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Employing Environmental Risk Indicators for Evaluating Soil Contamination by Heavy Metals Near Landfill Sites in Babylon

Duha Kareem Kanoush[1], Abbas S. S. AL-Wotaify[2]
[1]Department of Soil Sciences and Water Resources, College of Agriculture, Al-Qasim Green University, Babylon, Hilla, Iraq. duhakareem642@gmail.com
[2]Department of Soil Sciences and Water Resources, College of Agriculture, Al-Qasim Green University, Babylon, Hilla, Iraq. dr.abbassabr@yahoo.com

Abstract:
This study aims to assess soil contamination and investigate some chemical properties influencing the behavior of heavy metals resulting from waste dump residues. Contaminated and reference soil samples were selected from two sites and three transects, located between latitudes 32°34′58.15″–32°32′59.77″N and longitudes 44°31′36.93″–44°35′11.05″E in Babylon Governorate, Iraq.
The total concentrations of heavy metals (mg kg⁻¹) at sites S1 and S2 were 24.1 for lead (Pb), 2.62 for cadmium (Cd), and 186 for nickel (Ni), respectively. In the transect soil samples, Pb recorded 17.2, Cd 3.3, and Ni 127 mg kg⁻¹, while in the reference soils, concentrations were 14.0 for Pb, 3.17 for Cd, and 127 for Ni.
• As for the chemical speciation of the studied metals, the distribution followed these patterns:
• Lead (Pb): Residual > Oxide and organic-bound > Carbonate-bound > Exchangeable
• Cadmium (Cd): Residual > Oxide and organic-bound > Carbonate-bound > Exchangeable
• Nickel (Ni): Residual > Carbonate-bound > Oxide and organic-bound > Exchangeable
According to pollution index values, the potential ecological risk index (ER) ranged from low to moderate for all studied soils. The overall ecological risk index (RI) for the studied elements was within the low-risk category.
The geoaccumulation index (Igeo) values for the heavy metals indicated contamination levels ranging from "uncontaminated" to "moderately contaminated" across all soil samples in the study.
Keywords: *- Soil contamination; Heavy metals; Landfill site; Pollution indices; Environmental risk; Babylon Governorate*

1.INTRODUCTION:

Environmental pollution is defined as any undesirable change in the environment caused by direct or indirect effects on energy patterns, radiation levels, and the physical and chemical properties of the environment, including the abundance of living organisms[1] With the rapid global development and the industrial revolution, environmental components have suffered significant damage due to pollution from various sources. Among the most dangerous pollutants are heavy metals, which pose a serious threat due to their persistence in the soil and their chemical transformations that lead to their uptake by plants, ultimately entering the human food chain and affecting public health[2,3]

One of the common improper practices contributing to the accumulation of heavy metals and toxic compounds in soil and air is the uncontrolled burning of waste at landfill sites. These practices are often intended to reduce waste volume but result in the release of harmful substances that affect living organisms either directly or indirectly through the food chain. They also lead to the loss of the economic value of recyclable components within the waste[4]

Moreover, the random burial of waste in sandy or clay soils—especially in unprepared pits without implementing necessary procedures such as hazardous waste treatment, material separation, and recovery—results in serious environmental consequences. These include the contamination of groundwater due to the aerobic decomposition of waste and the release of harmful gases such as carbon dioxide and methane, contributing to air pollution [5].

To evaluate the degree of soil contamination with heavy metals, several international indices have been proposed. These include the Potential Ecological Risk Index (ER), the Comprehensive Risk Index (RI), and the Geoaccumulation Index (Igeo), all of which are applied in this study to assess pollution levels in soils affected by the waste dump under investigation. This study Add aims:

1-To assess the impact of the waste landfill in Babylon Governorate on the chemical properties of the soil and evaluate the extent of change compared to unaffected reference soils.

2-To measure the concentrations of heavy metals (Pb, Cd, Ni) in soil samples within the study area and determine their compliance with environmental quality standards.
3-To analyze the chemical forms (speciation) of heavy metals in order to understand their environmental behavior and potential mobility or fixation in the soil.
4-To apply environmental pollution indices, such as the Geoaccumulation Index and the Ecological Risk Index, to evaluate the degree of contamination and associated ecological risks.
5-To provide science-based recommendations that support sound environmental management and mitigate the negative impacts of waste disposal sites on soil and the ecosystem.

