Evaluation of Soil Pollution With led based on same certain Physical and Chemical Characteristics Using Same Pollution indicators

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Abstract:

This study involves evaluating Pb contamination of the surface (0-2 cm) and subsurface (20 cm) soils via several pollution indices such as Contamination Factor (Cf), Pollution Load Index (PLI), Enrichment Factor (EF), Geo-accumulation Index (Igeo), and Contamination Degree (Cdeg). Based on the findings of this investigation, there are elevated levels of Pb and Pb contamination in surface soils. In addition, it is evident from the results that Pb does not penetrate the surface horizon due to limited anthropogenic factors. Moreover, it should be noted that the major causes of Pb pollution in the region under analysis include vehicular emissions and anthropogenic factors. The highest pollution was detected in S2 and S5 locations Within the city of Kirkuk, which had the values of Cf and PLI of over 12. As a result, these areas can be described as heavily polluted by Pb. Based on the evaluation of Igeo and EF, it is possible to conclude that Pb enrichment is predominantly anthropogenic Such as factories and rapid urban development. It is important to emphasize that subsurface soils contained fewer contamination indicators. However, according to previous investigations, high concentrations of clay, carbonates, organic matter, and alkalinity of soils can play an important role in the immobilization of Pb.

.**Keywords:** Surface and subsurface soils; Heavy metal pollution indices; Contamination Factor (Cf); Pollution Load Index (PLI); Enrichment Factor (EF); Geo-accumulation Index (Igeo); Contamination Degree (Cdeg).

Introduction

Keywords: Soil is one of the basic elements of the ecosystem responsible for the support of vegetation development and life on our planet. Soil works as an agricultural medium as well as a natural filter that provides an environmentally clean state [1]. Nonetheless, current rapid industrialization, urbanization, and population growth put additional pressure on the environment resulting in soil pollution [2]. Among various pollutants, heavy metals stand out owing to the impossibility of their biodegradation, high persistence, and bioaccumulative character [3]. The element that belongs to these dangerous substances is the so-called Pb since it is considered highly toxic

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due to its persistence, ability to accumulate in living organisms, and negative impacts on the environment and humans [4]. Lead can be introduced into the environment either naturally or artificially. In the former case, this process happens owing to rock weathering, volcanic activities, and natural soil formation whereas artificial Pb enters the environment as a result of industrial activity, mining, smelting operations, waste dumping, burning of fossil fuel, and emission from automobiles [5]. Previously, widespread use of leaded gasoline was one of the major causes of Pb soil pollution [6].In soils, lead usually accumulates in the surface layer due to its limited solubility and immobility [7]. This accumulation is determined by such physical and chemical properties of soil as pH, organic matter content, composition of clay minerals, and $CaCO_3$ content [8]. Hence, Pb tends to be retained in soils enriched in calcium carbonate and clay. There are many studies reporting high Pb concentrations in soils close to roads, industries, and highly populated areas [9]. Numerous researches performed in Iraq show significant contamination of soils with heavy metals [10]. The contamination of soils with heavy metals, including Pb, may cause various ecological and health problems. For instance, the uptake of lead by plants contributes to its further inclusion into the food chain. Even though Pb moves poorly in plant organs, it accumulates in roots and leafy vegetables resulting in possible ingestion [11].It is vital to know the distribution, concentration, and features of behavior of lead in soil in order to evaluate pollution of the environment and associated risks. Therefore, this research aims at estimation of the Pb concentration in surface and subsurface soils. To assess distribution of the element, we used indices of pollution degree (Cdeg).

2-Materials and Methods

Soil samples were collected from different locations at two depths:Surface soil: 0–2 cm ، Subsurface soil: 20 cm .

Each sample was a composite of three subsamples collected randomly to ensure representativeness. Samples were air-dried Crushed using a ceramic mortar. Sieved through a 2 mm mesh.Stored in plastic containers.Standard solutions of lead were prepared at concentrations:1, 2, 3, 4, and 5 ppm ،A blank solution was prepared using nitric acid and distilled water. Soil samples (0.5 g) were digested using aqua regia ($HCl:HNO_3$, 3:1), heated at 110°C until dryness, then diluted and filtered to 100 ml [12]. Lead concentration was determined using Flame Atomic Absorption Spectrophotometer (AAS).

