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Assessment of Soil Fertility and Heavy Metal Contamination: Nutrient Analysis and Health Risk Evaluation in Sulaymaniyah Governorate, Northern Iraq

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Abstract

Soil quality plays a critical role in environmental sustainability, agricultural productivity, and human health. This study aimed to evaluate soil fertility status, heavy metal contamination, and associated non-carcinogenic health risks at 10 selected sites in Sulaymaniyah Province, Iraq. Soil samples (0-15) cm were collected and analyzed for essential nutrients (K^+, Mg^{2+}, Mn^{2+}, Ca^{2+}, and Mo^{2+}) and heavy metals (Zn, Pb, Cd, Cu, and Co) using standard analytical methods, including ICP-OES. Soil quality was evaluated using contamination factor (Cf), potential ecological risk index (RI), and the Canadian Council of Ministers of the Environment soil quality index (CCME-SoQI). Human health risks were assessed through estimated daily intake (EDI), hazard quotient (HQ), and hazard index (HI). The results indicated elevated concentrations of Zn (103.88 $mg.kg^{-1}$), Pb (114.02 $mg.kg^{-1}$), Cd (3.26 $mg.kg^{-1}$), and Cu (191.30 $mg.kg^{-1}$) at certain sites, exceeding WHO permissible limits, particularly at sites S7 and S9. Nutrient analysis indicated adequate levels of K (45.8-179.00 $mg.kg^{-1}$), Mg (177.7-253.7 $mg.kg^{-1}$), and Mn (22.3-43.4 $mg.kg^{-1}$), while Ca up to (8246.7 $mg.kg^{-1}$) and Mo up to (0.469 $mg.kg^{-1}$) were excessively high in several locations. CCME-SoQI values ranged from 36.68 to 78.03, classifying most sites as having medium to high environmental concern. Health risk assessment revealed that HQ and HI values were low, limited to HI (0.028 to 0.080), indicating no immediate non-carcinogenic risk through soil ingestion, although Pb and Co contributed relatively higher risk values. Overall, the results highlight localized heavy metal contamination and nutrient imbalance, emphasizing the need for continuous monitoring and sustainable soil management strategies.

1. Introduction:

Soil plays an important role in maintaining environmental health and agricultural productivity. Because it supports plant growth, which in turn feeds humans and animals, soil is extremely vital to the environment. However, as a result of human activity, soil becomes contaminated with a variety of pollutants, including fertilizers, pesticides, particulates, etc. [1]. In recent years, environmental and health issues have gained significant international attention [2]. Municipal solid waste, hospital waste, overuse of pesticides, fertilizers, and herbicides, ponding of industrial effluents, and the discharge of industrial solid waste on open land are the main causes of soil contamination. Because heavy metals are toxic and pose a hazard to both human health and the environment, soil pollution with these contaminants is a serious concern [3].

Heavy metals can accumulate in soil, plants, and water after being introduced into the environment. They do not biodegrade; whether inhaled, ingested, or absorbed via the skin, they remain and present serious health dangers [4], [5]. Acute exposure can cause rashes, gastrointestinal problems, nausea, and vomiting. Extended exposure can harm the nervous system and lead to conditions like Parkinson's and Alzheimer's [6] and can harm essential organs, including the kidneys, liver, and lungs. Human health depends on trace metals like Cu, Se, and Zn, yet high concentrations can be hazardous [7]. Plant growth and soil fertility are significantly affected by nutritional elements. Mineral nutrients are typically categorized into two groups: macronutrients (N, P, K, S, Ca, and Mg) and micronutrients (Cl, Fe, B, Mn, Zn, Cu, Mo, and Ni), which are needed by plants in much smaller amounts. However, some soils lack the necessary concentrations of essential nutrients for plants to grow rapidly and produce well. Under such circumstances, it is necessary to apply additional micronutrients by foliar sprays or commercial fertilizers [8].

Other elements like Na, Si, Co, and Se are beneficial to plants but probably not necessary for growth [9]. Fertile soil supports plant growth and yield, but the depletion or excess of these nutrients can lead to reduced productivity and environmental degradation [10]. In this study, we aim to assess both the fertility of soil and the contamination by heavy metals in some places in Sulaymaniyah, Iraq. This region, with agricultural importance, faces soil management and environmental health challenges. By analyzing essential nutrients and heavy metals, we aim to evaluate the potential risks to human health using health risk assessment frameworks.

2. Materials and Methods:

2.1 Study Area:

The study area was conducted in ten different sites in Sulaymaniyah province as shown in Figure 1. The area was selected to examine soil quality, the level of heavy metals in soil, and the effects of industrial activity on soil contamination, as well as to assess the risks of soil pollution to human health.

2.2 Soil Sampling:

Soil samples were collected during September 2024, situated from ten different sites (the samples were obtained from 0-15 cm using a steel auger). Following sample collection, soil samples were packaged in plastic bags and labeled, and then transported to the laboratory. In the laboratory, soil samples were air dried in a clean, dust-free environment at room temperature, 25^{o}C, for 3 to 5 days. Next, sieved soil samples using a 2mm sieve to prepare samples for digestion and analysis. The describtion of sample locations are presented in Table 1.

2.3 Soil Analysis:

Soil samples were analyzed at the University of Salahaddin, College of Science, Environmental Science and Health department for chemical properties of soil to determine essential elements of soil. Heavy metals (Zn, Pb, Cd, Cu and Co) were analyzed by using the acid digestion method 1 g of soil was placed in a 250 ml volume trick flask of digestion at first samples heat on at 95 ^{o}C with 10 ml of 50 % HNO3 without boiling after cooling samples were added slowly 10 ML of 30 % H2O2 after the mixture boiled with 10 ml 37% HCl at 95 ^{o}C for 15 minutes. After cooling, the digested solution obtained was filtered with a 0.45μm M membrane paper, then diluted to 100ml with deionized water and stored at 4^{o}C [11]. The Apric and Elmer optimum of 4300 DV inductively coupled plasma optical emission spectrometer. ICP- OES was used to determine metals. Nutrients like calcium and magnesium were quantified using the EDTA method as determined by [12]. Potassium was determined using a flame photometer instrument as determined by [13].

2.4 Statistical Analysis:

SPSS was used to conduct statistical analysis of data; the experimental design was one-way ANOVA to compare between locations and the correlation between metals. The significance level was set at P≤0.05.

