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Calculation of soil pollution indices with elements in residential areas of Baghdad city

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Abstract: Estimation of elements: Pb, Zn, Mn, Cd, and Cu, which were conducted seasonally from October-2021 till March-2022 in residential areas of Baghdad City using Geoaccumulation index (Igeo), enrichment factor ratios (EF), the factor of contamination (CF), contamination degree (Cd), index of pollution load (PLI) and index of potential ecological risk (Eif). The overall contamination factor in the research area is limited from low contamination with Cu, Mn, and Zn, moderately contaminated to very high contamination with Pb and Cd, while the assessment according to the I-geo index shows categories that vary from a slightly polluted to unpolluted by those examined heavy metals. The pollution load index indicates that the soils in some residential areas in Baghdad City have high levels of contamination by certain heavy metals. According to the EF results, the areas were moderately to significantly enriched with Pb and Cd and minimally enriched with Mn, Zn, and Cu. The potential for ecological risk had an irregular distribution, and the overall ecological risk level ranged from moderate to low. The PLI depicts the research area's vulnerability to soil heavy metal contamination and associated ecological concerns, particularly from lead and cadmium.

Key words: Pollution Index, Enrichment Factor, PLI index, Potential ecological risk.

Introduction

Soil is the habitat of many organisms, the skeleton of the terrestrial ecosystem and the most threatening factor of our environment due to the likely influences of various pollutants from human actions such as agricultural, industrial, etc[1]. Soil acts as a tank for heavy metals through surface complexation, ion exchange and surface precipitation[2]. Elements have been the topic of specific interest among pollutants due to their long-standing toxicity when the thresholds are exceeded and become one of the major environmental problems. These element ions are non-degradable and persistent in the environment[3]. Thus, the ecological issue of sediments and soil pollution by elements has increased in interest in the last decades in each developed and developing country worldwide[4]. Understanding the levels, degree and sources of elements contamination is fundamental for managing the environment[5].

Various methods of calculation based on the foundation of multiple algorithms may lead to a discrepancy in pollution estimation; simultaneously, these methods are estimating the soil quality or/and ecological sediment geochemistry. Thus, choosing an acceptable procedure to estimate sediment and soil quality is essential for urban planning decision-making[6]. This work aims to be a foundation for future studies of activities leading up to temporal changes in the metal concentrations within the soil of Baghdad City.

Materials and methods

Study area

Baghdad is the capital of Iraq and covers each side of the Tigris River. It lies around longitude 33.35° north and latitude 44.45° east. The municipality of Baghdad encompasses 40 administrative units, six in Karkh (west of the Tigris River) and eight in Rusafa (east of the Tigris River). The area of the municipality of Baghdad is 870 Km^2. Baghdad's climate is semi-arid, continental and subtropical; cool winters and short springs; hot and dry long summers; few precipitations, little relative humidity, and high sun brightness. The rainfall duration is from December to April, with an annual average of 100 and 180 mm[7]. The Baghdad area has streets with intensive automobile traffic and many industrial activities located in this area.

Soil sampling and processing

Soil samples were collected seasonally from October-2021 till March-2022. A control soil sample was collected from a rural area (Abu-Ghuraib). In contrast, other sites represent the urban regions in Baghdad City (Doura, Ameriya, Ghazaliya, Jaderia, Adhamiyah, Karadah, Jamia and Zafaraniya). Soil samples were taken to a depth of 10 cm from each experimental site, taken with plastic tools, and then stored using polyethylene sample bags. The samples

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Figure 1. Baghdad City with the sampling sites[7].

were oven-dried in the laboratory at 105°C for 24 h and passed through a 2-mm sieve. Then these samples were digested with a 3: 2: 2 mixture of HNO_3- H_2SO_4 – HCl. The digested soil samples were analyzed for their total Pb, Zn, Cu, Mn, and Cd concentrations by using atomic absorption spectrophotometer (Perkin-Elemer model 5000). While electrical conductivity, TDS and pH were measured as the method mentioned by Tandon[8] defined by making (1:2) soil and water solution for one hour was placed in a rotary shaker. Soil texture has been identified by the soil texture triangle method.

