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Science Journal of University of Zakho

Vol. 13, No.4 pp628 - 638October-December,2025

p-ISSN: 2663-628X
e-ISSN: 2663-6298

ASSESSMENT OF SOME HEAVY METAL CONCENTRATION IN WINTER WHEAT CROP (*Triticum aestivum l.)* GROWN IN SOIL AROUND INDUSTRIAL AREA WITHIN DUHOK CITY, KURDISTAN REGION OF IRAQ.

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Received: 30 May 2025 Accepted:23 Jun 2025 Published:12 Oct 2025 https://doi.org/10.25271/sjuoz.2025.13.4.1602

ABSTRACT:

Wheat (*Triticum aestivum L.*) is a crucial staple grain for global food security, but the accumulation of harmful trace metals can compromise its safety. This study investigated the concentrations of copper (Cu), cadmium (Cd), zinc (Zn), and lead (Pb) in wheat grains and soil from various locations near an industrial area in Duhok City, from February and June 2024. The metal concentrations in wheat grains were found to range from 0.539±0.0231 to 1.035±0.0028 mg/kg for lead, 0.417±0.0085 to 0.5666±0.0063 mg/kg for zinc, 0.2203±0.0033 to 0.2723±0.0016 mg/kg for copper, and 0.004±0.001 to 0.0293±0.0038 mg/kg for cadmium., The result showed that the levels of Zn, Cu, and Cd in wheat grain were within the permissible limit according to the World Health Organisation WHO Codex Alimentarius. This suggests that industrial pollutants pose significant health risks to populations living near contaminated environments. The results of agricultural soil samples collected from the industrial area showed that the area has been slightly contaminated with toxic metals. There were considerable variations ($P<0.05$) in the concentrations of metals across the study locations. P-values for Pb, Zn, Cu, and Cd in both soil and wheat grains indicate that industrial emissions and transformation are significant sources of contamination.

KEYWORDS: Heavy metals, Soil pollution, Wheat grain, Industrial pollutant

1. INTRODUCTION

Wheat *(Triticum aestivum L.)* is a vital food source for the rapidly growing global population. It is the primary winter grain crop cultivated in Iraq and serves as a staple diet for both urban and rural populations. (Faostat, 2014). The buildup of heavy metals in the environment is a significant environmental concern due to the potential risks it poses to human and animal health. The rapid expansion of the human population, urbanization, and industrialization markedly diminishes agricultural land, while several detrimental agents also negatively impact the territories designated for agricultural production (Ali *et al*., 2019). The impacts on grown plants become more noticeable as these areas are closer to the primary pollutants in the ecosystem (Abrahams, 2002). Moreover, environmental contamination seriously affects all living entities (Bhunia, 2017). Numerous studies conducted worldwide have shown that human-made industrial activities are a primary source of heavy metal contamination in soil and the surrounding environment. Furthermore, due to the use of pesticides and artificial mineral fertilizers, contemporary agriculture is a significant anthropogenic source of heavy metals (Li *et al*., 2014). The capacity of heavy metals to penetrate food chain systems and water sources, as well as their persistence, may have long-term consequences for human health and food security (Zhang *et al*., 2018). Their constant character, considerable toxicity, bioavailability, and the danger of increased bioaccumulation help to explain the negative consequences of heavy metals on people, animals, and plants (Jiang *et al*., 2022). Due to their absorption and accumulation in crops, toxic heavy metals enter the food chain, potentially posing a risk to human health. Heavy metals pose significant risks to both human health and the environment, as they cannot be broken down through degradation (Henry, 2000). There are numerous studies on how varying stress levels affect both natural soils and crops (Liu *et al*., 2005).Heavy metals, like Cu, Cd, Pb, and Zn, are often primarily cited as contaminants of concern, and the possibility of synergistic effects of two or more metals may be of considerable importance at some sites contaminated with trace elements (Nan *et al*., 2002). These metals may be absorbed and concentrated in plant tissues from the soil, thereby significantly reducing wheat grain production and growth (Panda *et al*., 2003). The objective of this study was to investigate the impact of the industrial zone on the heavy metal content in wheat grain and soil.

2. MATERIALS AND METHODS

Description of the Current Study Area:

Duhok governorate, showing the locations of the study area. The Industrial area near Duhok City and Hajiya site was chosen for comparison because it is about 12 km away from the industrial area. and falls within latitudes 36°58'46.3" north and latitudes 42°47'55.4" East. In this industrial zone, various types

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of manufacturing activities coexist, which may even pose a threat to environmental pollution caused by industrial emissions and waste discharge. Therefore, this study will assess heavy metal contamination in soil and wheat grain, and further analyze the chemical and physical aspects of the soil in the area from February to June 2024 at six different locations, as shown in Table 1. Samples were taken during this period, February to June, which provides for wheat plant growth, seasonal effects like rainfall, chemical reactions in the soil solution, and the possibility of toxic metals dissolving and being absorbed by plants; however, mean value ±S.E. and the standard error Values were calculated from three replicates of samples for every month. Soil and plant samples were taken from the agricultural fields. Due to the region's industrial activities, it is a critical area for environmental monitoring and assessment of pollution.

Table 1: Location and coordinates of soil and wheat plant samples.

Place name	Latitude	Longitude	Elevation
Moqble	36°55'33.1"N	42°46'03.0"E	497 M
Gas power station	36°56'25.3"N	42°46'45.4"E	543 M
Kwashe village	36°57'45.5"N	42°47'32.9"E	613 M
Oil storage	36°58'34.4"N	42°47'41.1"E	642 M
Oil refinery	36°58'54.5"N	42°46'53.7"E	709 M
Hajia as control	37°01'30.5"N	42°40'36.8"E	624 M

Wheat Grain Sample Collection:

A total of six Grain samples were randomly collected for the sampling location. Each field in the research region yielded approximately 250 grams of wheat grains. The wheat plants were randomly selected within a 5 m × 5 m area and severed with scissors at a height surpassing 10 cm above the soil surface when they reached kernel maturity. The wheat grains were washed with distilled water to remove any dirt or other contaminants that had adhered. The geographical location of each sample was used to designate it. These samples were preserved in a sterilized container for transit to the laboratory for examination after being labelled.