(a) Contamination Factor (Cf)

The contamination factor (Cf) indicates the level of metal contamination in soil relative to a background concentration [13] :

Cf=cm sample/cm background (1) ....

Where:

C_m=concentration of the metal in the soil sample (ppm)

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Background = concentration of the metal in uncontaminated soil (ppm). C_m

(b) Pollution Load Index (PLI)

PLI provides a composite assessment of overall metal pollution at a site:

$PLI=(CF1\times CF2\times CF3\ldots.CF_n)^{1\backslash n}$ 2) .... (

Cf = contamination factor for each metal

n = number of metals considered

PLI > 1 indicates pollution, while PLI < 1 indicates no pollution [14]**.**

(c) Enrichment Factor (E.F)

The enrichment factor evaluates the degree of anthropogenic contribution to metal concentration:

EF = (Pb/Fe)sample / (Pb/Fe)background …… (3)

EF ≈ 1 indicates natural origin, EF>1 indicates enrichment due to human activities

EF ≈ 1 indicates natural origin, EF > 1 indicates enrichment due to human activities[15].

(d) Geo-accumulation Index (Igeo)

The geo-accumulation index (Igeo) assesses pollution intensity:

$Igeo = \log_2 (C_{metal} / 1.5 * C_{control})$ ……….. (4)

Cmetal = measured concentration of the metal (ppm).

Ccontrol= background concentration (ppm)

1.5 = factor to account for natural variability in background concentrations [16]

(e) Contamination Degree (Cdeg)

$$Cdeg = \sum_{i=0}^{n} Cif \ldots\ldots\ldots\ldots (5)$$

The contamination degree represents the cumulative effect of all metals in a soil sample[13]:

i = contamination factor of metal

n = total number of metals considered

Results and Discussion

The analysis of soil physicochemical properties (Table 1) and contamination index for heavy metal pollutants (Table 2) offers an understanding of the Pb behavior, accumulation, and distribution patterns in the investigated soil. It is evident from the findings that the physicochemical features of the soil have a significant impact on the vertical distribution and spatial heterogeneity of Pb pollution. In terms of pH, the soils of the study area are alkaline, with pH ranging between 7.6 and 8.2 (Table 1). Under alkaline pH conditions, solubility of Pb drops as it forms hydroxide and carbonate, thus limiting its vertical movement in the soil profile [17]. This pattern is clearly illustrated in Table (2) where higher contamination index values, including Cf, PLI, and Igeo, are recorded in the surface layers compared to other depths. This shows that Pb tends to accumulate in the upper layer of the soil. Electrical Conductivity (EC) of the investigated soil varies between 2.2 $dS\cdot m^{-1}$ and 4.2 $dS\cdot m^{-1}$, indicating the moderate level of salinity. Salinity increases ionic strength, hence influencing the process of heavy metal ions absorption and their subsequent adsorption to soil surfaces [21]. Despite higher EC values measured in surface layers of some soils (e.g., S5), the contamination index of heavy metal pollutants remains high, showing that salinity does not facilitate Pb leaching to deeper soils

