ₃₁	60.00	100	55.75	34.17	32.34	9.84
Mean	59.32	100	47.93	27.91	26.07	8.30

Table 11 Classification of risk assessment code (RAC) in the studied soil

Criteria	Risk	Samples
< 1	No risk	-
1-10	Low risk	S ₁ , S ₇ , S ₈ , S ₉ , and S ₃₁ in Cu%.
11-30	Medium risk	S ₈ in Cr%. S ₁ , S ₇ , and S ₈ in Pb%. S ₁ , S ₇ , S ₈ , and S ₉ in Ni%. S ₂₅ in Cu%.
31-50	High risk	S ₈ in Cd%. S ₇ in Cr%. S ₉ , S ₂₅ , and S ₃₁ in Pb%. S ₂₅ and S ₃₁ in Ni%.
> 50	Very high risk	All selected samples except S ₈ in Cd%. All selected samples in As%. All selected samples in Cr% except S ₇ and S ₈ .

weakly bonded metals that may equilibrate with the aqueous phase and thus become more rapidly bioavailable (Singh et al. 2005; Li et al. 2011).

Tables 10 and 11 show that heavy metals are considered to be easily dissolved into the water by acidity (Perin et al. 1985; Jain 2004). The relative amounts of easily dissolved phase of heavy metals in the soils are in the order of As > Cd > Cr > Pb > Ni > Cu. According to RAC values, the risks of both of As, Cd, and Cr were very high. So, both As, Cd, and Cr should be recognized as priority pollutants in the soils of the study area.

Conclusion

The results indicated that the pollution with As, Cd, and Cr metals of some samples were the most of polluted samples according to the EF and I_{geo} and were subjected to sequential extraction, which indicated that Cd and As are mainly associated with carbonate fraction. On the other hand, Pb, Cr, Ni, and Cu are mainly incorporated in the residual fraction, and calculated RAC cleared the potential availabilities of As, Cd, and Cr in the study area.

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References

Abd Elsanad EEY (2010) Geophysics and hydrogeological studies for evaluation the groundwater potentiality in the reclaimed area, west Minia District, Egypt. M. Sc. Thesis, Geol. Dep., Faculty of Science, Minia univ., Egypt