Soil Sample Collection:

Monthly samples were collected from six distinct sites, with a distance of 1,000 to 2,000 meters between each location. In the investigation location, thirty (30) composite topsoil samples were collected at 0–15 cm depth. Approximately 1 gram of soil sample is sufficient to meet the requirements of atomic absorption spectroscopy. Nevertheless, the samples were combined, carefully homogenized, and ground using a mortar and pestle, then passed through a 200 mm mesh filter. The samples were first air-dried and then subjected to an oven at 105 °C for 24 hours. The samples were ultimately preserved in plastic vials labelled with the sample code for the duration of the analysis.

Digestion of Wheat Grain Samples:

Use a top-loading balance to measure one gram of the oven-dried sample. Transfer the sample to separate 250 ml beakers. Add 15 ml of a 3:1 mixture of 14% HCl and 70% high-purity HNO_3. A transparent solution was achieved by digesting the combination at 250°C. Whatman filter paper No. 42 was employed to filter the samples after they were diluted with distilled water to a final volume of 50 ml. The filtrate was transferred to a 100 mL volumetric flask and diluted to the designated level with deionized water. An atomic absorption spectrometer was employed to evaluate the concentrations of Cu, Zn, Pb, and Cd in the sample solution. The AAS instrument autonomously measured each sample and element in three replicates.

Digestion of Soil Samples:

To assess the quantity of hazardous metals in soil, 30 soil samples were collected. To generate a representative sample, 30 subsamples of soil were excavated to a depth of 0-15 cm using a rectangular grid with a surface area of 0.5 m2. Foreign entities were excluded, and samples were kept in clean plastic containers. Soil samples were air-dried, crushed, and sieved through a 2.0 mm screen in preparation for future research. They were then put in hermetic containers. The digesting process was completed effectively, and the receptacles were quantitatively transferred to glass beakers and allowed to settle at room temperature. A 5.0 ml diacid combination (HClO4 and HNO3) was mixed with 0.5 g of each soil sample. The digests were then heated to 200 to 250 °C, evaporated until empty, and the residual material was dissolved in double-distilled water to make the required 50 mL volume. The extracted solutions were transferred to polypropylene containers and refrigerated until analysis. The total concentrations of Cd, Zn, Cu, and Pb in soil samples were determined using an atomic absorption spectrophotometer (Analytik Jena novAA 800 F).

Statistical Analysis:

All the collected data were prepared in an Excel sheet. The data were inserted into the SPSS software program. According to the Shapiro-Wilk normality test, all data were found to be normally distributed; therefore, they were analysed using a one-way ANOVA test. Using Tukey's pairwise test for post hoc comparisons. The mean ± standard error of the mean was used to express the obtained results. Tables and figures were prepared in the Excel program. Pearson's correlation was used to indicate the correlation between data.

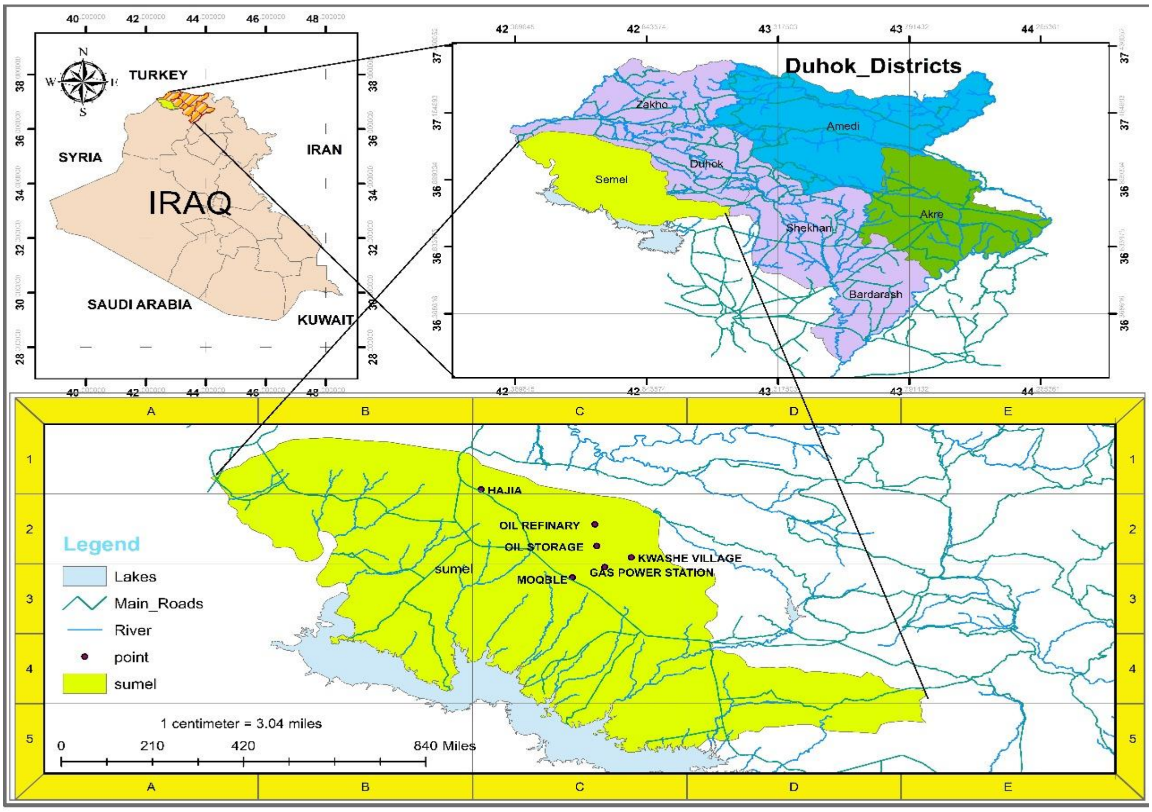

Figure 1: Location and coordinates of samples.