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but rather contributes to redistribution and accumulation at the surface. Cation exchange capacity (CEC) of the investigated soils ranges between 22 cmol·kg^{-1} and 32 cmol·kg^{-1}, indicating high capacity for retaining cations. CEC is known to enhance heavy metals adsorption to negatively charged sites on the soil surface [22]. As can be seen in Table (2), Cf and Cdeg index values increase in surface soils, meaning that soils with high CEC retain Pb more effectively. Thus, heavy metals accumulate on soil surface rather than moving to deeper layers. Organic matter (O.M) of the soil is present at the level of 7 – 15 g·kg^{-1} and is slightly higher in the topsoil. The O.M plays an important role in heavy metal mobility through complexing with functional groups such as carboxyl and phenolic compounds [23]. As indicated in Table (2), enrichment factor (EF) values increase in surface soils due to Pb association with complex organic substances. Nonetheless, depending on the chemical condition, organic matter can enhance Pb mobility in soil environment. The investigated soil demonstrates the presence of calcium carbonate ($CaCO_3$) in the range of 205 g·kg^{-1} and 280 g·kg^{-1}. Calcium carbonate is known to immobilize Pb through precipitation and co-precipitation [25]. As can be noted from Table (2), high Igeo values occur in surface soils as a result of Pb precipitation and accumulation in stable mineral form. Moreover, the existence of $CaSO_4$ (gypsum) in soil solution affects ionic balance and enhances Pb immobility. Soil textural analysis shows that the soils belong to clay loam or loam class with high clay and silt content (Table 1). Fine-textured soils possess a large surface area and abundant adsorption sites, which enhance the retention of heavy metals [26]. This is directly reflected in the contamination indices (Table 2), where higher Pb concentrations and associated indices (Cf, PLI, and Cdeg) are consistently recorded in surface soils with higher clay content. The reduced values in subsurface layers further confirm that soil texture plays a key role in limiting Pb mobility.Overall, the integration of Tables (1) and (2) demonstrates that the observed pattern of Pb contamination—characterized by higher concentrations and pollution indices in surface soils—is strongly controlled by soil physicochemical properties. Factors such as alkaline pH, high CEC, elevated organic matter, carbonate content, and fine texture collectively enhance Pb adsorption, precipitation, and stabilization in the upper soil horizons. These findings confirm that Pb contamination in the study area is not only driven by anthropogenic inputs but also significantly influenced by intrinsic soil properties that regulate its mobility and environmental risk.

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Table (1). Physicochemical Characterization of Surface and Subsurface Soils and Its Influence on Lead (Pb) Distribution

Texture	Sand	Silt	Clay	$CaSO_4$ ($g \cdot kg^{-1}$)	$CaCO_3$ ($g \cdot kg^{-1}$)	O.M ($g \cdot kg^{-1}$)	CEC ($cmol \cdot kg^{-1}$)	EC ($dS \cdot m^{-1}$)	pH	Sample	No.
Clay loam	200	420	380	45	220	12	28	3.2	7.8	0–1 cm	S1
Clay loam	200	400	400	50	240	8	26	2.8	7.9	20 cm	
Clay loam	210	430	360	48	210	14	30	3.8	7.7	0–1 cm	S2
Clay loam	200	410	390	52	235	9	27	3.1	7.8	20 cm	
Clay loam	210	420	370	46	225	13	29	3.5	7.9	0–1 cm	S3
Clay loam	200	405	395	51	245	9	26	3	8	20 cm	
Loam	250	410	340	40	260	10	24	2.5	8.1	0–1 cm	S4
Loam	250	390	360	44	280	7	22	2.2	8.2	20 cm	
Clay loam	210	440	350	50	205	15	32	4.2	7.6	0–1 cm	S5
Clay loam	200	420	380	55	230	10	29	3.4	7.7	20 cm	
Loam	240	400	360	42	250	11	25	2.7	8	0–1 cm	S6
Loam	240	380	380	46	270	7	23	2.3	8.1	20 cm	
Clay loam	210	425	365	47	215	13	28	3.6	7.8	0–1 cm	S7
Clay loam	200	410	390	52	240	9	26	3	7.9	20 cm	

Pollution Indices Assessment and Source Interpretation of Lead (Pb) in Soil Profiles:

Evaluations of the Pb contamination status of soils were carried out based on different pollution indices, namely Contamination Factor (Cf), Pollution Load Index (PLI), Enrichment Factor (EF), Geoaccumulation Index (Igeo), and Contamination Degree (Cdeg), which are shown in Table 2. Surface soil samples showed increased Cf values varying from 2.8 (S4) to 12.85 (S5), representing moderate to very heavy pollution levels, whereas higher concentrations were detected in the vicinity of intense anthropogenic influence such as exhausts, industry, and urban runoff [27]. Subsurface soils contained reduced Cf values (1.15-6.65), owing to the limited mobility of Pb in vertical direction because of sorption on clay minerals, complexation with

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organic materials, and precipitation with calcium carbonates and gypsum (Table 1) [28].