- Abollino O, Malandrino M, Giacomino A, Mentasti E (2011) The role of chemometrics in single and sequential extraction assays: a review. *Anal Chim Acta* 688:104–121
- Aiju L, Yanchun G, Honghai W, Gao Peiling G (2012) An assessment of heavy metals contamination in Xiaofu River sediments through chemical speciation study. *Int J Earth Sci* 5(5):1235–1240
- Ayodele JT, Mohammed SS (2011) Speciation of nickel in soils and cereal. *Res J Appl Sci Eng Technol* 3(3):202–209
- Buat-Menerd P, Chesselt R (1979) Variable influence of the atmospheric flux on the trace metal chemistry of oceanic suspended matter. *Earth Planet Sci Lett* 42:398–411
- Buccolieri A, Buccolieri G, Dell'Atti A, Strisciullo G, Gagliano-Candela R (2010) Monitoring of total and bioavailable heavy metals concentration in agricultural soils. *Environ Monitor Assess* 168(1–4):547–560
- Covelo EF, Vega FA, Andrade ML (2007) Simultaneous sorption and desorption of Cd, Cr, Cu, Ni, Pb and Zn in acid soils II: soil ranking and influence of soil characteristics. *J Hazard Mater* 147:862–870
- Davutluoglu OI, Seckin G, Ersu CB, Yilmaz T, Sari B (2011) Heavy metal content and distribution in surface sediments of the Seyhan River, Turkey. *J Environ Manag* 92:2250–2259
- Elnazer A, Salman A, Seleem M, Abu El Ella E (2015) Assessment of some heavy metals pollution and bioavailability in roadside soil of Alexandria-Marsa Matruh highway. *Egypt Int J Ecol* 689420:7p
- Frausto da Silva JTR, Williams RJP (1991) The biological chemistry of the elements: the inorganic chemistry of life. Clarendon Press, Oxford, p 561
- Ghaderi AA, Abduli MA, Karbassi AR, Nasrabadi T, Khajeh M (2012) Evaluating the effects of fertilizers on bioavailable metallic pollution of soils, case study of Sistan farms. *Iran Int J Environ Res* 6(2):565–570
- Gupta AK, Sinha S (2006) Role of Brassica juncea (L.) Czern. (var. Vaibhav) in the phytoextraction of Ni from soil amended with fly ash: selection of extractant for metal bioavailability. *J Hazard Mater* B136:371–378
- Hseu ZY (2006) Extractability and bioavailability of zinc over time in three tropical soils incubated with biosolids. *Chemosphere* 63:762–771
- Jain CK (2004) Metal fractionation study on bed sediments of River Yamuna, India. *J. Water Res* 38:569–578
- Kabata-Pendias A, Mukherjee AB (2007) Trace elements from soil to human. Springer, Berlin Heidelberg New York, p 550
- Kabata-Pendias A, Pendias H (2001) Trace elements in soils and plants. CRC Press, Boca Raton
- Kierczak J, Neel C, Aleksander-Kwaterczak U, Helios-Rybicka E, Brill H, Puziewicz J (2008) Solid speciation and mobility of potentially toxic elements from natural and contaminated soils: a combined approach. *Chemosphere*. 73:776–784
- Lee CSL, Li XD, Zhang G, Li J, Ding AJ, Wang T (2007) Heavy metals and Pb isotopic composition of aerosols in urban and suburban areas of Hong Kong and Guangzhou, South China - evidence of the long-range transport of air contaminants. *Atmos Environ* 41:432–447
- Li R, Yang H, Zhou Z, Lu J, Shao X, Jin F (2011) Fractionation of heavy metals in sediments from Dianchi lake, China. *J. Pedosphere* 17(2):265–272
- Maas S, Scheifler R, Benslama M, Crini N, Lucot E, Brahmia Z, Benyacoub S, Giraudoux P (2010) Spatial distribution of heavy metal concentrations in urban, suburban and agricultural soils in a Mediterranean city of Algeria. *Environ Pollut* 158:2294–2301
- McGrath SP (1995) Nickel. In: Alloway BJ (ed) Heavy metals in soils. Blackie Academic & Professional, London
- Mohamed WS, Ismail EA, Zaki R, Kamel A (2015) Regional assessment of heavy metals pollution in irrigated soils, west El Minia district, Egypt. *Egypt J of Geol* 59:101–112
- Muller G (1979) Index of geoaccumulation in sediments of the Rhine River. *Geol J* 2:109–118
- Nemati K, Abu Bakar NK, Radzi Abas M, Sobhanzadeh E (2011) Speciation of heavy metals by modified BCR sequential extraction procedure in different depths of sediments from Sungai Buloh, Selangor, Malaysia. *J Hazard Mater* 192(1):402–410
- Perez-Lopez R, Niet JM, Lopez-Coto I, Aguado JL, Bolivar JP, Santisteban M (2010) Dynamics of contaminants in phosphogypsum of the fertilizer industry of Huelva (SW Spain): from phosphate rock ore to the environment. *Appl Geochem* 25:705–715
- Perin G, Craboleda L, Lucchese M, Cirillo R, Dotta L, Zanette ML, Orto AA (1985) Heavy metal speciation in the sediments of northern Adriatic Sea- a new approach for environmental toxicity determination. In: Lekkas TD (ed) Heavy Metal in the Environment, vol 2, pp 454–456