2.5 Calculation of Indices:

2.5.1 Contamination Factor (*Cf*):

The level of contamination of heavy metals in soil expressed in contamination factor terms, calculated as follows,

$$Cf = \frac{CD(sample\ concentration)}{CR(Bachground\ concentation)} \tag{2.1}$$

CD is the measured concentration of heavy metal CR is the background value of heavy metal in soil Cf is the contamination coefficient [14]. The grading standard and classification of Cf values are shown in Table 2.

2.5.2 CCME soil quality index (SoQI):

The Canadian Council of Ministers of the Environment (CCME), soil quality index is an additional tool that tends to focus more on determining the relative risk through comparing pollutant concentration levels with the suitable soil quality guidelines. The SQoI for contaminated sites was developed by using three factors, namely, F1 (Scope), F2 (Frequency), and F3 (Amplitude) [15]. Table 3 ilustrate the concern levels of the soil quality index.

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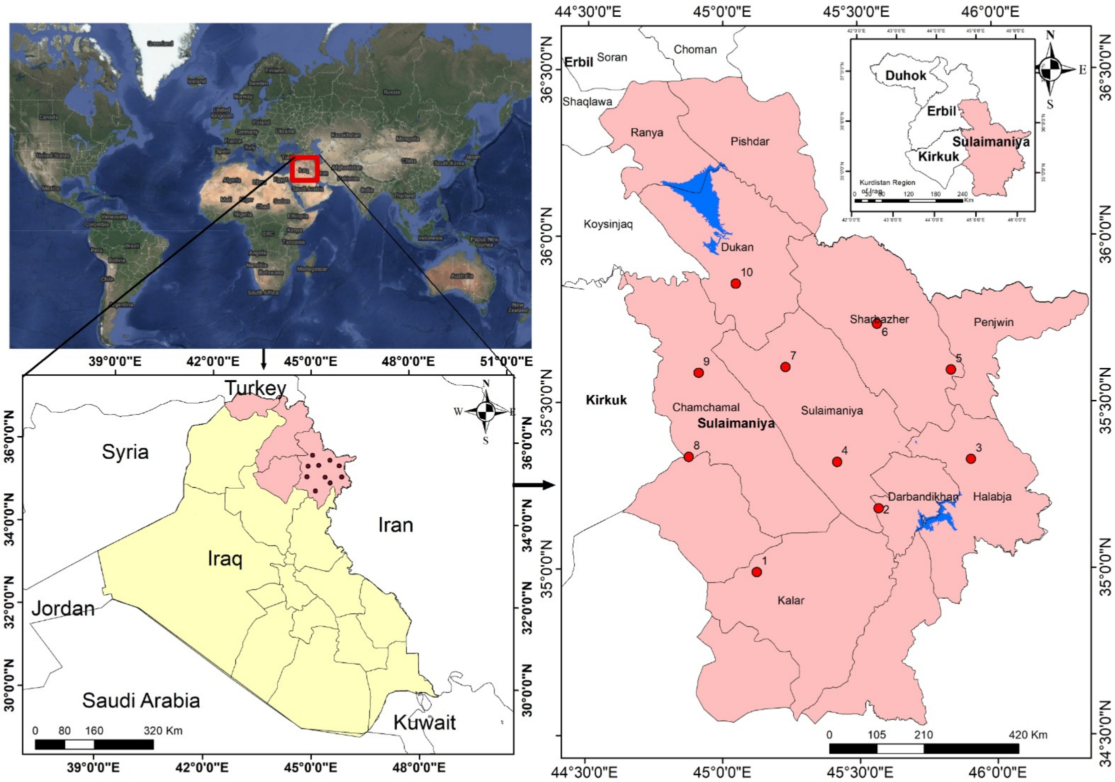

Figure 1. Map showing sampling locations.

$$F^1 = \frac{Number\ of\ failed\ contaminants}{Total\ number\ of\ contaminants} \times 100 \tag{2.2}$$

$$F^2 = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} \times 100 \tag{2.3}$$

$$Excursion^1 = \frac{Failed\ Test\ Vaue}{Guideline} - 1 \tag{2.4}$$

For the cases in which the test value must not fall below the guideline:

$$Excursion^2 = \frac{Guideline}{Failed\ Test\ Value} - 1 \tag{2.5}$$

$$ase = \frac{\sum_{i=1}^{n} excursion}{\#of\ failed\ tests} \tag{2.6}$$

$$F^3 = \frac{ase}{0.01\ ase + 0.01} \tag{2.7}$$

$$SoQI = 100 - \frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \tag{2.8}$$

2.6 Health Risk Assessment (Non-Carcinogenic):

Through ingestion, the population's health risk for the nearby soils was evaluated. The United States Environmental Protection Agency's (USEPA) health risk assessment techniques were used in this investigation [16]. Three indices were used to assess non-carcinogenic health risks associated with heavy metal consumption: the hazard index (HI), the target hazard quotient (THQ), and the estimated daily intake (EDI). These techniques were based on research [17] to evaluate possible risks to human health.

2.6.1 Estimated Daily Intake (EDI):

EDI for heavy metal ingestion through was calculated for each element in (mg/kg/day) by using equation (2.11). The exposure parameters used for heavy metal ingestion are shown in Table 4.

$$EDIing = \frac{Csoil \times IngREF \times ED}{BWAT} \times 10^{-6} \tag{2.9}$$

parameters and input assumtions for HMs ingestion in soil is shown in Table 4.

2.6.2 Hazard Quotient (HQ):

The non-carcinogenic risk associated with individual heavy metals was assessed using the hazard quotient (HQ). If the

Table 1. Description of Sample Locations.

Sample No.	Location		Coordinate	
	Area Name	Province	Latitude	Longitude
S1	Kalar	Sulaimaniah	N 34.992397^o	E 45.124672^o
S2	Derbandikhan	Sulaimaniah	N 35.182617^o	E 45.570728^o
S3	Halabja	Sulaimaniah	N 35.328788^o	E 45.910988^o
S4	Sulaimanyiah (Southern)	Sulaimaniah	N 35.323060^o	E 45.419855^o
S5	Penjwen	Sulaimaniah	N 35.597984^o	E 45.839820^o
S6	Center-Sharbazher	Sulaimaniah	N 35.737489^o	E 45.568986^o
S7	Center-Sulaimanyiah	Sulaimaniah	N 35.607936^o	E 45.231730^o
S8	Center-Chamchamal	Sulaimaniah	N 35.338594^o	E 44.875701^o
S9	Chamchamal (Northern)	Sulaimaniah	N 35.591194^o	E 44.911663^o
S10	Dukan	Sulaimaniah	N 35.858921^o	E 45.048224^o

Table 2. The grading standard level of contamination factor (Cf) in soil.

