



Application of Contamination Indices for Soil Pollution Assessment by Heavy Metals in Southern Erbil City

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ABSTRACT

The research was carried out in August and September 2024, to assess soil pollution from two major industrial sources. Twenty-three topsoil samples (0-30 cm depth) were collected from areas adjacent to a cement factory and an oil refinery, and their concentrations of copper (Cu), cadmium (Cd), and nickel (Ni) were determined. A comprehensive environmental assessment was performed using several established indices: the Geo-accumulation Index (Igeo), Contamination Factor (CF), Pollution Load Index (PLI), and Potential Ecological Risk Index (PERI). This multi-index approach enabled a detailed evaluation of pollution levels and associated ecological hazards in the soil. According to the results, heavy metal ranges in cement factory the (first location) were for Cu (91.43 - 377.42), Cd (1.91 - 15.46) and Ni (59.79 - 835.98) mg.kg-1 respectively, and for the second location (oil refinery) the ranges were of Cu (122.13 - 409.46), Cd (1.20 - 19.378) and Ni (99.42 - 558.39) mg.kg-1 respectively, this mean the cement factory average of HMs (Cu, Cd and Ni) was more than average of the HMs of the oil refinery, all applied indices confirmed pollution at both locations, comparative analysis of index classifications, however, revealed a higher degree of contamination at the cement factory site, driven by greater measured concentrations of heavy metals and particulate matter and this elevated contamination load translates to a more pronounced adverse effect on the surrounding ecosystem.

Keywords: Contamination Indices, Heavy Metals, Polluted Sites, Cement Factories, and Oil Refineries.

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INTRODUCTION

Rapid growth in industry, Particularly for countries that are developing, has led to significant soil contamination in the surrounding industrial areas [1]. HMs and other hazardous substances are accumulated and retained in soils due to their unique properties and structure. HMs accumulation in soil may deteriorate the quality of soil, diminish soil fertility and crop productivity, even risk human and animal health. It also causes changes in the makeup and activity of the soil microbial community [2]. Metal contamination pose a serious risk to both human life as well as the environment because of their hazardousness [3]. Soil pollution by HMs can be difficult on several levels since they do not dissolve naturally, resulting in a range of soil deficiencies that pose environmental concerns[4]. Cement manufacturing and the spilled oil from oil refineries can infiltrate and contaminated the soil surface and loading to adverse effects on soil health and ecosystem functioning[5]. The first source of pollution in the present study was Cement factories which contribute to environmental pollution by emitting dust and gases containing HMs , the most common HMs found in cement dust include Al, Be, Cr, Cu, Mn, Ni, Zn, As, Cd, Pb, and Hg[6]. Studies show that cement dust is a significant cause of HMs pollution in surrounding soil, particularly in Countries undergoing development[7], and Oil refineries are one of the main difficulties for worldwide environmental issues[8]. Crude oil can enter the soil via leaks and migrate deeper into the soil through infiltration, causing changes in the soil's physical and chemical qualities[9]. This study primarily aimed to investigate the amounts of HMs (Cu, Cd and Ni) in topsoil, and the level of contamination in the soil around the cement factory and the oil refinery by using some of the contamination indices. such as The Geoaccumulation Index (Igeo), Contamination Factor (CF), Pollution load Index (PLI) and Potential ecological risk index (PERI).

Materials and methods

Descriptions of the study area

The study was conducted at August and September 2024, in two location and sources of pollution As illustrated in (Fig.1) Cement Factory is located at the road of Erbil- Makhmur (35°43'20.1"N 43°46'40.5"E) about 64Km south-southwest of Erbil city and Oil Refinery is located in Erbil Gwer road (36°08'44"N 43°46'40"E) about 25Km south-southwest of Erbil city. The current study was the first investigation that carried out at different locations at the same time surrounding Erbil Province .