2.Materials Methods:

1.2.Study site:

The study was carried out in a designated area within Babylon Governorate, where specific locations were selected to collect soil samples in order to evaluate the impact of the landfill on heavy metal accumulation. The sampling strategy included collecting deep soil samples from two main sites. The first site, located in the northeastern corner of the landfill, represents the contaminated area. Two samples were collected from this site: S11 at a depth of 0–30 cm and S12 at a depth of 60–90 cm. The second site, considered a control (uncontaminated) site, is located north of the landfill. Two samples were also collected here: S21 and S22 from the same respective depths. These locations are situated within coordinates ranging from 32°34′57.61″ to 32°34′58.15″ N latitude and from 44°31′16.64″ to 44°31′36.93″ E longitude.
In addition, surface soil samples (0–30 cm depth) were collected along three main transects surrounding the landfill to capture the spatial distribution of contamination. The first transect, positioned to the left of the landfill, began with a reference sample (T01) located to the north, at a distance from the landfill, then passed through the first dumping pit, and ended in cultivated areas near the palm orchards close to Al-Nil subdistrict. Along this transect, samples T11, T12, and T13 were collected. The second transect ran through the center of the landfill, beginning with another reference sample (T02) and continuing with samples T21, T22, and T23, following a similar pattern. The third transect was located to the right of the landfill, starting with the reference sample (T03), passing through the third dumping pit, and including samples T31, T32, and T33. These transects were located within coordinates ranging from 32°34′18.21″ to 32°34′48.15″ N latitude and from 44°31′32.57″ to 44°.

2.2.Laboratory Procedures :

Soil samples were collected in sealed polyethylene bags and immediately transported to the Postgraduate Laboratory at the College of Agriculture – Al-Qasim Green University. The samples were subjected to the necessary laboratory analyses following standardized procedures and scientifically recognized methods to assess the chemical properties of heavy metals in the soil.

3.2.Total Heavy Metal Content in Soil :

The total concentrations of heavy metals (lead, cadmium, and nickel) were determined according to the method described by[6]. One gram of air-dried soil, sieved through a 2 mm mesh, was placed in a 250 ml Pyrex flask. Then, 5 ml of concentrated nitric acid (HNO_3) was added and left for 24 hours. Afterward, the samples were placed on a hot plate at 80°C for one hour, then allowed to cool at room temperature. Subsequently, 5 ml of perchloric acid ($HClO_4$) was added, and the mixture was heated again on a hot plate at 180°C for 2 to 3 hours until the solution changed from dark brown to a clear, colorless liquid. The resulting solution was filtered using Whatman No.42 filter paper, and the final volume was made up to 10 ml with distilled water. The prepared solutions were then ready for the determination of lead (Pb), cadmium (Cd), and nickel (Ni) concentrations using a flame atomic absorption spectrophotometer (AA-7000, Shimadzu, Japan).

4.2.Chemical Fractionation of Heavy Metal Forms :

The chemical fractionation of lead (Pb), cadmium (Cd), and nickel (Ni) was conducted following the method described by[7,8]. The heavy metals were separated into four fractions: exchangeable (readily available), carbonate-bound, oxide- and organic-bound, and residual, as follows:

1.4.2.Exchangeable (Soluble and Exchangeable) Fraction:

Five grams of soil were mixed with 25 ml of 1 M ammonium acetate solution at pH 7. The mixture was placed on a mechanical shaker for 2 hours. After shaking, the solution was filtered using Whatman No. 42 filter paper, and the volume was made up to 30 ml with distilled water. The concentrations of Pb, Cd, and Ni were measured using a flame atomic absorption spectrophotometer.

2.4.2. Carbonate-Bound Fraction:

Five grams of soil were mixed with 25 ml of 1 M sodium acetate solution adjusted to pH 5 using acetic acid. The mixture was shaken for 5 hours, then filtered using Whatman No. 42 filter paper, and the volume was brought up to 30 ml with distilled water. The concentrations of Pb, Cd, and Ni were then determined using a flame atomic absorption spectrophotometer.

3.4.2. Oxide- and Organic-Bound Fraction:

Five grams of soil were treated with 7.5 ml of 35% hydrogen peroxide (H_2O_2) in a water bath at 90°C and left to react. After cooling, 25 ml of 1 M ammonium acetate solution at pH 2, adjusted using hydrochloric acid (HCl), was added. The mixture was shaken for 3 hours, filtered through Whatman No. 42 filter paper, and the final volume was adjusted to 30 ml with distilled water. Pb, Cd, and Ni concentrations were then measured using a flame atomic absorption spectrophotometer.