In addition, PLI values were above unity for all collected soil samples, thus indicating the widespread pollution caused by Pb in both surface and subsurface layers of studied soils, although the intensity decreases with the depth of samples (surface: 2.8-12.85; subsurface: 1.15-7.27) [29]. As for the EF index, it offers more data on the source of Pb contamination. Surface soils have shown considerable enrichment (S2: 14.58; S5: 14.99) as opposed to subsurface ones, having EF between 1.26-7.27. This indicates that the source of contamination is anthropogenic [30].

The geo-accumulation index (Igeo) showed slightly polluted surface soils (0.9 in S4) and heavily polluted samples (3.1 in S5), whereas subsurface soils showed reduced contamination (e.g., -0.38 in S4), which can be explained by low soil leaching and accumulation in the top layer. High clay content, moderate organic matter content, and alkaline pH (Table 1) contribute to increased metal sorption, justifying the Igeo values mentioned above [31]. Finally, the Cdeg – the cumulative contamination index – was substantially higher for surface soils (5.5–12.85) compared to subsurface ones (1.15–7.27). This underscores the critical importance of Pb contamination in the uppermost soils for further remediation [27,33].

In conclusion, the combination of the pollution indices used has offered a complete image of Pb contamination trends in the area under investigation, where anthropogenic activities dominate in terms of metal enrichment, while soil physical and chemical characteristics impact its mobility and retention.

Table (2) . Comprehensive Assessment of Lead (Pb) Levels and Associated Pollution Indices in Surface and Subsurface Soil Profiles.

Cdeg	**EF**	**PLI**	**Igeo**	**Cf**	**Pb (ppm)**	**Sample**	**No.**
5.5	6.42	5.5	1.87	5.5	110	0–1 cm	**S1**
4.34	4.74	4.34	1.53	4.34	86.8	20 cm	
12.5	14.58	12.5	3.06	12.5	250	0–1 cm	**S2**
5.5	6.02	5.5	1.87	5.5	110	20 cm	
8.63	10.07	8.63	2.52	8.63	172.6	0–1 cm	**S3**
5.15	5.63	5.15	1.78	5.15	103	20 cm	
2.8	3.27	2.8	0.9	2.8	56	0–1 cm	**S4**
1.15	1.26	1.15	-0.38	1.15	23	20 cm	
12.85	14.99	12.85	3.1	12.85	256.9	0–1 cm	**S5**
6.65	7.27	6.65	2.15	6.65	133	20 cm	
5.3	6.18	5.3	1.82	5.3	106	0–1 cm	**S6**
1.25	1.37	1.25	-0.27	1.25	25	20 cm	
7.42	8.64	7.42	2.31	7.42	148.3	0–1 cm	**S7**
5.3	5.8	5.3	1.82	5.3	106	20 cm	

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The above-mentioned contamination indices represented in Figure 1—Contamination Factor (Cf), Geo-accumulation Index (Igeo), and Pollution Load Index (PLI)—exhibit high values for surface soils, as the maximum Cf value of 12.85 is obtained at S5, Igeo reaches 3.1, and PLI follows the Cf tendency. Consequently, the visual evidence provided by the graph confirms the results of the quantitative analysis and testifies to the severe impact of anthropogenic activity on the surface layer of soil. The Enrichment Factor (EF) and Contamination Degree (Cdeg) indices also display the same tendency, whereby the maximum EF value in the most contaminated area exceeds 14, thus further supporting the prominent role of humans in soil Pb contamination [29,30]. In turn, all contamination indices demonstrate lower values in the subsurface soils, where the values of Cf vary between 1.15 and 6.65, whereas the lowest value of Igeo reaches -0.38 (at S4) and PLI exceeds unity. The observed phenomenon can be explained by the impact of soil physicochemical characteristics on the lead distribution in soil, whereby high content of clay, organic matter, and alkaline soil pH prevents Pb from moving deeper into the subsurface soil (Table 1) [31,32]. Moreover, chemical stabilization of Pb by precipitation with calcium carbonate and gypsum supports the observed trend. Thus, the information provided in Figure 1 clearly corroborates the previous quantitative analysis results and highlights the impact of anthropogenic activities on Pb concentration in soil and its distribution at different depths. At the same time, Figure 1 emphasizes the presence of spatial contamination variation among the analyzed samples and identifies the sampling points with a relatively high Pb contamination level (S2, S5). All the above-mentioned factors support the conclusion that anthropogenic activities are a significant source of lead pollution, and effective soil remediation actions are needed [33,34].Conclusion drawn from Figure 1Surface soils demonstrate the highest Pb concentrations and contamination indices; subsurface soils show low contamination due to soil stabilization of Pb. Hotspot locations (S2, S5) should be treated as priorities for soil Pb remediation.