3. RESULTS AND DISCUSSION

Physical and Chemical Characteristics of the Soil Samples:

The solubility and mobility of metals were affected by soil characteristics, including pH, total metal concentration, texture, and organic matter content. The fundamental chemical characteristics of the 30 soil samples are shown in Table 2. The pH of the soil is a crucial factor in determining the availability of metals to plants. When the pH is high, most soils accumulate significant quantities of these metals, making them unavailable to plants. The pH values in Table 2 showed significant differences ($P < 0.05$) among sampling locations, ranging from 7.433 ± 0.033 to 7.833 ± 0.120. The pH values were mildly acidic at all of the stations. Therefore, it was anticipated that the crops grown in the studied areas would contain minimal concentrations of heavy metals. The organic matter contents of all the soils exhibited significant differences ($P < 0.05$) between sites, with concentrations ranging from 2.266 ± 0.371 to 3.712 ± 0.208. The wheat fields had the lowest organic matter content. Various factors influence the accumulation and distribution of heavy metals in soil and plants. The distance of the sample from the highway and industrial area, the soil's chemical and physical properties (e.g., pH, organic matter, silt content), wind direction, the density of cars on the road, and the duration of exposure are all factors that contribute to the results (Kalavrouziotis *et al*., 2008; Othman, 2023). The amount of organic matter, pH, and texture of soil influence the accumulation of heavy metals. Organic matter and the silt/clay fraction adsorb the heavy metal. The high pH, organic matter, and silt content facilitate the binding of heavy metals. Some of the physical and chemical properties of the soils that were investigated are detailed in Table 2. The soils that were examined had a minimal level of organic matter. The soils in the study area had a neutral pH, ranging from 7.4 to 7.8. The primary sources of heavy metals in soil and vegetation were traffic pollution and various industrial activities. Wheat field's low pH resulted from its high organic content. The electrical conductivity (EC) of the wheat field ranged from 493.2±8.8191 to 2280± 5.7735 µS/cm, while the organic contents were 0.966±0004 and 3.066±0.086. There were significant differences ($P<0.01$) between all sites regarding the EC of soil (Table 2). The highest electrical conductivity was observed in the atmospheric depositions during the oil refinery process, while the remaining locations were below the permissible limit of 2000 µS/cm. (Ryan *et al*., 2001).Total dissolved solids (TDS) also demonstrated highly significant differences ($P < 0.01$) between sites, with values ranging from 315.2 ± 4.409 to 1458 ± 6.064 mg/L.

Table 2: Physical and chemical properties of the soil sample.

Site /Duration	**Mean ± SE**				
	EC µS/cm	**TDS mg/l**	**pH**	**(OM)**	**Soil texture**
Moqble	676.6^{a}±8.8191	438.5^{a}±6.666	7.8^{a}±0.120	3.066^{ab}±0.088	Loam
Gas power station	493.3^{b}±8.8191	315.2^{b}±4.409	7.4^{b}±0.033	2.266^{b}±0.371	Clay loam

Kwashe village	863.0[c]±3.5118	551.4[c]±6.658	7.7[ab]±0.088	3.466[ac]±0.088	Clay
Oil storage	803.3[d]±8.8191	514.3[d]±3.929	7.7[ab]±0.057	2.833[ab]±0.233	Clay loam
Oil refinery	2280[e]±5.7735	1458[e]±6.064	7.6[ab]±0.057	2.466[ab]±0.317	Clay
Hajia as control	573.3[f]±3.3333	366.4[f]±7.264	7.6[ab]±0.057	3.712[ac]±0.208	Clay loam
P-value	0.01	0.01	0.05	0.05	

Note: Electrical conductivity (EC), Total dissolved solids (TDS), Organic matter (OM), and Different letters in the same column mean significant difference.

Lead (Pb^{2+}) in Soil Samples:

Lead is a heavy metal that is non-biodegradable and poses a greater threat to the population. It is primarily accumulated in the upper 8 inches of the topsoil and is highly immobile, resulting in long-term contamination (Tangahu *et al*., 2011). The analysis revealed that the mean concentration of Pb in soil samples varied from 2.4503 ± 0.019 to 8.0476 ± 0.012 mg/kg DW (Table 3). In March, the maximal value of 8.0476±0.012 mg /kg^{-1} DW was recorded at the oil storage site. The high concentration of lead resulted from the region's overcrowding by a variety of industrial detritus, the fumes emitted from vehicles, and a large number of cars. Additionally, the values indicate that automobiles frequently use leaded gasoline in the industrial zone. Nevertheless, the control site, Hajia, had a minimum concentration of 2.4503 ± 0.019 mg/kg^{-1} of Pb in the investigated region. This study demonstrated that the concentration of heavy metals decreased as the distance between the area and industrial refuse increased. The comparison site is about 12 km away from the industrial area. The reason for this was the presence of many agricultural commodities in the vicinity. Based on the findings, the lead (Pb) ion levels in soil samples are within the permissible limits of agricultural soil. The allowable limit recommended by the WHO is 85 mg/kg $^{-1}$ DW. Lead concentration showed a highly significant difference ($P < 0.01$) among sampling sites in February, April, May, and June, while significant differences ($P < 0.05$) were observed in March (Table 3). The findings of these results aligned with those of Pratishtha & Sura (2023), and the same results were also indicated by Mofor *et al*. (2017).

Table 3: Mean value ± standard error S.E. of Pb in soil during the study period mg /kg^{-1} DW

Site /Duration	Mean ± SE				
	Feb	**Mar**	**Apr**	**May**	**June**
Moqble	3.746[a]±0.003	3.9293[a]±0.009	4.954[a]±0.006	5.5696[a]±0.033	3.8783[a]±0.009
Gas power station	5.988[b]±0.005	6.642[b]±0.006	5.0836[b]±0.008	4.628[b]±0.006	4.4673[b]±0.008
Kwashe village	7.246[c]±0.011	7.976[c]±0.0051	5.08b[c]±0.0095	6.4333[c]±0.003	5.724[c]±0.0055
Oil storage	4.962[d]±0.005	8.0476[d]±0.012	6.3783[d]±0.0114	6.0246[d]±0.0093	6.8773[d]±0.0086
Oil refinery	5.432[e]±0.006	5.878[e]±0.0112	5.3736[e]±0.0082	5.235[e]±0.006	5.5306[e]±0.0125
Hajia - control	2.4503[f]±0.019	3.669[af]±0.01	3.0536[f]±0.0121	3.8493[f]±0.0086	3.331[f]±0.006
P. Value	0.01	0.05	0.01	0.01	0.01

Note: Different letters in the same column mean a significant difference.