- Phuong NK (2008) Geochemical study of arsenic behavior in aquifer of the Mekong Delta, Vietnam, Ph.D. Thesis, Graduate School of Engineering, Kyushu Univ
- Rao CRM, Sahuquillo A, Lopez Sanchez JF (2007) A review of the different methods applied in environmental geochemistry for single and sequential extraction of trace elements in soils and related materials. *Water Air Soil Pollution* 189:291–333
- Rao CRM, Sahuquillo A, Lopez-Sanchez JF (2010) Comparison of single and sequential extraction procedures for the study of rare earth elements remobilisation in different types of soils. *Anal Chim Acta* 662(2):128–136
- Rauret G, Lopez-Sanchez JF, Sahuquillo A, Rubio R, Davidson C, Ure A, Quevauviller P (1999) Improvement of the BCR three step sequential extraction procedure prior to the certification of new sediment and soil reference materials. *J Environ Monit* 1:57–61
- Reimann C, de Caritat P (2005) Distinguishing between natural and anthropogenic sources for elements in the environment: regional geochemical surveys versus enrichment factors. *Sci Total Environ* 337:91–107
- Rutkowska B, Szulc W, Bomze K (2013) Effects of soil properties on copper speciation in soil solution. *J Elem Sci*:695–703
- Said I, Salman A, Samy Y, Awad S, Melegy A (2019) Environmental factors controlling potentially toxic element behaviour in urban soils, El Tebbin, Egypt. *Environ Monit Assess* 191:267
- Said R (1981) *The geological evolution of the River Nile*. Springer Verlag, New York, Berlin, p 151
- Salman A, Elnazer A, Abu El Ella E (2018) Sequential extraction of some heavy metals in Southwest Giza soil, Egypt. *Egypt J Chem* 61(5):785–797
- Salman A, Elnazer A, El Nazer H (2016) Integrated mass balance of some heavy metals fluxes in Yaakob village, south Sohag, Egypt. *Inter J Environ Sci*. <https://doi.org/10.1007/s13762-016-1200-3>
- Sarkar SK, Favas PJC, Rakshit, D, Satpathy KK. Geochemical speciation and risk assessment of heavymetals in soils and sediments. In: Hernandez-Soriano, M.C. (Ed.), *Environmental Risk Assessment of Soil Contamination*. InTech. 2014: 918 p
- Singh KP, Mohan D, Singh VK, Malik A (2005) Studies on distribution and fractionation of heavy metals in Gomti river sediments- a tributary of the Ganges, India. *J Hydrol* 312:14–27
- Skala J, Vacha R, Jarmila CJ (2011) Evaluation of arsenic occurrence in agricultural soils of the Bohemian Forest region. *Research Institute for Soil and Water Conservation, Silva Gabreta, Vimperk*. 17(2–3):55–67
- Smith E, Naidu R (2009) Chemistry of inorganic arsenic in soils: kinetics of arsenic adsorption–desorption. *Environ Geochem Health* 31:49–59
- Tessier A, Campbell PGC, Blsson M (1979) Sequential extraction procedure for the speciation of particulate trace metals. *Anal Chem* 51:844–851
- Vega FA, Covelo EF, Andrade ML, Marcet P (2004) Relationship between heavy metals content and soil properties in mine soils. *Analytical Chem Acta* 524: 141–150
- Wali A, Coinet G, Khadhraoui M, Ksibi M (2013) Trace metals in surface soil contamination by release of phosphate industry in the surroundings of Sfax-Tunisia. *Environ Res Eng Manag* 65(3):20–30
- WHO (1996) *Biological monitoring of chemical exposure in the workplace*. World Health Organ Geneva 1:294
- Wuana RA, Adie PA, Asegh IN (2012) Seasonal variation in bioavailability of some toxic metals in waste dump soils of Makurdi, North-Central Nigeria. *J Biodiv Environ Sci* 2(11):7–17
- Yang Y, Chen F, Zhang L, Liua J, Wu S, Kang M (2012) Comprehensive assessment of heavy metal contamination in sediment of the Pearl River Estuary and adjacent shelf. *Mar Pollut Bull* 64:1947–1955
- Zemberyova M, Bartekova J, Hagarova I (2006) The utilization of modified BCR three-step sequential extraction procedure for the fractionation of Cd, Cr, Cu, Ni, Pb and Zn in soil reference materials of different origins. *Talanta*. 70:973–978

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