Contamination factor (Cf)	Pollution degree
Cf < 1	Refer to low contamination
1 ≤ Cf < 3	Refer to moderate contamination
3 ≤ Cf≤ 6	Refer to considerable contamination
Cf > 6	Refer to very high contamination

Table 3. Concern levels of the soil quality index.

Site Classes or Level of Concern	Soil Ranking Categories of the SoQI
Very low	90-100
Low	70-90
Medium	50-70
High	30-50
Very high	0-30

Hazard Quotient (HQ) is less than 1, the local population is considered safe. If the HQ is one or higher, it is considered unsafe for human health [17]. Each metals has different reference dose as shown in Table 5.

$$HQ = \frac{EDI}{RfD} \tag{2.10}$$

2.6.3 Hazard Index (HI):

The risk to human health is higher when there are several heavy metals than when there is only one. We use the total hazard index (HI), which shows the cumulative non-carcinogenic risks related to exposure to various heavy metals, to assess the overall health impact of these metals. The following is the formula (2.11).

$$HI = \sum_{j=1}^{m} HQi \tag{2.11}$$

A HI score larger than one (>1.0) implies a very high risk of harm to human health, whereas a value less than one (<1.0) suggests no obvious non-carcinogenic damage to the human body [19].

3. Results and Discussion:

3.1 Soil Fertility Assessment:

The analysis of soil samples from different sites (S1-S10), provided insights into the nutrient distributions, including potassium (K), magnesium (Mg), manganese (Mn), calcium (Ca), and molybdenum (Mo) as shown in Table 6.

Mean concentration of K ranged from 45.8 mg.kg^{-1} (S4) to 179 mg.kg^{-1} (S6). According to the recommended nutrient value for soils as shown in (Table 7), several samples, such as S1, S2, S3, S5, S6, S7, S9, and S10, exhibited concentrations within the optimum range (100-200) mg.kg^{-1},

Table 4. Parameters and input assumptions for HMs ingestion in soil.

Parameter	Symbol	Unit	Standard value
heavy metal	concentration	Csoil	mg kg−1
Ingestion ratio	IngR	Mg day	100
Exposure frequency	EF	days year−1	350
Exposure duration	ED	years	30
Average time	AT	days	ED × 365
Body weight	BW	Kg	70

Table 5. Reference dose values for metals [18].

Metal	RfD
Zn	0.3
Pb	0.0035
Cd	0.001
Co	0.04
Cu	0.0003

indicating adequate potassium for plant growth. while others like S4 and S8 were categorized as low (<50 mg.kg^{-1}), which could limit plant productivity, as K is critical for water regulation and enzymatic activity, photosynthesis, carbohydrate transport, and protein synthesis in plants [8]. Mg levels were consistently within the optimal range (177.667-235.4) mg.kg^{-1} across all samples. The highest mean value was observed at S6 (253.667) mg.kg^{-1}, suggesting a relatively homogeneous distribution with no alarming deficiencies or excesses and ensuring sufficient chlorophyll formation and enzymatic activation for plant growth [20].

The concentration of Mn varied significantly, ranging from 22.333 mg.kg^{-1} (S4) to 43.409 mg.kg^{-1} (S10). All the samples were within the high range (20-50) mg.kg^{-1}, indicating sufficient availability for plant growth without reaching toxicity levels. Manganese is important for photosynthesis [21]. Calcium is a structural component of plant cell walls [8]. Calcium concentrations displayed considerable variability, ranging from 3688.967 mg.kg^{-1} (S9) to 8246.667 mg.kg^{-1} (S7), most samples exceeded the extremely high threshold (>3000) mg.kg^{-1}, particularly S6, S7, and S10, indicating potential concerns about Ca accumulation in these areas. High Ca can interfere with the absorption of Mg and K, leading to deficiency despite their presence in soil. Additionally, elevated Ca can increase soil alkalinity, reducing the availability of micronutrients like Mn, and Zn. Molybdenum concentrations ranged from 0.145 mg.kg^{-1} (S4) to 0.469 mg.kg^{-1} (S10).

All the samples exceeded the optimum range (0.2-0.3 mg.kg^{-1}), with S10 showing an extremely high concentration. An elevated concentration of Mo could impact soil microbial activity and plant health, particularly nitrogen fixation [22]. This may indicate anthropogenic inputs such as fertilizer, industrial contamination, or localized geologic inputs. The correlation matrix Figure 1 illustrates the relationship among various metals and nutrients. Potassium shows a positive correlation with all parameters except for Pb (r = -0.063) and Cd (r = -0.030) which shows a negligible relation. Mg shows a weak correlation with all metals and nutrients except a moderate relation with Ca (r = 0.55). While, Mo shows a strong correlation with Mo (r = 0.882), a negative correlation with Cu, and a weak or negligible correlation with others.

Cadmium shows a positive correlation with nutrients and metals except for Pb (r = -0.29) and Cd (r = - 0.080). while Mo, shows a negative correlation with Cu and positive with others. The moderate and strong positive correlations like Mg and Ca and Mn and Mo, may result from their co-occurrence in geochemical cycles, similar environmental behavior, or synergistic roles in biological and soil processes. Weak correlations suggest limited interaction due to differing geochemical behavior, solubility or environmental availability. Negative correlations indicate distinct sources, minimal overlap in environmental pathways, or limited shared uptake mechanisms.

3.2 Heavy Metal Concentrations and WHO Comparison:

According to the data from Table 8, the mean of Zn concentrations in the samples range from 53.74 mg.kg^{-1} (S2) to 102.88 mg.kg^{-1} (S9). The World Health Organization (WHO) set the guidelines for Zn as 50 ppm Table 8 in soil, according to this norm all samples exceeded the limit. In S 9, the Z and concentration surpass 100 mg.kg^{-1}, suggesting potential contamination, particularly if related to industrial activities or waste. A similar finding was reported by [24]. However, this location may be subject to more industrial or agricultural activities, as Zn is often associated with fertilizers and metal processing. Zn is an essential micronutrient for plants, critical for enzyme function and growth [25], so moderate levels, may still support planned health without posing toxicity risks.

These findings stand with [23]. (Table 7). The post-hoc analysis has shown that the Zn is significantly different among

Table 6. Nutrient concentrations in soil samples.