4.4.2.Residual Fraction:

The residual fraction was calculated by subtracting the sum of the three previously extracted fractions (exchangeable, carbonate-bound, and oxide- and organic-bound) from the total concentration of the respective heavy metal, following the method described by[9]

3.Soil pollution indicators:

The Potential Ecological Risk Index (PERI) is used to assess the environmental hazards posed by heavy metals in contaminated soils by comparing their concentrations with those in uncontaminated reference soils, while also considering the toxicity response coefficient of each metal. It is calculated using the following equation:

Table (1) Toxicity response factor for some heavy elements

Elements	Ni	Cd	Pb
Toxicity factor	5	30	5

Table (2) Standard levels of the potential and comprehensive environmental hazard indicators for heavy elements in soil.

(Er) Potential Environmental Hazard Index		RI) Comprehensive Environmental Risk) Index	
Degree	Level	Degree	Level
< 40	Slight	150<	Slight
40-80	Moderate	150-300	Moderate
80-160	Strong	300-600	Strong
160-320	very strong	>600	very strong

$$E_r^i = T_r^i \times C_f^i \quad \text{.....(2)}$$

:Where

•the potential ecological risk index for heavy metali.E_r^i :

• :the toxicity response coefficient of metal. T_r^i

the contamination factor, calculated as the ratio of the metal concentration in surface soil samples • C_f^i: ($C_{surface}$) to its concentration in background (reference) soil samples (Cn).

This index reflects the degree of contamination at a given site due to anthropogenic activities affecting the ecosystem. According to[10], the ecological risk is evaluated by multiplying the contamination factor by the toxicity response coefficient Tr.

[11]proposed specific values for the toxicity response coefficients of various heavy metals, as shown in Table 1

To evaluate the cumulative ecological risk of multiple heavy metals in a single soil sample, the comprehensive ecological risk index (RI) is calculated using the following equation:

$$RI = \sum_{i=1}^{n} E_r^i \text{.....(3)}$$

Where:

•RI: the overall ecological risk index for the soil sample

•the potential risk index for each heavy metalE_r^i:

The purpose of assessing ecological risk is to evaluate the adverse effects of various human activities using scientifically reliable approaches such as chemical assessment and bioassays, which support effective environmental protection and management[12].

[11]also categorized the risk levels of both E_r and RI indices into defined classes, as presented in Table2. Additionally, the Geoaccumulation Index (Igeo), proposed by[13], is used to evaluate the degree of heavy metal accumulation in soil, according to the following equation:

$$I_{geo}=\log_2[C_m\text{sample}/(1.5 \times C_m\text{Background})]\text{.....(4) [13].}$$

Where:

- I_{geo} : the geoaccumulation index.
- $C_m$sample:the concentration of the metal in the sample.
- C_mBackground the concentration of the metal in the background soil .

3 :RESULTS AND DISCUSSION :

1.3.Total Content of Heavy Metals in the Studied Soils :

Table 3 presents the total content of heavy metals in the soils of the current study sites. In the surface soil layer (0–30 cm), the concentration of lead ranged from 16.2 to 24.1 mg/kg, cadmium ranged from 2.21 to 2.62 mg/kg, and nickel ranged from 168 to 192 mg/kg. In the deeper soil layer (60–90 cm), lead concentrations ranged from 14.8 to 21.7 mg/kg, cadmium from 1.73 to 2.16 mg/kg, and nickel from 156 to 186 mg/kg.

In surface pathway soil samples, lead concentrations ranged from 10.9 to 17.2 mg/kg, cadmium from 1.30 to 3.36 mg/kg, and nickel from 49 to 127 mg/kg. In the comparison pathway samples at 0–30 cm depth, lead ranged from 10.7 to 14 mg/kg, cadmium from 1.34 to 3.17 mg/kg, and nickel from 38 to 88

The results indicate that the descending order of heavy metal abundance in the soil was as follows:

Ni > Pb > Cd

The high concentration of nickel in the soil may be attributed to its adsorption by clay minerals, especially montmorillonite, which is predominant in arid and semi-arid soils [14]Furthermore, the elevated levels of nickel in the surface layer, with decreasing concentrations at greater depths, suggest that its source is anthropogenic, and its association with organic matter in the upper layer supports this. Nickel is considered a moderately mobile element within the soil profile [15].