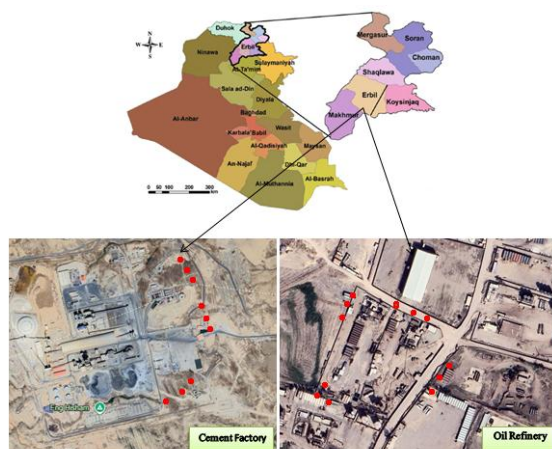


Fig.1. Location maps of the Study area

Soil sampling and preparations

23 Polluted soil samples were collected at about (100 m) away from the source of pollution. from 2 locations as shown in (Fig.1) with 3 replication, and the control samples were collected about 2 km away from the source of pollution and (0-30 cm) depth. During the pre-lab work, samples were collected, labelled, air dried, ground, sieved through a 2mm mesh and preserved in a labelled plastic bag.

Total heavy metal concentration

Heavy metals including (Cu, Cd, and Ni) mg.kg^{-1} in soil samples determined by Atomic-Absorption spectrometer (AAS). 0.5 g from dry soil sample were digested by mixed acid digestion (15 ml of HNO_3 , 5 ml of HClO_4 and 2 ml of H_2SO_4), after appearance of white fumes, the digested samples were diluted, filtered, then the volume was finished to 50 ml using distilled water and then stored until use according to [10].

Pollution indices used under the study

Pollution indices are one of the methods used to conduct a comprehensive assessment of the extent of the accumulation of heavy metals in the soil, levels of metal contamination were assessed by comparing soil metal concentrations to the reference (geochemical background) taken from an uncontaminated area about two kilometers from the sources of the pollution According to [11].

The Geoaccumulation Index (Igeo): The comparison of heavy metal concentrations in surface soil horizons (O or A) with the local geochemical background serves as a fundamental method for assessing contamination and quantifying the pollution index of individual elements [12,13].

The formula for calculating the Geoaccumulation Index as follows:

$$I_{geo} = \log_2 \left(\frac{C_n}{(1.5 * B_n)} \right) \dots\dots\dots 1$$

where C_n is the element's measured concentration in the sample and B_n is the concentration of the base element in the control sample. In the equation, a 1.5 coefficient is employed to account for the impacts of soil parent materials, natural variations, and very little changes induced by human activity. According to this index, soils are categorized into seven main classes (Table 1) [12,14].

Table 1 Geoaccumulation Index (Igeo) classification[1,2]

Igeo	Classification
$I_{geo} \leq 0$	Unpolluted
$0 < I_{geo} < 1$	Unpolluted To Moderately Polluted
$1 < I_{geo} < 2$	Moderately Polluted
$2 < I_{geo} < 3$	Moderately To Strongly Polluted
$3 < I_{geo} < 4$	Strongly Polluted
$4 < I_{geo} < 5$	Strongly To Extremely Polluted
$I_{geo} \geq 5$	Extremely Polluted

Contamination Factor(CF) : The contamination factor and degree of contamination are used to evaluate soil pollution.

The formula for determining the contamination factor is as follows:

$$CF = \frac{C_m \text{ sample}}{C_m \text{ background}} \dots\dots\dots 2$$

In this regard, CF represents the contamination factor, (C_m) sample represents the concentration of the element under investigation, and (C_m) background represents the concentration of the base element in the reference sample. In terms of contamination with heavy metals, soils can be divided into four classes (Table 2) [15,16].

Table 2 Contamination factor classification[15,16]

CF	Classification
CF<1	Low Contamination Degree
1<CF≤3	Moderate Contamination Degree
3 ≤CF< 6	Considerable Contamination Degree
CF ≥ 6	Very High Contamination Degree

Pollution load Index (PLI): is a relatively simple and comparable approach to assessing site quality, PLI measures the level of pollution for all heavy metals at a specific sample site.

The formula for computing the pollution load index is as follows.

$$PLI = \sqrt[n]{CF_1 * CF_2 * CF_n} \dots\dots\dots 3$$

where n is the number of metals assessed and CF is the contamination factor for each element. Based on it, the soil is divided into four categories (Table 3) [17,18].