Nutrients	Descriptive Statistics	Sample Locations									
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
K	Mean	132.816 ab	107.705 ab	101.449 ab	45.800 a	144.333 b	179.00 b	158.00 b	47.806 a	99.896 ab	119.749 ab
	ST.D	13.5192	43.0183	36.2572	59.0671	42.7356	39.5095	24.2693	59.5957	76.0958	21.1666
Mg	Mean	214.067 a	195.800 a	197.400 a	201.667 a	177.66 a	253.667 a	232.667 a	235.400 a	217.067 a	225.733 a
	ST.D	16.2583	38.3474	102.5914	30.1717	34.7035	53.2009	16.2891	27.8747	9.2916	9.8658
Mn	Mean	35.197 bc	29.528 ab	35.197 bc	22.333 a	30.033 ab	33.2 b	26.867 ab	32.967 b	31.474 ab	43.409 c
	ST.D	2.4906	8.5274	7.3385	3.8436	4.6231	7.119	3.6896	2.3477	2.9501	3.9823
Ca	Mean	73945.633 ab	4467.433 ab	4291.967 ab	3770.000 a	5413.333 ab	8183.333 c	8246.667 c	3868.967 ab	3688.967 a	6308.967 bc
	ST.D	584.3230	896.6988	2243.6734	858.4288	442.4176	2749.0786	331.2980	855.9400	730.0228	779.2518
Mo	Mean	0.365 c	0.27 bc	0.363 c	0.145 a	0.265 b	0.331 bc	0.281 bc	0.306 bc	0.296 bc	0.469 d
	ST.D	0.0174	0.1181	0.0202	0.0179	0.0491	0.0823	0.0305	0.0173	0.0056	0.014

⋆ Different letters (a, b, c, d) indicate statistically significant difference among sites at p-value < 0.05 according to one-way ANOVA followed by post-hoc test.

the studied soil samples (P = 0.001). The correlation matrix Figure 2. It has been demonstrated that Zn has a positive relationship with all elements except for Mn (r = 0.042) and Mo (r = 0.093) indicating no relation. The Pb concentrations range from 2.26 mg.kg^{-1} (S1) to 114.02 mg.kg^{-1} (S9). Lead at (S9) exceeded the acceptable limits of WHO (85 mg.kg^{-1}) (Table 8). the lower Pb concentration is recorded by [26]. where Pb concentration was lower than the WHO permissible limit. Elevated Pb levels can result from anthropogenic activities such as vehicular emissions, industrial waste, and the use of contaminated fertilizers [27]. High pb concentrations in soils are particularly concerning due to their potential to harm human health through the food chain. Pb contamination may reduce plant growth, affect microbial activities, and pose risks to soil quality and plant safety [28]. There is a significant difference in Pb content between all sites with S9 (p-value = 0.002).

The correlation matrix Figure 2, shows that Pb has a moderate positive correlation with Zn, and Cd, and a negative correlation with Cu, Co, K, and Ca. Cadmium concentration, the mean values range from 0.97 mg.kg^{-1} (S5) to 3.26 mg.kg^{-1} (S9), S9 showing the highest Cd content, this raises alarms due to their extreme toxicity, even at low concentrations. A similar result was recorded by [29]. where Cd was recorded as high as 2.74 mg.kg^{-1}, exceeding the WHO limit. Cd can accumulate in plants, especially in roots, leaves, and grains ultimately affecting food safety [25]. given the widespread use of phosphate fertilizers, which often contain Cd, its presence in soil is frequently associated with agricultural inputs, [30].

Significant difference among sites is obvious for Cd content with (P-value = 0.00002) the correlation matrix Figure 2, shows that Cd has a moderate positive correlation with Pb and Zn. Mg, and negative correlation with Co and K. Copper, concentrations are highly variable, ranging from 27.38 mg.kg-1^{-1} (S9) to 191.30 mg.kg^{-1} (S7). The high concentration of Zn, Pb, and Cd at site 9 maybe, attributed to intensive anthropogenic activities, including high traffic density, improper disposal of solid waste, use of phosphate fertilizer, and proximity to commercial or small-scale industrial activities. Copper concentrations have exceeded the limit of WHO (35 mg.kg^{-1}) at S2, S4, S5, S6, S7, and S10. While Cu is necessary for plant metabolism, the mean content of Cu as observed in S7 can cause soil toxicity and reduce beneficial microbial populations.

Elevated Cu concentration in soils are often associated with the use of fungicides and other Cu-based chemicals in agriculture, industrial activities, waste disposal containing electronic and industrial waste, or maybe due to the geochemistry of Cu-rich parent material [27]. Cu concentrations can also impair nutrient absorption in plants, particularly iron and phosphorus due to antagonistic interactions [31]. The opposite result is gained through the study conducted by [32], where Cu concentration was 28.7 mg/kg. Significant differ-

Table 7. Recommended values for soil nutrients.

Nutrients	Extreme low	Low	Optimum	High	Extreme high
Micronutrients					
K	<50	50-100	100-200	>200	-
Mg	<80	80-150	150-300	300-500	>500
Ca	<200	200-1000	1000-2000	2000-3000	>3000
Micronutrients					
Mn	<2	2-5	5-20	20-50	>50
Mo	-	<0.05	0.05-0.2	0.2-0.3	>0.3
Source: [23]					

ence is also found among sites for Cu content with (P-value = 0.002). Cu has a moderate positive correlation only with Ca, and a negative correlation with Mo, Mn and Pb. Cobalt concentrations are relatively consistent, ranging from 5.31 mg.kg^{-1} (S1) to 16.34 mg.kg^{-1} (S6), with (S6) having the highest concentration. However, all soil samples' Co content was within acceptable limits (40 mg.kg^{-1}) by [33].

Though essential for nitrogen vexation in legumes, the excessive limit of Co in soil may reduce overall soil fertility [27]. Co-toxicity can inhibit plant growth, particularly in nonluminous plants, where its excessive presence can disrupt enzyme activity and reduce crop yields [34]. A concentration of 13.44 mg.kg^{-1} was recorded by [32]. Significant variation among sites for Co content (P-value = 0.00004) exists. Cobalt has shown a moderate correlation with Ca and a negative correlation with Pb and Cd Figure 1. The positive correlation between metals indicates a common source for these environmental elements. Meanwhile, a negative correlation suggests opposing trends between these metals. The elevated heavy metal concentrations in certain areas, particularly Pb, Cu, and Cd in S9 and S10, indicate potential pollution hotspots.