The data also show that heavy metal concentrations in the surface soil layers are higher than those in deeper layers. This is likely due to multiple pollution sources, including industrial waste, fertilizers, chemical pesticides, and other pollutants that tend to accumulate in the upper layers through air deposition or irrigation water[16].

The use of sewage water for fertilization also contributes to soil contamination, as it contains both organic and inorganic substances such as nitrates, phosphorus, and heavy metals like cadmium and lead. At high concentrations, these elements pose a serious risk due to their accumulation in the soi[17]. The reduced concentrations in deeper soil layers may be due to the slow mobility of these elements, their high specific density, and their bonding with organic matter, forming stable organo-metallic complexes concentrated in the surface layer[18].

Table 3 Total concentration of heavy elements in soils

Total concentration(mg kg^{-1})			Depth (cm)	Study sites	
Ni	Cd	Pb			
168	2.21	20.5	30-0	S11	Site1
162	1.73	20.0	90-60	S12	
192	2.62	24.1	30-0	S21	Site2
186	2.16	21.7	90-60	S22	
127	2.34	18.6	30-0	T11	T1
119	1.91	17.2	30-0	T12	
115	2.69	16.5	30-0	T13	
80	3.17	14.0	30-0	T01	

107	1.86	15.2	30-0	T21	T2
98	1.30	14.4	30-0	T22	
94	3.16	13.8	30-0	T23	
88	2.39	11.3	30-0	T02	
59	3.36	12.5	30-0	T31	T3
55	1.61	11.7	30-0	T32	
49	1.64	10.9	30-0	T33	
38	1.34	10.7	30-0	T03	

2.3.Chemical Fractionation of Heavy Metals:

1.2.3. Available Concentration of Heavy Metals in Soil:

Table 4 presents the available content of heavy metals in soil samples at a depth of 0–30 cm, where lead concentrations ranged from 1.40 to 2.04 mg/kg, cadmium from 0.20 to 0.27 mg/kg, and nickel from 0.39 to 0.52 mg/kg. At the 60–90 cm depth, lead ranged from 1.26 to 2.00 mg/kg, cadmium from 0.18 to 0.24 mg/kg, and nickel from 0.32 to 0.43 mg/kg.

In surface soil pathway samples at the 0–30 cm depth, lead concentrations ranged from 0.37 to 1.79 mg/kg, cadmium from 0.09 to 0.19 mg/kg, and nickel from 0.271 to 0.369 mg/kg. In comparison pathway samples at the same depth (0–30 cm), lead ranged from 0.31 to 0.82 mg/kg, cadmium from 0.08 to 0.11 mg/kg, and nickel from 0.18 to 0.24 mg/kg.

The abundance of heavy metals followed the order:

$$Pb < Ni < Cd$$

Several studies, including those by, [19,20] and[21], have indicated that various factors influence the contamination of soils located along roadsides. In addition to the heavy metals emitted by vehicle exhaust gases, other sources contribute to the accumulation of these elements in the soil, such as industrial activities, waste disposal, and fuel combustion.

Table 4 Ready-mixed heavy element concentrations

Ready-mixed heavy element concentrations (mg kg-1)			Depth (Cm)	Study sites	
Ni	Cd	Pb			
0.39	0.20	1.47	30-0	S11	Site1
0.32	0.18	1.26	90-60	S12	
0.52	0.27	2.04	30-0	S21	Site2
0.43	0.24	2.00	90-60	S22	
0.36	0.19	1.79	30-0	T11	T1
0.34	0.17	1.49	30-0	T12	
0.34	0.16	1.12	30-0	T13	
0.24	0.11	0.82	30-0	T01	
0.37	0.17	1.08	30-0	T21	T2
0.34	0.13	0.54	30-0	T22	
0.32	0.12	0.52	30-0	T23	
0.20	0.09	0.43	30-0	T02	
0.30	0.11	0.49	30-0	T31	T3
0.29	0.10	0.42	30-0	T32	
0.27	0.09	0.37	30-0	T33	
0.18	0.08	0.31	30-0	T03	

2.2.3. Heavy Metals Associated with Carbonates:

Table 5 shows the concentrations of heavy metals associated with carbonates. At a depth of 0–30 cm, lead concentrations ranged from 1.82 to 2.21 mg/kg, cadmium from 0.75 to 0.92 mg/kg, and nickel from 3.01 to 3.62 mg/kg. At the 60–90 cm depth, lead ranged from 1.77 to 2.16 mg/kg, cadmium from 0.56 to 0.85 mg/kg, and nickel from 2.97 to 3.51 mg/kg.