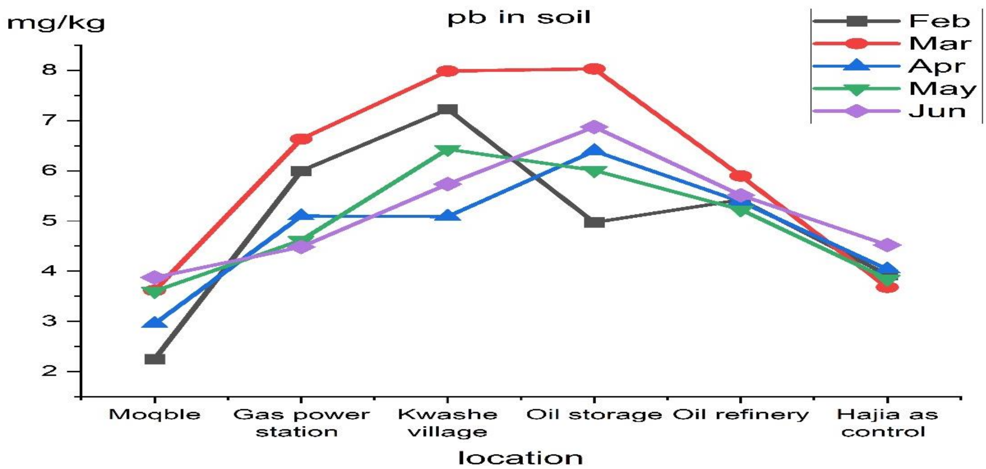

Figure 2: Concentration of Pb in soil during the study period, mg /kg–1 DW

Cadmium (Cd) In Soil Samples:

Cadmium is found in very low concentrations in soils, raising concern when it is detected in agricultural soils. The application of fertilisers and pesticides, as well as industrial activities, contributes to elevated cadmium levels in the environment (Alengebawy *et al*., 2021). The findings indicated that the concentrations of Cd in soil samples varied from 0.0634 ± 0.005 to 3.8425 ± 0.003 mg/kg DW (Table 4). The highest concentration of 3.8425±0.003 mg/kg–1 DW was reported at the Oil storage site in April. The composition of petroleum, motor oil, wear-and-tear of tires, roadside deposition of residues from these materials, and traffic density have all been linked to cadmium levels in exhaust emissions, as well as the use of Cd-contaminated phosphate fertilizers. The Hajia location was designated as the control site, as it registered the lowest concentration of 0.0634 ± 0.005 mg/kg DW. Throughout the entire study period (February to June), Table 4 shows highly significant ($P < 0.01$) variations in cadmium levels across all sampling points. When compared to the control site, the patterns of cadmium contamination at industrial sites are consistent, as evidenced by the significant differences observed across all months. These spatial and temporal fluctuations indicate that industrial operations have a lasting impact on soil cadmium levels throughout the study period. The results suggest that the soil samples are outside the permissible limits, except for the control location, as the distance from the industrial area increases. The concentration of Cadmium generally decreases. The maximum permissible concentration of Cadmium in soil, as determined by the WHO (1996), is equivalent to 0.8 mg/kg-1. The results are in agreement with those reported by Kacholi and Sahu (2018), which were found at extremely low concentrations in soils. Fertilisers and pesticides used, as well as industrial activity, and their results raise cadmium levels in the surroundings. (Alengebawy *et al*., 2021).

Table 4: Mean value ± standard error S.E. of Cd in soil during the study period, mg /kg^{-1} DW.

Site /Duration	Mean ± SE				
	Feb	Mar	Apr	May	Jun
Moqble	1.0642^{a}±0.005	1.318^{a}±0.0036	1.0854^{a}±0.005	2.9415^{a}±0.005	2.0029^{a}±0.005
Gas power station	3.0444^{b}±0.006	2.8329^{b}±0.005	2.0552^{b}±0.004	1.3732^{b}±0.004	0.9291^{b}±0.0085
Kwashe village	1.7143^{c}±0.028	0.9354^{c}±0.004	2.5072^{c}±0.005	3.0132^{c}±0.005	1.3817^{c}±0.0063
Oil storage	2.7643^{d}±0.017	1.744^{d}±0.0094	3.8425^{d}±0.003	2.3720^{d}±0.006	2.0034^{d}±0.0060
Oil refinery	2.8676^{e}±0.012	3.0548^{e}±0.006	2.7813^{e}±0.025	3.1604^{e}±0.006	3.3323^{e}±0.0046
Hajia - control	0.3487^{f}±0.008	0.4044^{f}±0.006	0.2638^{f}±0.007	0.0634^{f}±0.005	0.0972^{f}±0.0061
P. Value	0.01	0.01	0.01	0.01	0.01

Note: Different letters in the same column mean a significant difference.