3.3 Soil Quality Index (SoQI):

In this study, the Canadian soil quality index was used because it is an important measure for assessing soil health and productivity for agriculture and its relation to human health. The highest soil quality index value indicates preferable soil quality and lower environmental concern. Data as shown in Table 10 indicated that the minimum and maximum values of SQoI ranged between 36.680 in S7 and 78.030 in S1.

The highest SQoI value categorizes the low level of concern, which shows that the S1 has the minimal risk for environment and it is considered a healthy and suitable soil for agriculture or planting. Medium concentration concerns were recorded at S3 and S8. This level has no high risk to the environment or health; however, it should focus on good monitoring to prevent pollutant sources and control and maintain good soil fertility.

While the lowest SQoI index value which recorded at S2, S3, S4, S5, S6, S7, S9, and S10 those level categorize the high concentration of concern as shown Table 3 this level indicates low soil management low fertility and high contamination as well as cues to decreasing nutrients in soil at this extent recommended to remediate soil by natural compounds such as green Nano technology or woody biochars to control soil contamination and remediate to good fertility, and high soil management which can use to agriculture those results are similar to those results reported by [35] used the SQoI index to inform decision making for remediation. Their results of the index were ranged between 39.9 and 49.1, respectively, which indicated that all s sites had a high-level concern for pollutants and were required to use the best method for remediation of soil.

3.4 Pollution Indices:

3.4.1 Contamination Factor Cf:

Contamination factor index is used to assess the toxic level of elements in soil. Data in Table 11 indicated that the Zn value ranged between 2.057 and 1.074, showing the contamination was moderate in all locations, if compare to guidelines as show in (Table 2) which is not critically harmful for agriculture, but probably should control the pollutant sources of Zn in soil. Pb values ranged between 1.341 and 0.026, low in all sites that had not been environmentally effective or harmful to soil fertility and management. Cd values ranging between 4.075 and 1.212 indicated contamination levels in the moderate to critical range of contamination recommended to prevent pollutant sources near those locations.

Exceptions of S9 are considered a strong contamination level by Cd. Cu values ranged between 5.313 and 0.760 contamination level of Cu is considered moderate in all locations, except S7, which is considered to have a strong contamination level of Cu. Co values ranged between 0.265 and 0.817, considering no contamination in all locations. Results indicated Co concentrations were within acceptable limits and safe to the environment, agriculture, and human health.

Table 8. Heavy metal concentrations in the studied soil.

Heavy metals	Descriptive Statistics	Sample Locations									
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Zn	Mean	56.35 ab	53.74 a	64.73 abc	54.17 a	69.95 abc	84.87 cd	83.88 bcd	59.84 Abc	102.88 d	77.34 abcd
	ST.D	8.766	5.355	5.315	22.461	27.234	2.979	0.163	21.048	16.374	2.868
Pb	Mean	2.26 a	3.30 a	3.17 a	2.81 a	2.82 a	3.21 a	3.23 a	27.79 a	114.02 b	29.77 a
	ST.D	0.268	0.732	1.182	0.226	0.175	0.131	0.070	43.039	14.926	45.914
Cd	Mean	1.45 ab	1.25 a	1.76 ab	1.04 a	0.97 a	0.98 a	2.27 b	1.89 ab	3.26 c	1.60 ab
	ST.D	0.085	0.384	0.269	0.070	0.053	0.303	0.081	0.996	0.918	0.503
Cu	Mean	27.39 a	52.78b c	33.31 a	64.20	54.43 bc	87.53	191.30	32.18 a	27.38 a	741.57 ab
	ST.D	3.718	17.219	5.248	8.508 c	11.590	19.735 d	1.000 e	5.866	2.804	5.716
Co	Mean	5.31 a	7.09 a	8.69 a	8.71 a	8.64 a	16.34 b	7.75 a	9.12 a	6.10 a	9.25 a
	ST.D	0.242	0.692	0.890	2.177	1.755	6.271	0.586	0.800	1.630	1.043

⋆ Different letters (a, b, c, d) indicate statistically significant difference among sites at p-value < 0.05 according to one-way ANOVA followed by post-hoc test.

Table 9. The WHO has set the following permissible limits for heavy metals in soil.

Parameters	Soil Target Values
Zn	50
Pb	85
Cd	0.8
Cu	36
Co	40 [32]

Source: WHO (1996).

In general, the results of contamination factor CF indicated most of levels are medium to moderate of Zn and Pb, while the high level contamination were by Cd and Cu especially in S7 and S9 recorded highest level contamination which pose risks to human health luck soil fertility, as well as cues bioaccumulation of metals in agriculture crops, those results similar to [36] results indicated the study area polluted by Cd, and the contamination level of the other heavy metals were medium to moderate in more locations.

3.5 Human Health Risk Assessment (EDI, HQ, and HI):

The estimated daily intake (EDI) values for the metals via soil ingestion Table 12 were generally low, with Zn and Cu showing relatively high values due to higher soil concentrations. Hazard quotient (HQ) for all metals Table 13 at all sites was below 1, indicating no risks to humans. if compare to guidelines as show in Table 5 Notably, Pb at S9 contributed the largest HQ value among all metals, which corresponds to the high level of Pb at this site. The hazard index, which represents the cumulative risk Table 13, ranged from 0.028 to 0.078, also below 1, which indicates that combined exposure to these metals through soil ingestion poses minimal or no health risks. The non-carcinogenic risk of heavy metals arranged from highest to lowest is as follows: Co > Pb > Cu > Cd > Zn. So, although cobalt concentrations did not exceed permissible limits, its relatively low reference dose resulted in higher HQ values compared to other metals. This indicates that toxicity potential, rather than concentration alone, governs health risk outcomes of cobalt concentration despite low

	Zn	Pb	Cd	Cu	Co	K	Mg	Mn	Ca	Mo
Zn	1	0.57	0.578	0.194	0.166	0.501	0.111	0.042	0.258	0.093
Pb	0.57	1	0.797	-0.280	-0.244	-0.063	0.103	0.079	-0.298	0.082
Cd	0.578	0.797	1	0.044	-0.333	-0.030	0.223	0.144	-0.080	0.163
Cu	0.194	-0.280	0.044	1	0.182	0.356	0.273	-0.297	0.699	-0.210
Co	0.166	-0.244	-0.333	0.182	1	0.175	0.242	0.125	0.552	0.151
K	0.501	-0.063	-0.030	0.356	0.175	1	0.240	0.070	0.466	0.102
Mg	0.111	0.103	0.223	0.273	0.242	0.240	1	0.344	0.555	0.162
Mn	0.042	0.079	0.144	-0.297	0.125	0.070	0.344	1	0.285	0.882
Ca	0.258	-0.298	-0.080	0.699	0.552	0.466	0.555	0.285	1	0.286
Mo	0.093	0.082	0.163	-0.210	0.151	0.102	0.162	0.882	0.286	1

Figure 2. Correlation matrix among the studied parameters.