Soil pollution indices

To assess elements contamination in soils, some ecological indexes of soil pollution were calculated by using the following formulas:

Index of Geo-accumulation (I_{geo})

According to Muller,1969[9] procedure I_{geo}= log2 (Cn / Bn .1.5)

where Cn = Measured concentration of heavy metal in soil, Bn= Geochemical background value in average shale of element n. The seven proposed descriptive classes for I-geo deals are as follows: <0 = practically unpolluted; 0 – 1= unpolluted to slightly polluted, 1 – 2 = moderately polluted; 2 – 3= moderately to strongly polluted; 3 – 4= strongly polluted; 4 – 5 = strongly to very strongly polluted and >5 = very strongly polluted.

Degree of Contamination and Contamination Factor

Values of Cf are proposed to define the factor of contamination which is calculated by the formula[9]:

CF = C metal / C background value

Where C metal= concentration of metal

C background value= Reference value for each element.

The following terminologies are used to describe the contamination factor: CF <1, low contamination factor; 1≤CF<3, moderate contamination factors; 3≤CF<6, important contamination factors; and CF≥6, very high contamination factor. The degree of contamination (Cd) was defined as the sum of all contamination factors. The following terminology was adopted to describe the degree of contamination (Cd values) for the selected metals. Cd< 6: low degree of contamination; 6 = Cd< 12: moderate degree of contamination; 12= Cd< 24: considerable degree of contamination; Cd= 24: very high degree of contamination indicating serious anthropogenic pollution[9].

Pollution Load Index (PLI)

All sites were estimated for the range of metal pollution using the formula submitted by Thomilson *et al.* 1980[10].

PLI = (CF1 × CF2 × CF3 ×…× CFn) 1/n

Where n is the number of metals studied (five in this study), and CF is the contamination factor calculated as described in the equation mentioned above. The PLI provides simple but comparative means for assessing a site quality, where a value of PLI < 1 denote perfection; PLI = 1 presents that only baseline levels of pollutants are present, and PLI > 1 would indicate deterioration of site quality.

The enrichment Factor (EF) is calculated by comparing each tested metal concentration with that of a reference metal submitted by Sinex and Helz[11].

Enrichment Factor (EF) = (C_x / CFe) sample / (C_x / CFe) reference soil

Where: Cx/CFe sample of the heavy metal to the Fe ratio in the same sample and Cx/CFe reference is the natural background value of the metal ratio to Fe. Iron was chosen as a reference element because it is one of the most significant parts of soil, and iron is difficult to change by other human sources.

Six contamination categories were recognized because of the enrichment factor. As the enrichment factor increases, the anthropogenic origins' contributions also increase. Therefore, this study used Mn as the reference metal because it was found most abundantly in the soil and environment.

Potential Ecological Risk Index (Eif)

The potential ecological risk for a given contaminant was calculated according to Hakanson12.

$E^i_f = C^i_f * T^i_f$

Where T^i_f is the toxic response factor for a given heavy metal, C^i_f is the contamination factor.

T^i_f for Pb, Zn, Cu, Mn and Cd are 5, 1, 5, 5 and 30, respectively. The potential ecological risk of heavy metals is classified into five levels, according to the values of E^i_f:< 20 →low, 20-40 → moderate, 40-80 → considerable, 80-160 → high and > 160 →very high.

Statistical analyses

All statistical analyses were performed using SPSS version 12 for Windows. The significance level was set at P ≤ 0.05. One-way ANOVA was done to estimate significant differences between the concentrations of heavy metals in the study area, followed by Tukey's honesty test to compare the mean soil contamination levels. Correlation coefficients were also tested in this study.

Results and discussion

Soil characteristics and texture

The values of soil textures taken from residential areas are given in Table 1.