Table 3 Pollution load Index classification

PLI	Risk Levels
< 1	Perfection
1	Baseline Levels Of Pollutants
> 1	Deterioration Of Site Quality

Potential ecological risk index (PERI): To evaluate the ecological, environmental, and toxicological effects of heavy metals. The following equation can be used to calculate the potential ecological risk indices of every single metal element.

The formula for computing the Potential ecological risk index is as follows.

$$Ei^f = Ci^f * Ti^f \dots\dots\dots 3$$

The formula for determining the total index of potential ecological risk for many heavy metals is as follows:

$$IRE = \sum Ei^f \dots\dots\dots 4$$

where: Ti is the hazardous response factor; Ci (mg kg⁻¹) is the observed heavy metal level; and Ci (mg kg⁻¹) is the heavy metal reference ratio.

The standard categorization of the potential ecological risk index is given in (Table 4) [19].

Table 4 Potential ecological risk index classification[19]

IRE	Risk Levels
<150	Low
150-300	Moderate
300-600	Considerable
>600	Very High

Statistical Analysis

The data were analyzed statistically using the ready statistical program SAS (Statistical Analysis System) (SAS, v. 9.3) least significant different test [20].

Results and discussion

Total Heavy Metal Concentration in soil

Concentrations of HMs in the topsoil of the current study show in (Table 5). For the Cement Factory The highest mean concentrations of Cu, Cd and Ni were 377.42, 15.46 and 835.98 mg.kg⁻¹, respectively and the lowest mean concentration of them was 91.43, 1.91 and 59.79 mg.kg⁻¹. Also depending on the Pearson Correlation Coefficients the Cu had significant correlation -0.22* with Ni and also significant correlation -0.30* with Cd. But Cd had significant correlation 0.79** with Ni, and for the Oil Refinery the highest mean concentrations of Cu, Cd and Ni were 409.46, 19.378 and 558.39 mg.kg⁻¹, respectively and the lowest mean concentration of them were 122.13, 1.20 and 99.42mg.kg⁻¹. Depending on the Pearson Correlation Coefficients the Cu had significant correlation -0.16* with Ni and also significant correlation -0.11* with Cd. And Cd had significant correlation 0.93** with Ni. The present study showed that The mean concentration for each one of HMs surpassed the established background values of (38.9, 48, 17.3) for Cu ,(0.41, 0.33,0.28) for Cd and (29,26,37) for Ni according to [21,22 and 23] as showed in table(6).

Heavy Metals Indices

Geoaccumulation Index (I_{geo})

Their values are shown in a table (7). For the Cement Factory the I_{geo} of Cu ranged from moderately polluted to strongly polluted but in[24] study found uncontaminated to moderately contaminate. Cd ranged with unpolluted to moderately polluted

to strongly polluted this disagree with study of [25] which found it between non-contaminated to slightly contaminated. Ni ranged from unpolluted to moderately to strongly polluted this agreed with [24]. Oil Refinery for the Cu ranged from unpolluted to moderately polluted to moderately to strongly polluted. Cd ranged with unpolluted to strongly polluted and Ni ranged from the unpolluted to moderately to strongly.

Contamination Factor (CF)

Their values are shown in a table (7). For Cement Factory the CF of Cu ranged from considerable contamination degree to very high contamination degree the results for Cd was ranged with moderate contamination degree to very high contamination degree, and Ni ranged from low contamination degree to very high contamination degree but in [26] study the Cu was moderate contamination level and in [27] study the Ni was low to moderate contamination and the Cd was considerable levels of contamination. Oil Refinery for the Cu ranged from moderate contamination degree to very high contamination degree Cd ranged low contamination degree to very high contamination degree Ni ranged from moderate contamination degree to very high contamination degree but in [28] study the Ni, Cu was extremely polluted and Cd was practically unpolluted.

Pollution load Index (PLI)

Their values are shown in a table (7). The value of both the locations (Cement Factory and Oil Refinery) under the current study was higher than the normal rang all the PLI values was indicated deterioration of site quality, for the cement factory this agreed with [27] and for the oil refinery this agreed with [29].