Table 10. CCME Soil Quality Index (SQoI).

Locations	SoQI	Soil Ranking	Level concern
S1	78.030	70– 90	Low
S2	48.607	30– 50	High
S3	64.524	50– 70	Medium
S4	48.410	30– 50	High
S5	48.545	30– 50	High
S6	44.823	30– 50	High
S7	36.680	30– 50	High
S8	58.690	50- 70	Medium
S9	40.044	30– 50	High
S10	46.738	30– 50	High

Table 11. Contamination factors (CF) of heavy metals.

	Contamination Factor (CF)				
Locations	Zn	Pb	Cd	Cu	Co
S1	1.127	0.026	1.812	0.760	0.265
S2	1.074	0.038	1.562	1.466	0.354
S3	1.294	0.037	2.200	0.925	0.434
S4	1.083	0.033	1.300	1.783	0.435
S5	1.399	0.033	1.212	1.511	0.432
S6	1.697	0.037	1.225	2.431	0.817
S7	1.677	0.038	2.837	5.313	0.387
S8	1.196	0.326	2.362	0.893	0.456
S9	2.057	1.341	4.075	0.760	0.305
S10	1.546	0.350	2.000	1.154	0.462

risk levels at those sites. Periodic monitoring is recommended, especially for Pb and Co, as localized hotspots could pose long-term health concerns.

4. Conclusion:

This study provides an integrated evaluation of soil nutrient status, heavy metal contamination, soil quality, and associated non- carcinogenic health risks in selected areas of Sulaymaniyah Province. The results indicate that while several essential nutrients were generally sufficient to support plant growth, imbalances in certain elements and elevated concentrations of specific heavy metals were detected in some locations, reflecting the influence of anthropogenic activities on soil quality. Soil quality assessment indices revealed that most sites fall within medium to high levels of environmen-

Table 12. Estimate daily intake for metals.

Site	EDI (Zn)	EDI (Pb)	EDI (Cd)	EDI (Cu)	EDI (Co)
S1	7.7×10^{-5}	3.1×10^{-6}	2.0×10^{-6}	$3.8\ 1\times 10^{-5}$	$7.3\ 1 \times 10^{-6}$
S2	7.4×10^{-5}	4.5×10^{-6}	$1.7\ 1\times 10^{-6}$	7.2×10^{-5}	9.7×10^{-6}
S3	8.9×10^{-5}	4.3×10^{-6}	2.4×10^{-6}	4.6×10^{-5}	1.2×10^{-5}
S4	7.4×10^{-5}	$3.8\ 110^{-6}$	1.4×10^{-6}	8.8×10^{-5}	1.2×10^{-5}
S5	9.6×10^{-5}	3.8×10^{-6}	1.3×10^{-6}	7.5×10^{-5}	1.2×10^{-5}
S6	1.16×10^{-4}	4.4×10^{-6}	1.3×10^{-6}	1.2×10^{-4}	2.2×10^{-5}
S7	1.15×10^{-4}	4.4×10^{-6}	3.1×10^{-6}	2.6×10^{-4}	1.1×10^{-5}
S8	8.2×10^{-5}	3.8×10^{-5}	2.6×10^{-6}	4.4×10^{-5}	1.2×10^{-5}
S9	1.41×10^{-4}	1.56×10^{-4}	4.5×10^{-6}	3.8×10^{-5}	8.3×10^{-6}
S10	1.06×10^{-4}	4.1×10^{-5}	2.2×10^{-6}	5.7×10^{-5}	1.3×10^{-5}

Table 13. Hazard quotients and hazard index for metals.

Site	HQ (Zn)	HQ (Pb)	HQ(Cd)	HQ(Cu)	HQ(Co)	HI
S1	2.57×10^{-4}	8.85×10^{-4}	1.99×10^{-3}	9.38×10^{-4}	2.42×10^{-2}	0.028
S2	2.45×10^{-4}	1.29×10^{-3}	1.71×10^{-3}	1.81×10^{-3}	3.24×10^{-2}	0.037
S3	2.96×10^{-4}	1.24×10^{-3}	2.41×10^{-3}	1.14×10^{-3}	3.97×10^{-2}	0.044
S4	2.47×10^{-4}	1.10×10^{-3}	1.41×10^{-3}	2.2×10^{-3}	3.98×10^{-2}	0.044
S5	3.19×10^{-4}	1.10×10^{-3}	1.33×10^{-3}	1.86×10^{-3}	3.95×10^{-2}	0.044
S6	3.88×10^{-4}	1.26×10^{-3}	1.34×10^{-3}	2.99×10^{-3}	7.46×10^{-2}	0.080
S7	3.83×10^{-4}	1.26×10^{-3}	3.11×10^{-3}	6.55×10^{-3}	3.54×10^{-2}	0.046
S8	2.73×10^{-4}	1.09×10^{-2}	2.59×10^{-3}	1.1×10^{-3}	4.16×10^{-2}	0.056
S9	4.70×10^{-4}	4.46×10^{-2}	4.47×10^{-3}	9.38×10^{-3}	2.79×10^{-2}	0.078
S10	3.53×10^{-4}	1.17×10^{-2}	2.19×10^{-3}	1.42×10^{-3}	4.22×10^{-2}	0.057

tal concern, suggesting reduced soil management practices. Although the health risk assessment showed no immediate non-carcinogenic risks to the local population through soil ingestion, it highlighted the importance of preventive measures to avoid long-term environmental and health impacts. Overall, the study emphasizes the necessity of continuous monitoring, effective pollution control, and sustainable soil remediation strategies to improve soil quality, protect human health, and ensure environmental sustainability in the study area.

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References

[1] Kumar De Anil. *Environmental chemistry*. New Age International, 2003.

[2] Ana-Irina Smical, Vasile Hotea, Vasile Oros, Jozsef Juhasz, and Elena Pop. Studies on transfer and bioaccu-

mulation of heavy metals from soil into lettuce. *Environmental Engineering and Management Journal*, 7(5):609–615, 2008, doi:10.30638/eemj.2008.085.