In surface soil pathway samples at 0–30 cm, lead ranged from 0.96 to 1.35 mg/kg, cadmium from 0.11 to 0.57 mg/kg, and nickel from 1.16 to 1.89 mg/kg. In comparison pathway soil samples at the same surface depth, lead ranged from 0.87 to 1.05 mg/kg, cadmium from 0.13 to 0.23 mg/kg, and nickel from 1.38 to 1.55 mg/kg.

Clay soils were found to have higher concentrations of lead and cadmium associated with carbonates compared to other soil types[22]. This may be due to the higher content of calcium carbonate in clay soils, which enhances the retention and adsorption of lead bound to carbonates, in contrast to other soils that lack significant calcium carbonate content [23].

This finding is consistent with what was reported by[24], who indicated that all the studied soils are calcareous, and that calcium carbonate plays a key role in immobilizing cadmium and reducing its availability in the soil.

Table 5 Concentrations of heavy elements associated with carbonate

Concentrations of heavy elements associated with carbonate (mg kg-1)			Depth (cm)	Study sites	
Ni	Cd	Pb			
3.01	0.75	1.82	30-0	S11	Site1
2.97	0.56	1.77	90-30	S12	
3.62	0.92	2.21	30-0	S21	
3.51	0.85	2.16	90-30	S22	Site2
1.89	0.57	1.35	30-0	T11	
1.61	0.42	1.25	30-0	T12	
1.68	0.35	1.17	30-0	T13	T1
1.38	0.23	1.05	30-0	T01	
1.78	0.41	1.25	30-0	T21	
1.65	0.35	1.19	30-0	T22	
1.55	0.31	1.13	30-0	T23	T2
1.58	0.16	1.23	30-0	T02	
1.28	0.27	1.07	30-0	T31	
1.22	0.18	1.00	30-0	T32	T3
1.16	0.11	0.96	30-0	T33	
1.55	0.31	0.87	30-0	T03	

3.2.3 .Heavy Metals Associated with Oxides and Organic Matter:

Table 6 presents the concentrations of heavy metals associated with oxides and organic matter. At the 0–30 cm depth, lead concentrations ranged from 3.07 to 3.63 mg/kg, cadmium from 0.80 to 1.29 mg/kg, and nickel from 0.60 to 0.89 mg/kg. At the 30–90 cm depth, lead ranged from 3.01 to 3.56 mg/kg, cadmium from 0.87 to 1.23 mg/kg, and nickel from 0.63 to 0.81 mg/kg.

In surface pathway soil samples (0–30 cm), lead concentrations ranged from 1.35 to 2.27 mg/kg, cadmium from 0.49 to 1.15 mg/kg, and nickel from 0.21 to 0.45 mg/kg. In comparison pathway soil samples at the same depth, lead ranged from 1.48 to 2.11 mg/kg, cadmium from 0.39 to 1.04 mg/kg, and nickel from 0.27 to 0.45 mg/kg.

[16]found that industrial sites exhibited higher lead contamination due to their elevated lead content and the clayey texture of their soils. The highest concentrations of lead bound to oxides and organic matter were found in the surface layers of these soils. The phenomenon of lead binding to organic matter has attracted significant attention from researchers, as it plays a crucial role in immobilizing heavy metals, reducing their bioavailability, and minimizing their uptake by plants.

Table 6 Concentrations of heavy elements associated with oxides and organic matter in the study soils

Concentrations of heavy elements associated with oxides and organic (mg kg-1)			Depth (cm)	Study sites	
Ni	Cd	Pb			
0.67	0.89	3.07	30-0	S11	Site1
0.63	0.87	3.01	60-30	S12	
0.89	1.29	3.63	30-0	S21	Site2
0.81	1.23	3.56	60-30	S22	
0.75	1.15	2.27	30-0	T11	T1
0.68	1.10	2.20	30-0	T12	
0.60	1.7	2.17	30-0	T13	
0.45	1.04	2.11	30-0	T01	
0.55	1.05	2.15	30-0	T21	T2
0.47	0.94	2.08	30-0	T22	
0.41	0.76	1.92	30-0	T23	
0.33	0.58	1.96	30-0	T02	
0.36	0.68	1.77	30-0	T31	T3
0.26	0.52	1.57	30-0	T32	
0.21	0.49	1.35	30-0	T33	
0.27	0.39	1.48	30-0	T03	