Potential Ecological Risk Index (PERI)

Their values are shown in a table (7). For Cement Factory is between low and considerable risk level but in [26] study the result shows it is considerable in some location and moderate in other, and for Oil Refinery include low, moderate and considerable but in [29] study is only low which mean low ecological risk potential.

The difference between the result under the current study and the previous studies due to the topographical features difference, The concentration of heavy metals varies by location, and the amount of heavy metals in a sample varies when compared to other samples, the value of heavy metals in the control sample is also difference and the pollution sources may vary from one site to another among the sites under the study, or may be return to soil physio-chemicals properties.

Table 5 The GPS reading and the heavy metals concentration in soil (mg.kg^{-1}) samples surrounding the cement factory and the oil refinery locations

Locations	GPS	Cu	Cd mg.kg^{-1}	Ni
Cement Factory	35°43'19"N 43°46'39.0"E	174.85	9.5	59.79
	35°43'20"N 43°46'39.0"E	102.45	14.04	637.53
	35°43'20.4"N 43°46'40.4"E	153.2	14.32	835.98
	35°43'21.1"N 43°46'36.4"E	138.97	1.91	518.72
	35°43'24.9"N 43°46'37.5"E	225.74	2.55	236.52
	35°43'20.8"N 43°46'36.5"E	214.6	10.95	449.47
	35°43'31.9"N 43°46'32.0"E	91.43	15.29	327.87
	35°43'32.1"N 43°46'31.7"E	377.42	2.11	113.29
	35°43'31.8"N 43°46'32.2"E	205.14	15.46	91.28
Control	35°43'55"N 43°47'24"E	25.82	1.01	90.97
Average		187.09	9.57	363.4
Oil Refinery	36°08'48.3"N 43°46'34.7"E	167.62	1.63	187.51
	36°08'48.0"N 43°46'34.9"E	236.62	2.26	558.39
	36°08'47.8"N 43°46'34.6"E	122.13	1.77	364.71
	36°08'44.2"N 43°46'41.6"E	257.6	1.2	176.26
	36°08'43.6"N 43°46'40.7"E	284.61	1.59	188.36
	36°08'42.7"N 43°46'39.7"E	166.98	3.06	427.45
	36°08'46.6"N 43°46'40.6"E	409.46	15.21	383.94
	36°08'46.5"N 43°46'40.1"E	284.72	1.47	409.46
	36°08'46.2"N 43°46'41.2"E	363.89	2.11	301.21
	36°08'43.5"N 43°46'33.4"E	208.3	10.6	220.55
	36°08'43.4"N 43°46'32.8"E	170.3	1.81	99.42
	36°08'43.6"N 43°46'31.4"E	246.3	19.38	341.68
Control	36°09'07"N 43°45'22"E	57.23	1.42	76.78
Average		265.8	6.27	283.15

Table 6 Commonly Reported Average Background Contents of Trace Elements in Surface Soils (mg.kg⁻¹)

Cu	Cd	Ni	References
38.9	0.41	29	[21]
48	0.33	26	[22]
17.3	0.28	37	[23]

Table 7 the pollution indices used in the current study (I geo, CF, PLI and PERI)

Locations	Geoaccumulation Index (I geo)			Contamination Factor (CF)			Pollution load Index(PLI)	Potential ecological risk index (PERI)
	Cu	Cd	Ni	Cu	Cd	Ni		
Cement Factory	2.18	2.65	-1.19	6.77	9.41	0.66	3.47	319.44
	1.4	3.21	2.22	3.97	13.9	7.01	7.29	472.00
	1.98	3.24	2.62	5.93	14.18	9.19	9.18	501.08
	1.84	0.34	1.93	5.38	1.89	5.7	3.87	112.22
	2.54	0.75	0.79	8.74	2.52	2.6	3.86	132.44
	2.47	2.85	1.72	8.31	10.84	4.94	7.64	391.51
	1.24	3.34	1.27	3.54	15.14	3.6	5.78	489.86
	3.29	0.48	-0.27	14.62	2.09	1.25	3.36	141.97
	2.41	3.35	-0.58	7.95	15.3	1	4.96	503.89
Oil Refinery	0.97	-0.39	0.7	2.93	1.15	2.44	2.02	61.27
	1.46	0.08	2.28	4.14	1.59	7.27	3.63	104.74
	0.51	-0.26	1.66	2.13	1.25	4.75	2.33	71.89
	1.59	-0.83	0.61	4.5	0.85	2.3	2.06	59.34
	1.73	-0.42	0.71	4.97	1.12	2.45	2.39	70.79
	0.96	0.52	1.89	2.92	2.15	5.57	3.27	106.99
	2.25	2.84	1.74	7.16	10.71	5	7.26	382.07
	1.73	-0.53	1.83	4.98	1.04	5.33	3.02	82.62
	2.08	-0.01	1.39	6.36	1.49	3.92	3.34	96.09
	1.28	2.32	0.94	3.64	7.46	2.87	4.27	256.42
	0.99	-0.23	-0.21	2.98	1.28	1.3	1.70	59.68
	1.52	3.19	1.57	4.3	13.65	4.45	6.39	453.16