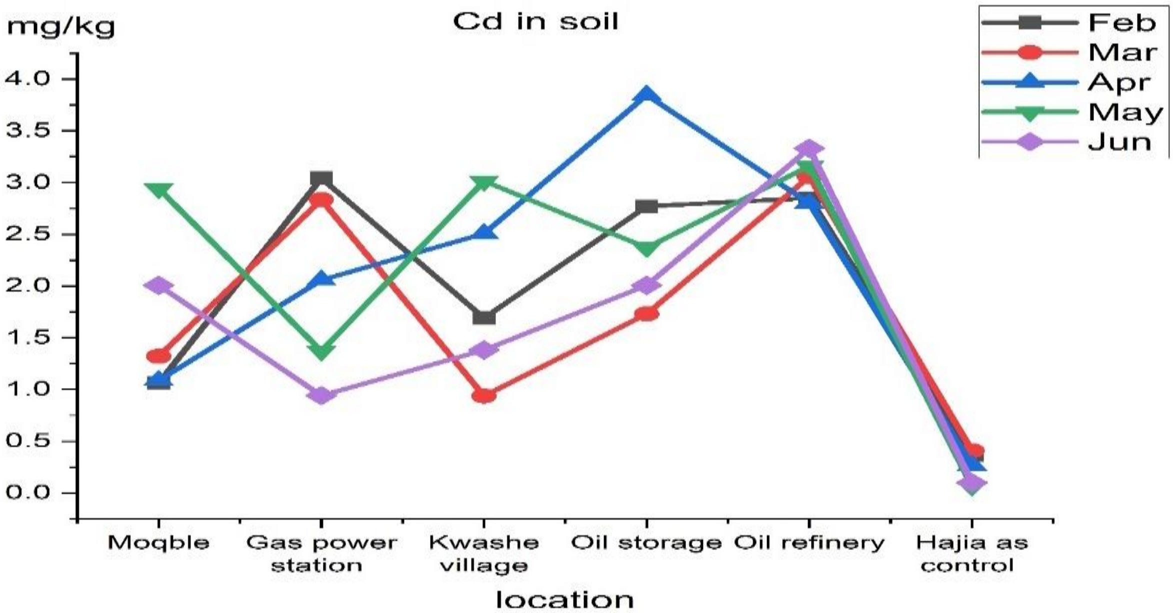

Figure 3: Concentration of Cd in the soil during the study period, mg /kg^{-1} DW

Copper (Cu) In Soil Samples:

The average content of Cu in agricultural soils varied from 0.4276±0.0125 to 4.784±0.03517 mg/kg^{-1} (Table 5). The lowest concentration of Cu in the examined area was 0.4276 ± 0.0125 mg/kg^{-1} DW, observed at the Hajia location, designated as the control site. The findings demonstrated that the concentration of copper decreased as the distance from the industrial zone increased, as cited by Kareem and Abdulla (2023). It was observed that Industrial activity can affect the concentration of trace elements. The highest concentration of Cu in the examined area was 4.784 ± 0.03517 mg/kg^{-1} DW, observed near the oil storage site. Trace elements in soil content can be increased by the combustion of fossil fuels (Jindy *et al*., 2020). Copper mainly originates from the abrasion of automotive tires since copper serves as a hardness component in tire composition, and from the agricultural process (Qin *et al*., 2012; Qaseem *et al*., 2023). The findings demonstrated that the soil samples fall within acceptable thresholds. The recommended threshold was suggested by WHO(1996). The dosage is 36 mg/kg^{-1}. Copper concentrations showed a considerable variation ($P<0.05$) among sampling sites in February, with a highly significant ($P<0.01$) variation in March, April, May, and June. Seasonal variations in copper concentrations revealed that industrial activities exhibited considerable variation ($P < 0.05$) among sampling sites in February, with a highly significant ($P < 0.01$) variation observed. Continuous activities had a significant influence on soil contamination patterns throughout the majority of the study period, with the most substantial contamination impacts occurring from March onwards. These results were similar to the findings of Kirchmann *et al*.(2009). The same findings were also shown by Zhao *et al*.(2010). The results showed that the studied agricultural soils contain higher levels of metals nearer the industrial zone.

Table 5: Mean value ± standard error of Cu in soil during the study period mg/kg^{-1} DW

Site /Duration	Mean ± SE				
	Feb	Mar	Apr	May	Jun
Moqble	1.1283^{a}±0.0033	2.0443^{a}±0.0086	1.401^{a}±0.0580	2.2376^{a}±0.0093	1.973^{a}±0.0063
Gas power station	3.0936^{b}±0.0084	4.1263^{b}±0.0090	2.6286^{b}±0.0092	1.0403^{b}±0.0151	1.763^{b}±0.01
Kwashe village	1.1293a^{c}±0.0093	3.3716^{c}±0.0084	3.918^{c} ± 0.0055	2.3393^{c}±0.0233	2.217^{c}±0.0063
Oil storage	4.161^{d}±0.0105	4.784^{d}±0.03517	2.0556^{d}±0.0066	3.9301^{d}±0.0417	3.1583^{d}±0.0086
Oil refinery	2.9613^{e}±0.0148	1.7806^{e}±0.0084	3.0713^{e}±0.0090	2.525^{e}±0.0121	2.873^{e}±0.0051
Hajia – control	0.4276^{f}±0.0125	0.2926^{f}±0.0033	0.4813^{f}±0.0082	0.5776^{f}±0.009	0.435^{f}±0.01
P. Value	0.05	0.01	0.01	0.01	0.01

Note: Different letters in the same column mean a significant difference.

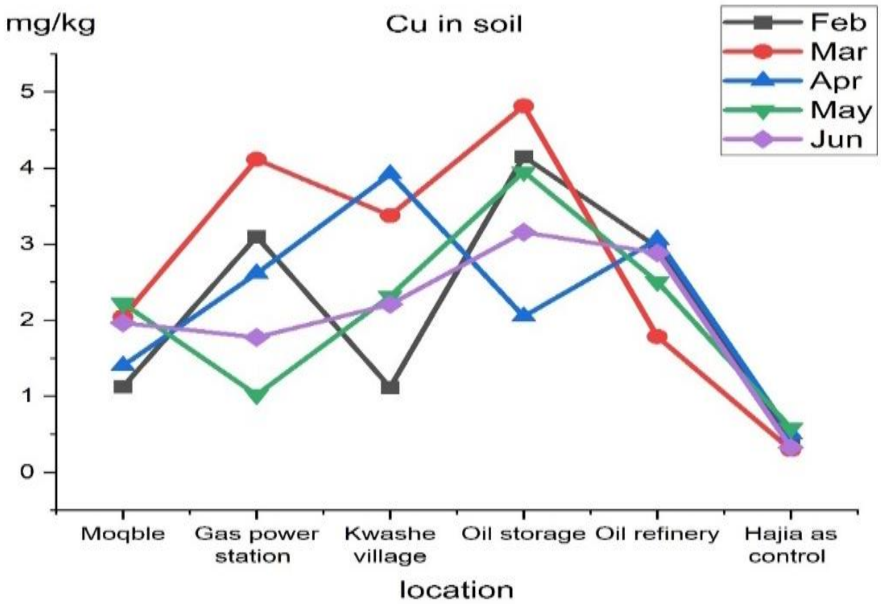

Figure 4: Concentration of Cu in the soil during the study period mg /kg^{-1} DW

Zinc (Zn^{2+}) In Soil Samples:

The average content of Zinc in agricultural soils varied from 1.9343 ± 0.0128 to 8.8506 ± 0.0165 mg /kg–1 DW (Table 6). The lowest Zinc concentration in the examined area was 1.9343 ± 0.0128 mg/kg–1 DW, observed at the Hajia location, designated as the control site. The decline in Zn levels with increasing distance from the industrial zone suggests that industrial emissions have a significant influence on zinc concentrations in agricultural soil. The highest Zinc concentration in the examined area was 8.8506±0.0165 mg/kg, observed in Kwashe village. Pollutants from automobile exhaust and a neighbouring industrial sector pollute the soil. This value is within the allowable threshold for copper in the soil, as advised by (WHO), 1996) The dosage is 50 mg/kg^{-1}. Zinc concentrations showed significant differences ($P < 0.05$) among sampling sites in February, April, and June, while highly significant differences ($P < 0.01$) were observed in March and May. The alternating patterns of significance levels throughout the study period indicated temporal variations in zinc contamination, possibly influenced by seasonal industrial activities and environmental factors affecting zinc mobility and deposition in agricultural soils. The results also showed that emissions from gas power stations, oil refineries, and vehicle exhaust have considerably contaminated agricultural soils in the industrial zone. These results were similar to the findings of Laribi and Saidani, (2016). Furthermore, the same results were also indicated by Kacholi and Sahu, (2018).

Table 6: Mean value ± standard error S.E. of Zn in soil during the study period, mg /kg^{-1} DW.

Site /Duration	Mean ± SE				
	Feb	Mar	Apr	May	Jun
Moqble	5.434^{a}±0.0068	6.703^{a}±0.0575	8.5233^{a}±0.0068	4.9343^{a}±0.0128	4.1543^{a}±0.0133A
Gas power station	4.4853^{b}±0.0049	5.7466^{b}±0.0095	4.8433^{b}±0.01186	6.2746^{b}±0.0348	5.2956^{b}±0.0348
Kwashe village	7.102^{c}±0.0017	8.8506^{c}±0.0165	3.7393^{c}±0.0128	7.065^{b}±0.0335	6.0233^{c}±0.0084
Oil storage	5.4153^{ad}±0.0071	7.7566^{d}±0.0188	5.1143^{d}±0.0148	3.8846^{d}±0.065	8.311^{d}±0.0981
Oil refinery	6.1446^{e}±0.0068	4.0603^{e}±0.0118	3.9713^{e}±0.0118	5.4783^{e}±0.0332	5.695^{bce}±0.153
Hajia - control	2.0586^{f}±0.0105	1.9343^{f}±0.0128	3.782^{cf}±0.0215	2.0773^{f}±0.0133	2.3216^{f}±0.1218
P. Value	0.05	0.01	0.05	0.01	0.05

Note: Different letters in the same column mean a significant difference.

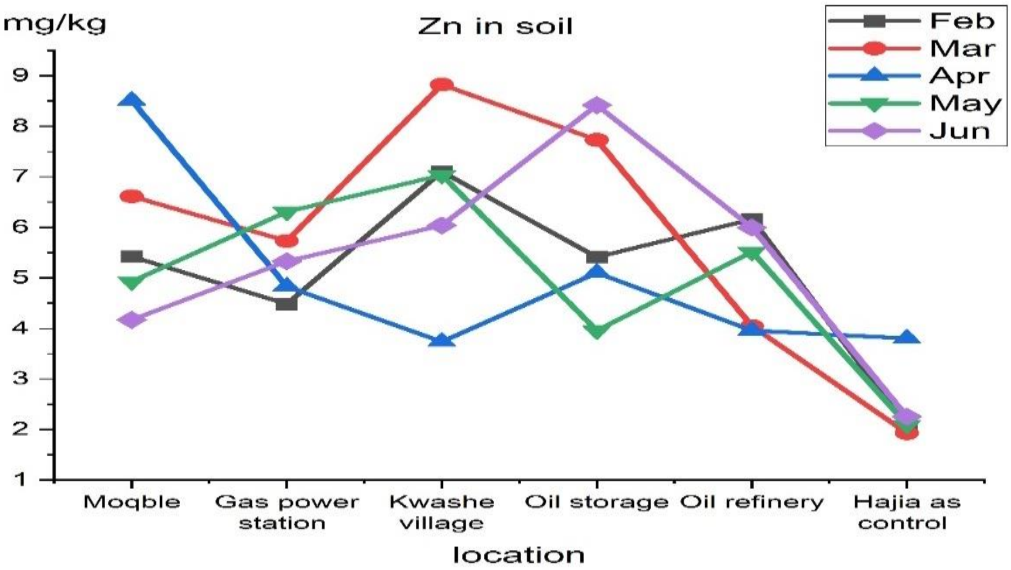

Figure 5: Concentration of Zinc (Zn2+) in soil during study period mg /kg^{-1} DW

Concentration of Lead (Pb^{2+}) In Wheat Grains:

The average amounts of lead (Pb^{2+}) in wheat grain collected from an industrial zone ranged from 0.539±0.0231 to 1.035±0.0028 mg /kg^{-1} DW (Table 7), with the maximum value found in samples from the Moqble site (1.035±0.0028 mg/kg^{-1}). Major roads and significant mobility in the mobile area indicated that the elevated Pb levels in wheat grain samples from this site were attributable to (Pb^{2+}) emissions from transportation. Nonetheless, the concentration of (Pb^{2+}) in all samples remained under the highest allowable limit (0.1 mg/kg^{-1}). The lowest mean value in Hajia, designated as the control site, was (0.006±0.0001) mg /kg^{-1} DW. In this region, transportation infrastructure is underdeveloped, and irrigation relies heavily on the regularity of rainfall. Consequently, the flora in this region had minimal levels of Pb. The results indicated that all samples exceeded the established acceptable level, as set by the FAO and WHO (Commission, 2001), which was below 0.1 mg/kg^{-1}, except the control region. Lead concentrations in wheat grains showed significant differences ($P<0.05$) among all sampling sites (Table 7). The findings of this investigation were similar to those reported by Wahab and Jamil (2023) in Sulaimani, Kurdistan Region, Iraq, and by Tawfeeq and Hakeem (2025), but higher than those reported by Pratishtha and Sura (2023). Pb poisoning of the environment has negative consequences on human health, as Lead mostly affects the nervous system. If someone spends much time with a lead, their nervous system's natural operation is affected. Furthermore, prolonged exposure has negative effects on both the kidneys and the brain. Pb is not a necessary metal in plants; rather, it is taken up by industries from anthropogenic sources such as Pb fertilisers and vehicular emissions by means of soil (Rahman *et al*., 2024).

Concentration of Zinc (Zn^{2+}) In Wheat Grains:

(Zn^{2+}) It is an essential mineral for plant growth, and people need it for various purposes, including growth, brain development, behaviour, bone formation, and wound healing. There was a range of 0.417±0.0085 mg /kg–1 DW to 0.5666±0.0063 mg /kg^{-1} DW of (Zn^{2+}) in all the plant samples (Table 7). The (Zn^{2+}) distribution revealed that the highest mean concentrations of Zn were observed in samples from Kwashe village (0.5666±0.0063 mg /kg^{-1} DW). The FAO advises the allowed limit of zinc in wheat grains (FAO, 2006). The dosage is < 0.5 mg/kg. The samples fell short of the acceptable threshold. Fertiliser and vehicular emissions are regarded as key sources of hazardous metals that contaminate agricultural soils. The lowest mean concentration in the control area, Hajia, was (0.3206±0.0033 mg /kg^{-1} DW). Zinc concentrations in wheat grains showed significant differences (P<0.05) among all sampling sites (Table 7). The concentration of Zn in this site was low, and the amounts of Zn in wheat plants originated from the geological layers. The amounts of Zn identified in the current investigation are lower than those reported in wheat plant samples (Umer *et al*., 2021) in Badinan province, Kurdistan Region, Iraq.

Concentration of Copper (Cu^{2+}) In Wheat Grains:

Copper is released into the environment through natural weathering of soil and emissions from industrial activities and domestic waste disposal (Cepa, 2007). The study demonstrated that the copper concentration in wheat grain ranged from 0.2203 ± 0.0033 to 0.2723 ± 0.0016 mg/kg DW across all analysed samples (Table 7). The greatest concentration in wheat grain samples was detected at the oil storage location (0.2723±0.0016 mg /kg^{-1} DW). The minimum mean concentration was recorded in wheat grain samples from the Hajia region, identified as the control site (0.1406±0.0012 mg/kg^{-1}). A study conducted in Baghdad, Iraq, indicated that Cu levels ranged from 0.22 to 0.63 mg /kg^{-1} DW (Jawad & Allafaji, 2012). The findings demonstrated that the copper content in all analysed samples was below the allowable limit of 3 mg/kg in wheat grains (WHO, 1996), and 10 mg/kg^{-1} (Commission *et al*., 2007). Copper concentrations in wheat grains showed significant differences (P<0.05) among all sampling sites (Table 7). The findings of this study were similar to those of Alhendi and Al (2018) in many different provinces of Iraq. Industrial activity next to agricultural land leads to the absorption of heavy metals from the soil, resulting in their accumulation in wheat grains (Khan *et al*., 2019).

Concentration of Cadmium (Cd) In Wheat Grain:

The cadmium (Cd) level in wheat grains varied between a low of 0.002 mg/kg in the control point (Hajia) and 0.0293 mg/kg at the Gas Power Station. Cadmium concentrations in wheat grains showed significant differences (P<0.05) among all sampling sites Table 7. They were all well below the FAO/WHO tolerable limit of 0.1 mg/kg (Commission, 2001). This finding was similar to that reported by Umer *et al*., (2021) ranging from 0.002 to 0.01 mg/kg in various provinces of Iraq. It means that the wheat produced in these regions is comparatively safe for human consumption in terms of cadmium contamination. Despite being at acceptable levels, Wahab and Jamil, (2023) Observed that even a relatively small amount of cadmium, assuming cumulative addition into the body over time, may cause chronic health conditions, that is, kidney functioning and bones. Various health effects are attributed to chronic contact with cadmium, including kidney disease, osteoporosis, and cancer in severe forms (Umer *et al*., 2021). They also stated that industrial sites, e.g., the ones in the vicinity of the Gas Power Station, may also cause contamination of soil and, consequently, a long-term effect of cadmium bioaccumulation in flora. Although the concentrations are still within harmless limits, there is a risk of cumulative build-up. Due to its biological inability to decompose, cadmium will persist in the environment in the long term, with its accumulation in crops posing a future health hazard.

Table 7: Mean value ± standard error S.E. of Pb, Zn, Cu, and Cd in wheat grains during the study period, June, mg /kg^{-1} DW

Site /Duration	Mean ± SE			
	Pb	Zn	Cu	Cd
Moqble	1.035^{a}±0.0028	0.5566^{ac}±0.0355	0.2423^{a}±0.0031	0.012^{a}±0.0006
Gas power station	0.7533^{b}±0.0272	0.5323^{ac}±0.0057	0.2383^{a}±0.008	0.0293^{b}±0.0038
Kwashe village	0.6353^{c}±0.0224	0.5666^{c}±0.0063	0.2586^{a}±0.0057	0.021^{c}±0.0012
Oil storage	0.539^{d}±0.0231	0.4653^{ab}±0.0088	0.2723^{a}±0.0016	0.004^{bd}±0.001
Oil refinery	0.6706^{ce}±0.0103	0.417^{b}±0.0085	0.2203^{a}±0.0033	0.005^{bde}±0.0061
Hajia - control	0.006^{bef}±0.0001	0.3206^{ac}±0.0033	0.1406^{a}±0.0012	0.002^{bdef}±0.0005
P. Value	0.05	0.05	0.05	0.05

Note: Different letters in the same column mean a significant difference.