The texture of most samples is sandy clay loam. Clay loam soil has a tremendous nutrient-holding capacity and a great water-holding capacity[13]. Its aeration and permeability might be a little restricted. The soil texture taken from Jaderia and Zafaraniya is loam. Loamy soil composes clay, silt, sand and organic matter in equally mixed particles of different sizes. Loamy soil is porous, which permits the better keeping of moisture and air circulation. During this work, the pH of the ground was reported to be alkaline (7.1-8.7). Charman and Murphy[14] recorded that the basic soil pH decreases the solubility of all micronutrients (excluding boron, chlorine and molybdenum), particularly those of copper, zinc, manganese and iron.

However, the minimum values of EC (458 µS/cm) and TDS (200 ppm) were found in the Karadah site, and the maximum values of EC (2500 µS/cm) and TDS(1220 ppm) were in the Doura site respectively, with significant (p ≤0.05) difference reported in all study sites (Table 2). The regions of high EC readings are represented by the area of Al-Doura that was recorded (1503-2500 µS/cm).

Elements concentration

The range of elements concentration Pb, Zn, Cu, Mn, and Cd in the studied sites are shown in Table-2.

The lead concentration in different regions ranged between a maximum value of 220 ppm in the Al-Jaderia site during the Summer and a minimum value of 40 ppm in the Abu-Ghuraib site during the Winter (Fig.2).

A significant variation (P ≤0.05) in Zn content during the investigation period in all the regions, which varied from 20 ppm in the Abu-Ghuraib site to 115 ppm in the Karadah site in Autumn (Fig.3). Regarding Cu, the current study has shown that the highest value was 60 ppm in the Doura site in the Summer, and the lowest value was 17ppm in the Adhamiyah site during winter (Fig.4). The results of Mn in the current study have shown that the highest value was 511 ppm in the Adhamiyah site during Summer, while the lowest mean data was 147 ppm in the Karadah region during Summer(Fig.5). Among the ten study sites, the Cd content of the soil was found to be the highest in the Doura region (1.1ppm) in Summer, and the lowest value (0.33 ppm) was found in the Zafaraniya site during the Autumn (Fig 6).

Sites	pH	EC(µS/cm)	TDS (ppm)	Soil texture
Abu-Ghuraib	7.6-7.8 7.7^a	1126-1800 1400^c	269-480 380^c	Sand clay loam
Doura	7.1-7.7 7.6^a	1503-2500 2000^a	760-1220 800^a	Sand clay
Ameriya	7.3-7.8 7.6^a	841-1780 1200^c	568-1200 807^a	Sand clay loam
Ghazaliya	7.7-8.2 7.9^a	860-1800 1234^c	450-900 742^b	Sand clay loam
Jaderia	7.7-8.2 7.9^a	1400-2180 1800^b	700-1120 890^a	loam
Adhamiyah	7.8-8.7 8.2^b	950-1740 1367^c	450-870 600^b	sand
Karadah	7.4-7.6 7.5^a	458-790 600^d	200-410 370^c	Sand loam
Jamia	7.7-8.2 7.9^a	463-1300 980^e	300-777 521^b	Sand clay loam
Zafaraniya	7.6-7.9 7.8^a	1000-1300 1120^e	400-700 532^b	loam

Different superscript letters (a,b,c and d) in a row show significant differences (P < 0.05) indicated by Tukey Honest (HSD) significant difference tests

Table 1. Basic statistical data (range and mean) of the soil characteristics measured in the present study.