[3] Kohinoor Begum, KM Mohiuddin, HM Zakir, M Moshfiqur Rahman, and M Nazmul Hasan. Heavy metal pollution and major nutrient elements assessment in the soils of bogra city in bangladesh. *Canadian Chemical Transactions*, 2(3):316–326, 2014, doi:https://doi.org/10.23880/oajwx-16000132.

[4] Mark A Lovell. A potential role for alterations of zinc and zinc transport proteins in the progression of alzheimer's disease. *Journal of Alzheimer's Disease*, 16(3):471–483, 2009, doi:10.1002/biof.199.

[5] Anna A Gybina and Joseph R Prohaska. Copper deficiency results in amp-activated protein kinase activation and acetylcoa carboxylase phosphorylation in rat cerebellum. *Brain research*, 1204:69–76, 2008, doi:10.1016/j.brainres.2008.01.087.

[6] Marilena Kampa and Elias Castanas. Human health effects of air pollution. *Environmental pollution*, 151(2):362–367, 2008, doi:10.1016/j.envpol.2007.06.012.

[7] Mohammad Oves, Mohammad Saghir Khan, Almas Zaidi, and Ees Ahmad. Soil contamination, nutritive value, and human health risk assessment of heavy metals: an overview. *Toxicity of heavy metals to legumes and bioremediation*, pages 1–27, 2012, doi:10.1007/978-3-7091-0730-0_1.

[8] Steven C Hodges. Soil fertility basics. *Soil science extension, North carolina state university*, 22:46–59, 2010, doi:10.13031/2013.4865.

[9] PA Niklaus, J Alphei, C Kampichler, E Kandeler, Ch Körner, D Tscherko, and M Wohlfender. Interactive effects of plant species diversity and elevated co2 on soil biota and nutrient cycling. *Ecology*, 88(12):3153–3163, 2007, doi:10.1890/06-2100.1.

[10] Hassan R El-Ramady, TA Alshaal, M Amer, É Domokos-Szabolcsy, N Elhawat, J Prokisch, and M Fári. Soil quality and plant nutrition. In *Sustainable agriculture reviews 14: agroecology and global change*, pages 345–447. Springer, 2014, doi:10.1007/978-3-319-06016-$3_1$1.

[11] Duyuşen Güven and Görkem Akıncı. Comparison of acid digestion techniques to determine heavy metals in sediment and soil samples. *Gazi University Journal of Science*, 24(1):29–34, 2011.

[12] George Estefan, Rolf Sommer, and John Ryan. Methods of soil, plant, and water analysis. *A manual for the West Asia and North Africa region*, 3(2):65–119, 2013.

[13] SE Allen, HM Grimshaw, JA Parkinson, C Quarmby, and JD Roberts. Blackwell scientific publications. *Chemical Analysis of Ecological Materials. Oxford*, 1974.

[14] Weihua Guo, Xianbin Liu, Zhanguang Liu, and Guofeng Li. Pollution and potential ecological risk evaluation of heavy metals in the sediments around dongjiang harbor, tianjin. *Procedia environmental sciences*, 2:729–736, 2010, doi:10.1016/j.proenv.2010.10.084.

[15] Kelly Potter. Canadian soil quality guidelines for the protection of environmental and human health: benzene. 2005.

[16] US EPA. Baseline human health risk assessment vasquez boulevard and i-70 superfund site demver, co, 2001.

[17] Shahla Sherwan Rasool, Raad Mohammed Abdullah, Karwan Kawa Hamakarim, Badir Qadir Surchi, and Dalshad Aziz Darwesh. Health risk assessment of heavy metals in selected culinary and medicinal herbs: A case study of rose, thyme, turmeric, chamomile, and fennel. *EURASIAN JOURNAL OF SCIENCE AND ENGINEERING*, 11(2):70–81, 2025, doi:10.23918/eajse.v11i2p5.

[18] Md Saiful Islam, Md Kawser Ahmed, Md Habibullah-Al-Mamun, and Shigeki Masunaga. Trace metals in soil and vegetables and associated health risk assessment. *Environmental monitoring and assessment*, 186(12):8727–8739, 2014, doi:10.1007/s10661-014-4040-y.

[19] O Arigbede, G Olutona, and M Dawodu. Dietary intake and risk assessment of heavy metals from selected biscuit brands in nigeria. 2019.

[20] Horst Marschner. *Marschner's mineral nutrition of higher plants*. Academic press, 2011.

[21] Rayen Millaleo, M Reyes-Díaz, Alexander G Ivanov, ML Mora, and M Alberdi. Manganese as essential and toxic element for plants: transport, accumulation and resistance mechanisms. *Journal of soil science and plant nutrition*, 10(4):470–481, 2010, doi:10.4067/s0718-95162010000200008.

[22] Umesh C Gupta and John Lipsett. Molybdenum in soils, plants, and animals. *Advances in agronomy*, 34:73–115, 1981, doi:10.1016/s0065-2113(08)60885-8.

[23] Fernando García, Miguel Boxler, Jorge Minteguiaga, Ricardo Pozzi, Luis Firpo, and German Deza. Direct and residual effects of balanced fertilization in field crops of the pampas. *Better Crops*, page 11, 2007.

[24] Siatwiinda M Siatwiinda, Gerard H Ros, Olusegun A Yerokun, and Wim de Vries. Options to reduce ranges in critical soil nutrient levels used in fertilizer recommendations by accounting for site conditions and methodology: A review. *Agronomy for sustainable development*, 44(1):9, 2024, doi:10.1007/s13593-023-00943-3.

[25] Brian J Alloway. Sources of heavy metals and metalloids in soils. In *Heavy metals in soils: trace metals and metalloids in soils and their bioavailability*, pages 11–50. Springer, 2012, doi:10.1007/978-94-007-4470-7_2.

[26] Oghenerobor Benjamin Akpor, Gladys Onolunose Ohiobor, and DT Olaolu. Heavy metal pollutants in wastewater effluents: sources, effects and remediation. *Advances in Bioscience and Bioengineering*, 2(4):37–43, 2014, doi:10.11648/j.abb.20140204.11.

[27] Alina Kabata-Pendias. *Trace elements in soils and plants*. CRC press, 2000.

[28] Domy C Adriano. Bioavailability of trace metals. In *Trace elements in terrestrial environments: biogeochemistry, bioavailability, and risks of metals*, pages 61–89. Springer, 2001, doi:10.1007/978-0-387-21510-5$_3$.