Note : each color has its own shades, from darkest to lightest, meaning from highly polluted to lowest polluted.

Conclusion

This study demonstrates that residues from cement factories and oil refineries have introduced hazardous pollutants, particularly Cu, Cd, and Ni, into surrounding soils. The concentrations of these heavy metals in nearby areas were significantly higher than background levels, and pollution indices confirmed elevated contamination at both sites. Excessive accumulation of heavy metals poses serious risks to environmental health, including reduced soil fertility, diminished agricultural productivity, contamination of surface water, and atmospheric pollution. These findings highlight the urgent need for continuous monitoring and effective management strategies to mitigate the ecological and public health impacts of industrial activities.

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تطبيق مؤشرات التلوث لتقييم تلوث التربة بالمعادن الثقيلة في جنوب مدينة أربيل جامعة صلاح الدين، أربيل، علوم الهندسة الزراعية

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الخلاصة

أجريت الدراسة في شهري آب وأيلول من عام 2024 في موقعين ملوثين مختلفين في مدينة أربيل، بهدف تقصي أثر مصادر التلوث على البيئة. ولتحقيق ذلك، جُمعت 23 عينة من التربة بعمق (0-30) سم من محيط معمل الأسمنت ومصفى النفط، ثم جرى قياس تراكيز بعض العناصر الثقيلة بما في ذلك النحاس، الكاديوم (Cd) والنيكل (Ni). بعد ذلك استخدمت مجموعة من المؤشرات مثل معامل التراكم الجيولوجي ($Igeo$)، ومعامل التلوث (CF)، ومؤشر الحمل التلوثي (PLI)، ومعامل المخاطر البيئية المحتملة ($PERI$) لتحديد تأثير العناصر الثقيلة على مستوى تلوث التربة السطحية. توفر هذه التقنية الشاملة متعددة المؤشرات تقيماً معمقاً للصحة البيئية والمخاطر المحتملة المرتبطة بالأنشطة الصناعية المذكورة. وفقاً للنتائج، تراوحت تراكيز النحاس والكاديوم والنيكل في موقع معمل الأسمنت بين (91.43 – 377.42)، (1.91 – 15.46)، و (59.79 – 835.98) ملغ/كغم-1 على التوالي، بينما تراوحت في موقع مصفى النفط بين (122.13 – 409.46)، (1.20 – 19.378)، و (99.42 – 558.39) ملغ/كغم-1 على التوالي. وهذا يعني أن متوسط تراكيز العناصر الثقيلة (Cu, Cd, Ni) في موقع معمل الأسمنت كان أعلى مقارنة بمتوسط التراكيز في موقع مصفى النفط. وباعتماد على المؤشرات المستخدمة في هذه الدراسة، تبين أن كلا الموقعين ملوثان، غير أن تصنيف المؤشرات أوضح أن موقع معمل الأسمنت أكثر تلوثاً من موقع مصفى النفط، ويعود ذلك أساساً إلى ارتفاع مستويات العناصر الثقيلة والمواد العالقة في عينات التربة المحلية، مما يزيد من الآثار السلبية على النظام البيئي المحلي.

الكلمات المفتاحية: مؤشرات التلوث، المعادن الثقيلة، المواقع الملوثة، مصانع الإسمنت، مصافي النفط.