Correlation Coefficient of Heavy Metals Between Soil and Wheat Grain:

The results of the heavy metal correlation coefficients between wheat grain and soil during the study period, illustrated in Table 8, are vital information on soil contamination and wheat grain concentration at different study locations. The heavy metals considered were Zn, Cu, Cd, and Pb.

In Moqble, correlation values are positive for Zn (0.79) but negative for Cd (-0.69) and Pb (-0.74), indicating that Zn concentration increases in wheat grains with the rise in soil concentration, but in the case of Cd and Pb, there is an opposite trend where soil concentration rises. However, in wheat grains, the accumulation is reduced. correlation for Cu (0.07) suggests no or minimal relationship between soil and wheat grain concentration for this element at this location.

For the Gas Power Station Location, a more complex pattern is observed. Zn and Cu are negatively correlated (-0.52 and -0.34), and Cd and Pb are positively correlated (0.68 and 0.62). This reveals that while Zn and Cu are less prone to be accumulated in wheat grain with greater amounts in soil, Cd and Pb accumulate more in the grain as soil concentration rises, which could be owing to the distinctive mobility or bioavailability of these metals at this site.

The Kwashe Village data show a negative correlation for Cd (-0.45), a weak positive correlation for Cu (0.22), and a stronger positive correlation for Pb (0.52). The negative correlation for Cd observed herein may indicate that the metal does not readily migrate from soil to wheat grains. In contrast, Pb shows higher accumulation in wheat grains with higher soil concentration.

Zn, Cu, and Cd at the Oil Storage site have negligible negative or no correlation (-0.32, -0.012, and 0.08, respectively), suggesting little or no proper movement of these metals from soil to grain. Pb has a moderate correlation value of 0.41, which suggests that lead accumulates more in the wheat grain for higher soil concentration at this site.

The location of the Oil Refinery suggests a negative correlation for Zn (-0.43), whilst Cu and Cd suggest positive, although weak, correlations (0.04 and -0.52). Pb suggests a positive correlation (0.26), but one which is weaker than elsewhere. This suggests that some metals, such as Cu and Cd, may have limited bioavailability for wheat concentration, but Pb can still be translocated, albeit to a lesser extent.

The Hajia control station, which typically serves as a baseline under ordinary circumstances, exhibits high positive correlations for Cu (0.66) and Cd (0.84), as well as a negative correlation for Pb (-0.80). The high positive relationship between Cd and Cu is consistent with the relatively efficient transfer of these metals from soil to wheat grains under ordinary regimes of non-heavy contamination. At the same time, Pb exhibits an inverse relationship, implying a decrease in accumulation in wheat grains with increasing soil concentrations of Pb.

In general, differences in the values of correlation among each metal between the different locations can be explained by several factors, including soil pH, organic matter content, metal speciation, and the plant's ability to uptake and transport heavy metals. Biological factors, industrial contamination, and differences in soil properties all influence the mobility and accumulation of heavy metals in wheat grain.

Table 8: Correlation Coefficient of heavy metals between soil and wheat grain during the study period.

Heavy metal	Zn	Cu	Cd	Pb
Moqble	0.79	0.07	-0.69	-0.74
Gas power station	-0.52	-0.34	0.68	0.62
Kwashe village	-0.11	0.22	-0.45	0.52
Oil storage	-.32	-.012	0.08	0.41
Oil refinery	-0.43	0.04	-0.52	0.26
Hajia - control	0.37	0.66	0.84	-0.80

CONCLUSION

This research reveals heavy metal contamination of wheat grains (*Triticum aestivum* L.) in agricultural fields adjacent to an industrial zone in Duhok, Kurdistan Region, Iraq, with Pb, Cd, Zn, and Cu. The grains had accumulated the aforementioned metals to an alarming extent, despite concentrations of Zn, Cu, Pb, and Cd in the studied soils generally being below the permissible upper limits. With maximum levels observed close to major roads, lead (Pb) concentrations in wheat grains from all industrial locations (0.539–1.035 mg/kg^{-1}) well surpassed the WHO permissible limit (0.1 mg/kg). Copper (Cu) was found below tolerance, but cadmium (Cd) and zinc (Zn) concentrations in grains were also above the safe limits at the majority of locations. In wheat, the sequence of accumulation was Pb > Zn > Cu > Cd. The concentrations of (Pb, Zn, Cu, and Cd) in wheat grains showed significant differences ($P<0.05$) among all sampling sites. Higher levels of contamination around industrial installations (Gas Power Plants, oil refineries, and oil storage facilities) and major highways clearly suggest that industrial emissions and traffic are major contributors to the spatial pattern of contamination. Although usually near-neutral pH lowers metal bioavailability, measured absorption into wheat grains clearly suggests effective transfer from soil to plant, thus constituting an apparent dietary health concern. These observations suggest the possibility of wheat produced close to the industrial area of Duhok as a human source of metal toxicity, lead and cadmium, for instance, Chronic consumption of contaminated wheat can lead to long-term health consequences.

Data Accessibility:

All foundational data are included inside the paper, and no extra sources of data are necessary.

Author Contributions:

The manuscript was written, evaluated, and edited by B. M. M., who also conducted the investigation and developed the methodology. M. R. A. was responsible for designing the methodology, supervising the study, and composing, reviewing, and editing the manuscript.

Acknowledgements:

The authors would like to express their gratitude to Dr. Chiayee Salih Ajaj and Dr. Nizar Jalal for their assistance.

Ethical Approval:

No ethical approval was needed since the research did not include human participants or animals.

Conflicts of Interest:

The author discloses no conflicts of interest.

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