Sites	*Pb ppm*	*Zn ppm*	*Cu ppm*	*Mn ppm*	*Cd ppm*
Abu-Ghuraib	40-140 78^{b}±53	25-53 37^{c}±	20-30 25^{b}±4	200-337 262^{d}±69	0.4-0.6 0.49^{c}±0.12
Doura	110-137 119^{a}±15	95-130 102^{a}±	39-60 45^{a}±10	255-440 303^{c}±100	0.6-1 0.8^{a}±0.19
Ameriya	50-120 83^{b}±35	40-75 55^{c}±	26-33 29^{b}±2.8	200-330 239^{b}±61	0.43-1.1 0.6^{b}±0.2
Ghazaliya	80-102 90^{b}±13	44-110 68^{b}±	20-50 33^{b}±12	140-300 215^{d}±66	0.75-0.9 0.8^{a}±0.06
Jaderia	90-220 136^{a}±72	60-115 82^{a}±	23-55 35^{a}±13	190-390 235^{b}±59	0.43-1 0.78^{a}±0.28
Adhamiyah	47-120 82^{b}±36	60-75 68^{b}±	17-50 25^{b}±15	180-511 290^{a}±153	0.7-1 0.88^{a}±0.1
Karadah	55-112 92^{b}±32	40-60 46^{c}±	22-29 35^{a}±3	147-340 235^{b}±86	0.4-1 0.82^{a}± 0.23
Jamia	60-120 80^{b}±34	37-65 47^{c}±	20-30 25^{b}±4	200-220 211^{d}±10	0.43-1 0.68^{b}±0.28
Zafaraniya	50-95 66^{c}±24	29-70 49^{c}±	26-33 28^{b}±1.7	150-212 190^{d}±27	0.3-0.9 0.62^{b}±0.23
Reference value [9]	20	95	45	900	0.3
EPA soil quality guidelines	40	110	64	-	0.6

Different superscript letters (a,b,c and d) in a row show significant differences ($P < 0.05$) indicated by Tukey Honest (HSD) significant difference tests

Table 2. Basic statistical data of the five elements measured in the present study (Range, mean ± standard deviation).

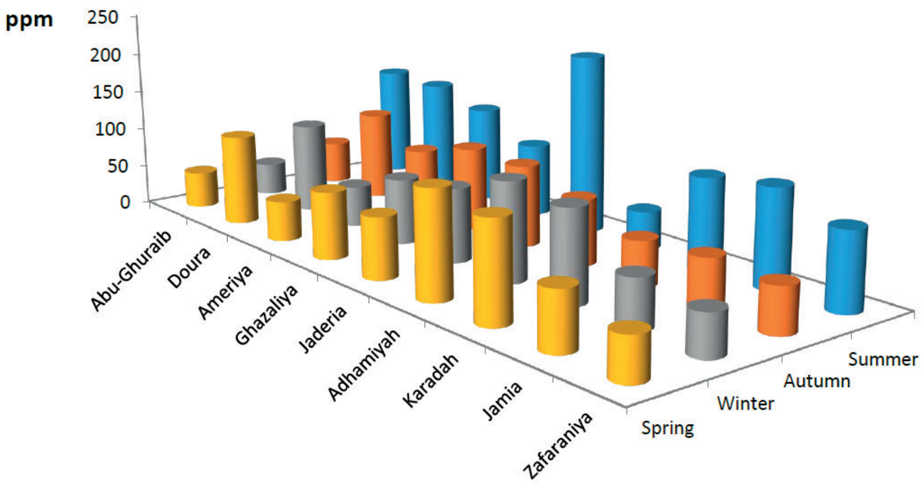

Figure 2. Seasonal variations of Pb in various residential areas of the Baghdad City.