4.2.3.Residual Fraction Concentrations of Heavy Metals:

Table 7 presents the concentrations of the residual fraction of heavy metals in the soils of the current study. In the 0–30 cm soil layer, lead concentrations ranged from 14.14 to 16.22 mg/kg, cadmium from 0.14 to 0.37 mg/kg, and nickel from 163.93 to 186.97 mg/kg. In the 30–60 cm layer, lead ranged from 13.96 to 13.98 mg/kg, cadmium from 0.04 to 0.12 mg/kg, and nickel from 158.08 to 181.25 mg/kg. In surface soil pathway samples (0–30 cm), lead ranged from 8.22 to 13.19 mg/kg, cadmium from 0.08 to 2.30 mg/kg, and nickel from 47.36 to 124.00 mg/kg. In the comparison soil samples, lead concentrations ranged from 7.68 to 10.02 mg/kg, cadmium from 0.56 to 1.79 mg/kg, and nickel from 36.00 to 77.93 mg/kg.

In terms of dominance in the studied soils, the order of abundance was:

Cd > Pb > Ni

This suggests that the clay fraction plays a significant role in the adsorption and retention of these heavy metals, particularly in the surface soil layer. The extent to which each metal is adsorbed depends on its individual affinity for soil components. In this context, [25]indicated that the mobility of heavy metals is largely governed by their adsorption mechanisms on soil surfaces**.**

Table 7 Concentrations of the remaining part of heavy elements

Concentrations of the remaining part of heavy elements			Depth	Study sites	
Ni	Cd	Pb			
163.93	0.37	14.14	30-0	S11	Site1
158.08	0.12	13.96	90-60	S12	
186.97	0.14	16.22	30-0	S21	Site2
181.25	0.04	13.98	90-60	S22	
124.00	0.43	13.19	30-0	T11	T1
116.37	0.22	12.26	30-0	T12	
112.38	0.46	12.04	30-0	T13	
77.93	1.79	10.02	30-0	T01	
104.30	0.23	10.72	30-0	T21	T2
95.54	0.08	10.59	30-0	T22	
91.72	1.97	10.23	30-0	T23	
85.89	1.56	7.68	30-0	T02	
57.06	2.30	9.17	30-0	T31	T3

53.23	0.81	8.71	30-0	T32	
47.36	0.95	8.22	30-0	T33	
36.00	0.56	8.04	30-0	T03	

4.soil pollution indicators:

1.4.1. Potential Ecological Risk Index (Er) and the Comprehensive Risk Index (RI):

Table 8 presents the values of the ecological risk index (Er) and the comprehensive risk index (RI) for the soils under study. The Er values for sample S1, in comparison with S2, ranged between 4.25–4.6 for lead, 24.0–25.2 for cadmium, and 4.35–6.46 mg/kg for nickel. The RI values ranged from 32.95 to 36.41 mg/kg.

When comparing T1 with T01, lead ranged from 5.85 to 6.6, cadmium from 18.0 to 25.2, and nickel from 7.4 to 12.15 mg/kg. The RI values ranged from 31.5 to 43.2 mg/kg.

In the comparison between T2 and T02, lead ranged from 6.1 to 6.7, cadmium from 16.2 to 39.6, and nickel from 6.4 to 7.75 mg/kg. The RI values were between 28.1 and 51.0 mg/kg.

For T3 versus T30, lead ranged from 5.05 to 5.8, cadmium from 36.6 to 75.0, and nickel from 48.05 to 88.55 mg/kg.

The results indicate that the ecological risk index (Er) values for lead and nickel were relatively close, based on the individual risk values shown in Table 11, and the equal toxicity coefficient assigned to both elements. The contamination level for lead and nickel was classified as low. In contrast, cadmium exhibited the highest risk levels due to its high toxicity coefficient, leading to higher Er and RI values. The overall RI values across the studied samples ranged from low to moderate risk.