[29] Yingfeng Kuang, Xiaolong Chen, and Chun Zhu. Characteristics of soil heavy metal pollution and health risks in chenzhou city. *Processes*, 12(3):623, 2024, doi:10.1016/j.ecofro.2024.02.012.

[30] Michael J McLaughlin, DR Parker, and JM Clarke. Metals and micronutrients-food safety issues. *Field crops research*, 60(1-2):143–163, 1999, doi:https://doi.org/10.1016/s0378-4290(98)00137-3.

[31] Garrison Sposito. *The chemistry of soils*. Oxford university press, 2008.

[32] Hadil A Rifat, Abbas R Ali, and Murad I Ahmed. Distributions of some heavy metals in agricultural soil and their environmental impacts in chamchamal district, sulaymaniya governorate, northeastern iraq. *The Iraqi Geological Journal*, pages 80–94, 2024, doi:10.46717/igj.57.2a.6ms-2024-7-16.

[33] Provisional SQGHH and SQGE Provisional. Canadian soil quality guidelines for the protection of environmental and human health. *Canadian Soil Quality Guidelines*, 2007.

[34] Amar M Chaudri, Steve P McGrath, Kenneth E Giller, Egbert Rietz, and Dieter R Sauerbeck. Enumeration of indigenous rhizobium leguminosarum biovar trifolii in soils previously treated with metal-contaminated sewage sludge. *Soil Biology and Biochemistry*, 25(3):301–309, 1993, doi:10.1016/0038-0717(93)90128-x.

[35] Reuben N Okparanma. Prioritisation of crude oil contaminated sites to inform risk decision making using soil quality index. *Engineering and Applied Sciences*, 2019, doi:10.11648/j.eas.20190404.12.

[36] Muhammad Hamzah Saleem, Manar Fawzi Bani Mfarrej, Khalid Ali Khan, Sezai Ercisli, Mohsen Mohamed Elsharkawy, and Shah Fahad. Advances in physiochemical and molecular mechanisms of abiotic stress tolerance in plants. *Journal of Crop Health*, 76(4):753–767, 2024, doi:10.1007/s10343-024-00993-x.

تقييم خصوبة التربة وتلوث المعادن الثقيلة: تحليل العناصر الغذائية وتقييم المخاطر الصحية في محافظة السليمانية، شمال العراق

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الخلاصة

تلعب جودة التربة دورًا حاسمًا في الاستدامة البيئية والإنتاجية الزراعية وصحة الإنسان. هدفت هذه الدراسة إلى تقييم حالة خصوبة التربة، وتلوث المعادن الثقيلة، والمخاطر الصحية غير السرطانية المرتبطة بها في عشرة مواقع مختارة في محافظة السليمانية، العراق. تم جمع عينات التربة من عمق 0 – 15 سم وتحليلها لتحديد العناصر الغذائية الأساسية (البوتاسيوم *K*، المغنيسيوم *Mg*، المنغنيز *Mn*، الكالسيوم *Ca*، والموليبدينوم *Mo*) والمعادن الثقيلة (الزنك *Zn*، الرصاص *Pb*، الكادميوم *Cd*، النحاس *Cu*، والكوبالت *Co*) باستخدام الطرق التحليلية القياسية، بما في ذلك مطيافية الانبعاث البصري بالبلازما المقترنة حثيًا (*ICP–OES*). تم تقييم جودة التربة باستخدام عامل التلوث (*Cf*)، ومؤشر المخاطر البيئية المحتملة (*RI*)، ومؤشر جودة التربة التابع للمجلس الكندي لوزراء البيئة (*CCME–SoQI*). كما تم تقييم المخاطر الصحية على الإنسان من خلال حساب المدخول اليومي المقدر (*EDI*)، ومعامل الخطر (*HQ*)، ومؤشر الخطر الكلي (*HI*). أظهرت النتائج وجود تركيزات مرتفعة من الزنك (حتى 103.88 ملغم . كغم $^{-1}$)، والرصاص (114.02 ملغم . كغم $^{-1}$)، والكادميوم (3.26 ملغم . كغم $^{-1}$)، والنحاس (191.30 ملغم . كغم $^{-1}$) في بعض المواقع، متجاوزة الحدود المسموح بها لمنظمة الصحة العالمية (*WHO*)، وخاصة في الموقعين *S7* و *S9* . كما أظهر تحليل العناصر الغذائية وجود مستويات مناسبة من البوتاسيوم (45.8 179.00 ملغمكغم $^{-1}$) والمغنيسيوم (177.7 253.7 ملغم . كغم $^{-1}$) والمنغنيز (22.3 43.4 ملغم . كغم $^{-1}$)، بينما كانت مستويات الكالسيوم (حتى 8246.7 ملغم . كغم $^{-1}$) والموليبدينوم (حتى 0.469 ملغم . كغم $^{-1}$) مرتفعة بشكل مفرط في عدة مواقع. تراوحت قيم مؤشر جودة التربة الكندي (*CCME–SoQI*) بين 36.68 و 78.03 ، مما يصنف معظم المواقع ضمن فئة المناطق ذات القلق البيئي. كما أظهر تقييم المخاطر الصحية أن قيم *HQ* و *HI* كانت منخفضة ومحدودة، حيث تراوحت قيمة *HI* بين 0.028 و 0.080 ، مما يشير إلى عدم وجود خطر صحي ملحوظ نتيجة ابتلاع التربة، على الرغم من أن الرصاص والكوبالت ساهما بقيم خطر أعلى نسبيًا.

الكلمات الدالة : المخاطر الصحية؛ المخاطر البيئية؛ المعادن الثقيلة؛ جودة التربة؛ العناصر الغذائية.

التمويل: تم تمويل هذا البحث بالكامل من قبل المؤلفين المشاركين.

بيان توفر البيانات: جميع البيانات المقدمة في هذه الدراسة متاحة عند الطلب.

اقرارات:

تضارب المصالح: يؤكد المؤلفون عدم وجود أي تعارض في المصالح.

الموافقة الأخلاقية: طبيعة هذه الدراسة لا تتطلب الحصول على موافقة أخلاقية.

مساهمات المؤلفين: شارك جميع المؤلفين بشكل كامل في تصميم الدراسة، وجمع البيانات، وتحليلها وتفسيرها. وقد تمت مراجعة النسخة النهائية من هذا المقال بدقة من قبل جميع المؤلفين والموافقة عليها.