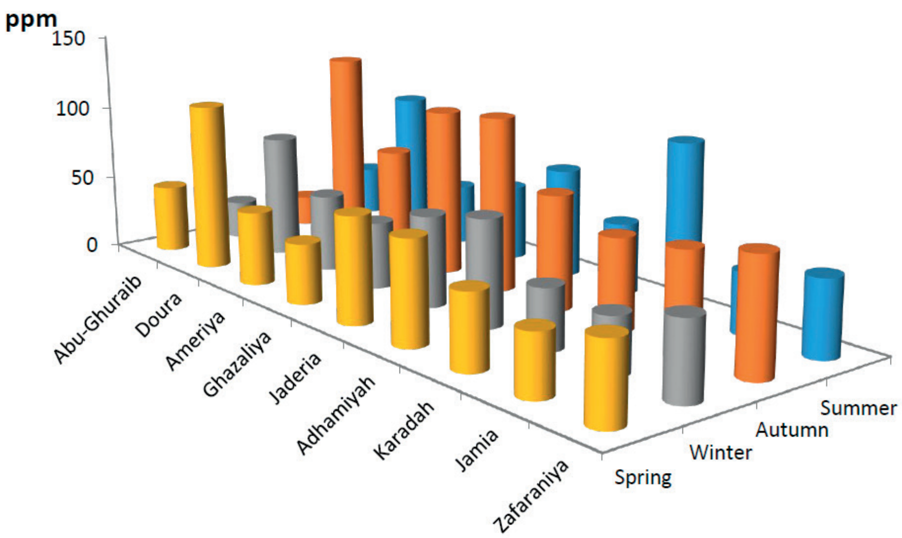

Figure 3. Seasonal variations of Zn in various residential areas of the Baghdad City.

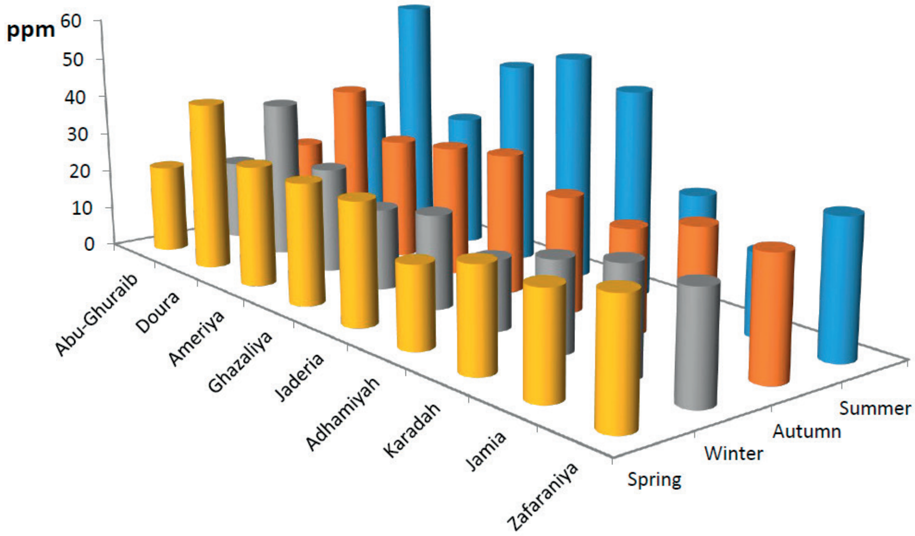

Figure 4. Seasonal variations of Cu in various residential areas of the Baghdad City.

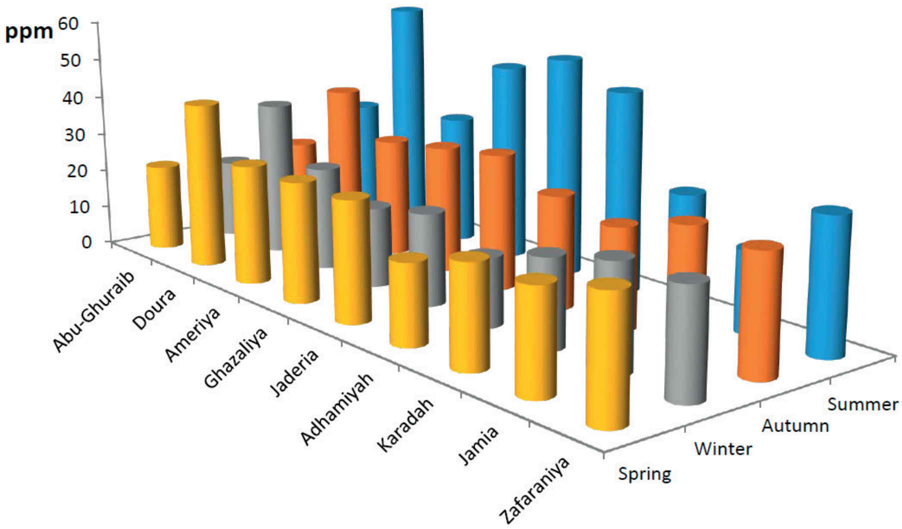

Figure 5. Seasonal variations of Mn in various residential areas of the Baghdad City.