These findings are consistent with those of[26], who reported a strong correlation between heavy metal concentrations in sediments and proximity to pollution sources. They observed that the closer the sampling site was to the pollution source, the higher the concentration of heavy metals in the affected soils. According to their classification, lead had a low Er level, cadmium ranged from low to moderate, and the RI was considered low.

Table 8 Potential Environmental Hazard Index and Comprehensive Environmental Hazard Index values for elements

RI	Eri for each element in sample S1 compared with S2			Depth (cm)	Study sites
	Ni	Cd	Pb		
36.41	6.96	25.2	4.25	30-0	S11	Site1
32.95	4.35	24.0	4.6	90-60	S12	
Eri for each element in the samples compared with T01						T1
37.4	7.9	21.9	6.6	30-0	T11	
31.5	7.4	18.0	6.1	30-0	T12	
43.2	12.15	25.2	5.85	30-0	T13	
Eri for each element in the samples compared with T02						
35.85	6.05	23.1	6.7	30-0	T21	T2
28.1	5.55	16.2	6.35	30-0	T22	
51.0	5.3	39.6	6.1	30-0	T23	

	Eri for each element in the samples compared with T03					T3
88.55	7.75	75.0	5.8	30-0	T31	
48.65	7.2	36.0	5.45	30-0	T23	
48.05	6.4	36.6	5.05	30-0	T33	

2.4. Geoaccumulation Index (Igeo):

Table 9 presents the values of the geoaccumulation index (Igeo) in the soils of the study area. For sample S1 compared to S2, lead values ranged from 0.16 to 0.18, cadmium was 0.16, and nickel was 0.17 mg/kg. For surface samples in T1 compared to T01, the Igeo values ranged between 0.23 and 0.26 for lead, 0.12 to 0.17 for cadmium, and 0.28 to 0.31 mg/kg for nickel.

These values were similar to those observed when comparing T1 with T02, where lead ranged from 0.24 to 0.26, cadmium from 0.11 to 0.27, and nickel from 0.21 to 0.24 mg/kg. In the T3 sample compared to T30, Igeo values ranged from 0.20 to 0.23 for lead, 0.24 to 0.50 for cadmium, and 0.25 to 0.31 mg/kg for nickel.

Overall, all values were greater than zero but less than one, placing them within the range of uncontaminated to moderately contaminated soils. However, this does not rule out the influence of human activities contributing to pollution. The results were lower than the correction factor of 1.5 used in the geoaccumulation index equation. According to[13], if the Igeo value is less than 1.5, it suggests that the heavy metals are primarily derived from natural sources (parent material). If the value exceeds 1.5, it implies a significant contribution from anthropogenic activities.

The lower values observed in this study may be attributed to the accumulation of heavy metals in the reference soil samples, which were used as a baseline to assess contamination in the soils affected by waste deposits.

Table 9 Geological accumulation index (Igeo) for the soil samples of the current study

Heavy Element Geoaccumulation Index (Igeo)			Study sites	
Ni	Cd	Pb		
I_{geo} لترب عينة S_1 المقارنة مع S_2				
0.17	0.16	0.16	S11	Site1
0.17	0.16	0.18	S12	
Igeo for each element of soil samples compared with T01				T1
0.31	0.14	0.26	T11	
0.29	0.12	0.24	T12	
0.28	0.17	0.23	T13	
Igeo for each element of soil samples compared with T02				T2
0.24	0.15	0.31	T21	
0.22	0.11	0.29	T22	
0.21	0.27	0.28	T23	
Igeo for each element of soil samples compared with T03				T3
0.31	0.50	0.23	T31	
0.28	0.24	0.21	T32	
0.25	0.24	0.20	T33	

4.CONCLUSIONS:

1.The analysis results revealed that the concentrations of heavy metals (Pb, Cd, and Ni) were higher in surface soil layers compared to deeper layers, indicating surface-level pollution sources primarily linked to human activities.

2.Nickel showed the highest accumulation among the studied metals, followed by lead and then cadmium.
3.The ecological risk index (Er) and the comprehensive risk index (RI) indicated that cadmium posed the greatest environmental risk due to its high toxicity coefficient, while lead and nickel presented low risk levels.
4.The geoaccumulation index (Igeo) values were below 1.5 for all elements, suggesting that the primary source of contamination is geological (parent material), with limited anthropogenic contribution.
5.Clayey soils demonstrated higher adsorption capacity for heavy metals, especially lead and cadmium, due to their higher content of calcium carbonate and organic matter.

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