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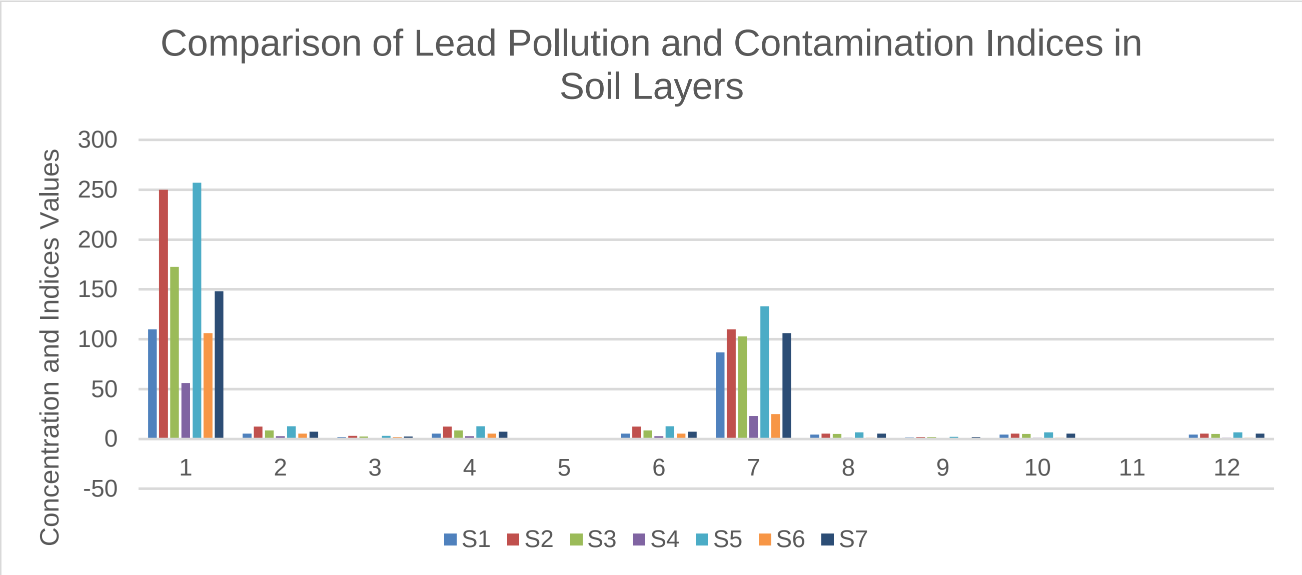

Figure 1. Graphical Comparison of Lead (Pb) Distribution and Pollution Indices (Cf, Igeo, PLI, EF, Cdeg) Across Surface and Subsurface Soil Samples

Conclusions

The results showed that subsurface soils had lower levels and indicators of pollution compared to surface soils, reflecting the limited migration of lead to deeper soil layers. These findings indicate a clear impact of human activity on soil quality in the studied area, which could negatively affect human health, agricultural production, and the environment in general.

Therefore, the study recommends conducting quantitative studies and periodic monitoring of heavy metal concentrations in the soil, along with developing plans to reduce pollution sources, given the significant importance of this aspect in protecting human health, ensuring the sustainability of agricultural lands, and preserving the environment.

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