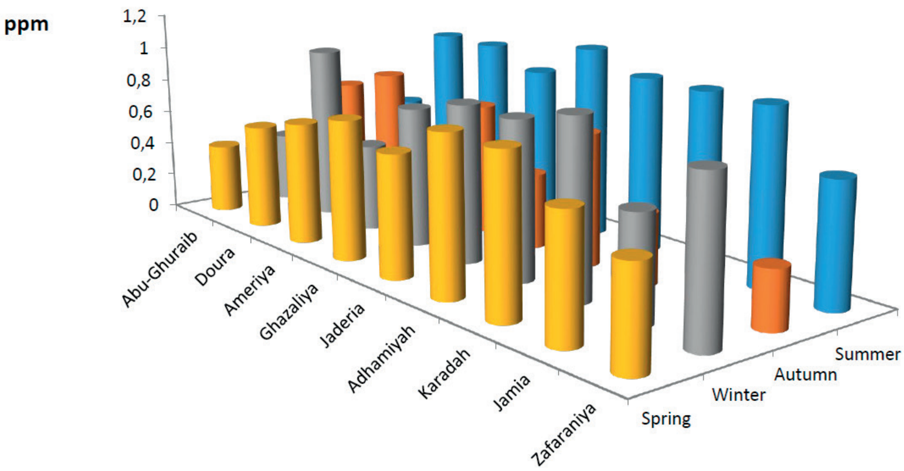

Figure 6. Seasonal variations of Cd in various residential areas of the Baghdad City.

The order of the heavy metals in this study is Mn>Pb >Zn>Cu>Cd. Manganese is comparatively affluent, with an average upper earth crust and a bulk continental crust mean of 1400 mg/kg[15].

Low concentrations of examined heavy metals were recorded in the Abu-Ghuraib site, a rural area, compared to other regions that represent urban areas. As well as, the metropolitan area has intensive anthropogenic activities, and high population density, which means urban surfaces collect different sources like industrial discharges, vehicle emissions, waste disposal, and other human anthropogenic actions[16].

Seasonally, the results reflect that the highest concentrations of heavy metals were recorded in the Summer, while the minimum values were recorded in the winter. This may be due to the effect of the rainfall factor. The descriptive statistics affecting the heavy metals concentrations, taken from soils in Baghdad residential areas, displayed the values of the heavy metals. Compared with their background values, except for Pb and Cd, they were lower and were more than their background value. This result showed that lead and Cd in Baghdad City pollute soils. Similar results were recorded in previous studies in Baghdad City[17] and Al-Hila City[18] in Iraq.

The selected sites display a significant difference (P≤0.05) between the group means of the elements. A significant correlation was found between the contaminants of Cu and Mn (r = 0.6), Pb and Cd (r = 0.57). Pb and EC(r=0.770). EC and Zn(r=0.540), TDS and Cu (r = 0.880), Cu and TDS(r=0.840), Pb and TDS(r=0.868). These results suggest that mixed origins of pollution sources include different human activities. Mn, Cu and Zn are of mixed origins of pollutants, with Mn being predominant lithogenic and emissions of vehicular characterized by Pb. The comparison of the contents of heavy metals in urban soils (residential areas) with the rural area (Abu-Ghuraib) reveals that the contamination levels of the metals in urban are higher than that in rural soils.

Assessment of elements contamination

The actual results of the calculation for I-geo in various soil samples are displayed in Table 3.

Studying geo-accumulation index (I-geo) values showed that the soils in residential areas in Baghdad City are unpolluted with Zn, Cu and Mn but slightly polluted with lead and cadmium.

Soils in Baghdad City were assessed for another contamination factor: factor of concentration, contamination degree, and pollution load index. The results are displayed in Table 4. Based on the CF values, the overall contamination of soils in Baghdad residential areas indicates that soils were low contaminated with Cu, Zn and Mn, moderately contaminated to very high contamination with Pb and Cd.

The degree of contamination varied from 6.3 in Abu-Ghuraib to 11.3 in the Jaderia area. The PLI values for Pb, Mn, Zn, Cu and Cd were more than 1 in Doura, Ghazaliya and Jaderia, indicating a high contamination level. Using the contamination factor categories previously described, residential areas of Baghdad suffered from a moderate degree of contamination by all heavy metals. The contamination index highlighted the harm that each element may have to the ecosystem and the human body. Alternatively, the pollution load index reflected the effects of the heavy metals in the soil and stressed the overall environmental impact of high concentrations of heavy metals.

In this work, we used the enrichment factor to estimate the possible anthropogenic impact and contamination in Baghdad soils (Table 5).

Therefore, to define the degree of metal contamination relatively, comparisons were made to background concentrations in the crust of the earth's using Mn as (a reference element). This index was used to quantify the pollution level and the potential of anthropogenic results in urban soils. Ultimately, while the enrichment factor values are rising, the anthropogenic sources' contributions are increasing too. Suppose the factor of enrichment is more significant than unity. In that case, it references that the richness of the heavy metal in the soil might not appear from the background of localized ground but from other natural or/and anthropogenic sources in urbanized areas, including industrial discharge, vehicle emissions, and other actions[19]. The results of EF indicated that the soils taken from residential areas of Baghdad City were moderately enriched to significantly enriched with Pb and Cd and minimally enriched with Zn and Cu. Mn was chosen as a fixed element that calculated the single enrichment index and was ignored in other counting methods.

	I-geo Pb	I-geo Zn	I-geo Cu	I-geo Mn	I-geo Cd
Abu-Ghuraib	0.9	-1.3	-0.9	-1.6	1
Doura	1.3	-0.3	-0.3	-1.4	1.7
Ameriya	1	-0,9	-0.8	-1.7	1.2
Ghazaliya	1	-0.73	-0.7	-1.6	1.7
Jaderia	1.5	-0.54	-0.5	-1.7	1.7
Adhamiyah	1	-0.72	-0.98	-1.5	1.8
Karadah	1.1	-1.1	-0.96	-1.4	1.7
Jamia	0.9	-1	-0.98	-1.8	1.4
Zafaraniya	0.7	-1.1	-0.95	-1.9	1.4

Table 3. Geo-accumulation index (I-geo) values of elements in residential areas in Baghdad City.

Sites	CF-Pb	CF-Zn	CF-Cu	CF-Mn	CF-Cd	Cd index	PLI-index
Abu-Ghuraib	3.9	0.3	0.5	0.29	1.5	6.4	0.67
Doura	5.6	1	1	0.33	2	9.9	1.2
Ameriya	4	0.5	0.4	0.33	2	7.2	0.88
Ghazaliya	4.5	0.7	0.7	0.26	2.6	8.7	1
Jaderia	6.8	0.8	0.6	0.62	2.5	11.3	1.1
Adhamiyah	4	0.48	0.5	0.32	2.5	7.7	0.91
Karadah	4.6	0.48	0.7	0.26	2.3	8.2	0.98
Jamia	4	0.47	0.5	0.23	2	7.1	0.84
Zafaraniya	3.1	0.5	0.6	0.2	2	6.4	0.82

Table 4. Contamination Factor, Degree of Contamination and PLI index values of heavy metals in residential areas of Baghdad City.

Sites	EF-Pb	EF-Zn	EF-Cu	EF-Cd
Abu-Ghuraib	13	1	1.7	5
Doura	16	3	3	6
Ameriya	12	1.3	1.2	6
Ghazaliya	17	2.6	2.3	4
Jaderia	10	1.3	1	4
Adhamiyah	12	1.1	1.8	7.8
Karadah	17	1.7	2.5	8.8
Jamia	17	2.1	2	8.6
Zafaraniya	15	2.5	3	10

Table 5. Enrichment Factor (EF) values of heavy metals in residential areas of Baghdad City.

It is possible to conclude that Pb, followed by Cd, was the most critical enriched element in the residential areas of Baghdad. It can observe that the values of enrichment factors significantly higher than one indicate an area of heavy metals and do not come from the background of localized soil but from other (anthropogenic or/and natural) sources in urbanized areas, including industrial discharges, vehicle emissions and other actions[20]. Well, as the presence of a large number of private generators. In environmental contamination studies, a popular strategy to assess how much soil is affected anthropogenic or naturally with elements is to estimate the enrichment factor for metal concentrations above uncontaminated background or levels of reference[21].

Assessment according to the potential ecological risk index

Meanwhile, the soil is contaminated with elements. It will be able to enter the body of humans through different exposure routes[22]. High toxic levels of heavy metals in soil can cause critical health and ecological risks[23,24]. The potential ecological risk index estimated their ecological potentiality and environmental impacts on toxicology in soil. The Hakanson potential ecological risk index is based on careful consideration of the heavy metals' ecological and environmental effects and toxicology in soils. The Hakanson index also provides a quantitative method of directly isolating the extent of potential hazards[25]. According to the ecological potentiality risk index, all examined locations have moderate potential ecological risk with lead, considerable potential environmental risk with cadmium, and low potential ecological risk with Zn, Cu, and Mn, respectively (Table 6). The chances of each element based on the likely environmental risk index were various, especially for the Cd. The possible reason may be the higher values of toxicity for Cd. The potential ecological risk index (RI) values are classified as the severe environmental risk for Cd in other Iraqi local studies[26].

Relatively high values for each Cd and Pb, which were recorded by the potential ecological risk index, indicate the seriousness of these metals and may threaten the people of Baghdad. There is a rising environmental interest in Cd as one of the most eco-toxic metals that shows a high level of adverse effects on soil's biological activity, plant metabolism, and the health of both animals and humans. One of the most important symptoms of exposure to cadmium (Cd) anemia is resistance to treatment and osteomalacia and urinary tract problems, kidney problems, prostate and lung cancer, and the loss of sense of smell[24]. Cd's other health complications in humans include kidney dysfunction, hepatic damage, and hypertension[26]. The poisonous (Lead) makes combinations with Oxo-groups in enzymes to impact practically all steps in the process of hemoglobin synthesis and porphyria metabolism. The levels of lead toxicity in the human body are connected with seizures, mental retardation and encephalopathy[27,28].

Conclusions

The investigation of soil elements content in the Residential Areas of Baghdad City indicated that the concentrations of Cd and Pb often exceeded the calculated average mean for the world scale of unpolluted soil. The pollution indices spatial Potential Ecological Risk Index (Eif) is vital for analyzing, treating, and transferring basic environmental information to managers, technicians, decision-makers, and their partners.

Sites	Eif -Pb	Eif -Zn	Eif -Cu	Eif -Mn	Eif -Cd
Abu-Ghuraib	19.5	0.3	2.5	1.4	45
Doura	28	1	5	1.6	60
Ameriya	20	0.5	2	1.6	60
Ghazaliya	22.5	0.7	3.5	1.3	78
Jaderia	34	0.8	3	3.1	75
Adhamiyah	20	0.48	2.5	1.6	75
Karadah	23	0.48	3.5	1.3	69
Jamia	20	0.47	2.5	1.1	60
Zafaraniya	15	0.5	3	1	60

Table 6. Potential Ecological Risk Index (Eif) values of elements in residential areas of Baghdad City.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Conflicts of Interest

The authors declare no conflict of interest.

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