

## RESEARCH ARTICLE

# Assessment of Lead and Iron Contamination in Soil and Plants in Al-Kifil, Babylon Governorate, Iraq

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## ABSTRACT

Heavy metal contamination in agricultural soil poses a significant threat to food safety and public health. This study investigated the concentrations of Lead (Pb) and Iron (Fe) in various plant species and their associated soils at the Al-Kifil site compared to a control site (Al-Ibrahimiya).

Soil and plant samples (Onion, Swiss Chard, Broad Beans, Spinach, Garden Cress, and Barley) were analyzed for Pb and Fe content. Soil physicochemical properties, including pH, Salinity (EC), and Organic Matter (OM), were evaluated to determine their influence on metal mobility.

All plant samples from Al-Kifil exceeded the FAO/WHO permissible limit for Pb (0.3 ppm), with Swiss chard and Spinach reaching 8.82 ppm and 8.46 ppm, respectively. Soil Pb at Al-Kifil (up to 99.83 ppm) exceeded the Kabata-Pendias safety threshold (70 ppm). Transfer Factor (TF) analysis identified Garden cress (0.478) and Swiss Chard (0.405) as the most efficient accumulators. The lower soil pH at Al-Kifil (5.93) was identified as a key driver for increased metal bioavailability compared to the control (7.11). This suggests a synergistic relationship driven by both soil chemistry (acidity) and plant physiology:

The Al-Kifil site presents a severe Pb toxicity risk. Immediate soil remediation via liming and restricted cultivation of leafy accumulator crops are required to mitigate health risks to the local population.

**Keywords:** Plant and Soil Contamination; Al-Kifil - Iraq; Pb-Fe Accumulation; Fe-Pb Interaction; Health Risk

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## 1. Introduction

Heavy metals such as Lead and Iron have become a significant threat to both environmental and human health. When soil becomes contaminated by heavy metals, these elements can leach into the food chain through polluted water, soil, plant, and waste landfill sites. This leads to their accumulation at increasing levels along the food chain, a phenomenon known as bioaccumulation [1,2]. Soil is considered a primary medium for the accumulation of heavy metals, especially lead and iron. Iron is an essential nutrient for plants, but at high concentrations it becomes harmful, disrupting the uptake of other nutrients and damaging plant cell components [3]. Lead, on the other hand, has no biological function and is highly toxic to both humans and plants. It accumulates easily in plant tissues, leaves, and roots, eventually entering the food chain and posing health risks. Soil is also exposed to other forms of pollution, including chemical contamination from the accumulation of metal residues and pesticides, as well as organic pollution from animal waste and sewage sludge.

These forms of pollution degrade the soil's physical and chemical properties, negatively affecting plant growth and productivity [4]. The mobility and bioavailability of these metals depend strongly on soil pH, organic matter, and cation exchange capacity, making certain soils more vulnerable to contamination [5]. Long-term exposure to heavy metals such as iron and lead, has been shown to impair soil microbial diversity and reduce essential ecosystem services [6]. Soil is a sensitive medium that is directly impacted by industrial and agricultural activities, leading to the accumulation of heavy metals such as iron (Fe) and lead (Pb). Although iron is an essential nutrient for plants, excessive levels disrupt the absorption of other elements like zinc and manganese, adversely affecting plant growth and physiological functions [7]. Lead, being non-essential, is harmful even at low concentrations; exposure causes cell wall damage, enzyme inhibition, and reduced photosynthetic efficiency. Its accumulation in plants poses a risk to the food chain, affecting both humans and animals [8]. Soil contamination by chemicals occurs when toxic and unnatural substances enter the soil due to human activities, especially pesticides, wastewater, synthetic fertilizers, and industrial waste. This chemical pollution alters the soil's chemical balance, reduces its fertility, and disrupts soil microorganisms, which play a vital role in maintaining soil fertility and nutrient cycling [9]. Recent research studies have shown that levels of chemical pollution with heavy elements have reached high levels in various environments such as water, soil, plants and animals [10-12].

## 2. Materials and Methods

### 2.1. Study Area

The study area and samples, as shown in figure (1) and table (1), the sampling methodology was defined within a 1000 m<sup>2</sup> (20 m × 50 m) area to best represent the spatial variation in soil and plant composition.

To achieve this, the site was divided into sub-areas with similar general characteristics, and sampling points were systematically distributed within the area to ensure coverage of different parts of the field.

Six soil samples were collected from different locations within this area, along with six plant samples from plants grown at the same soil points to ensure correlation between the two environments.

The same number of soil and plant samples were also collected from a control site with similar environmental conditions for comparison and to determine the impact of any contamination.

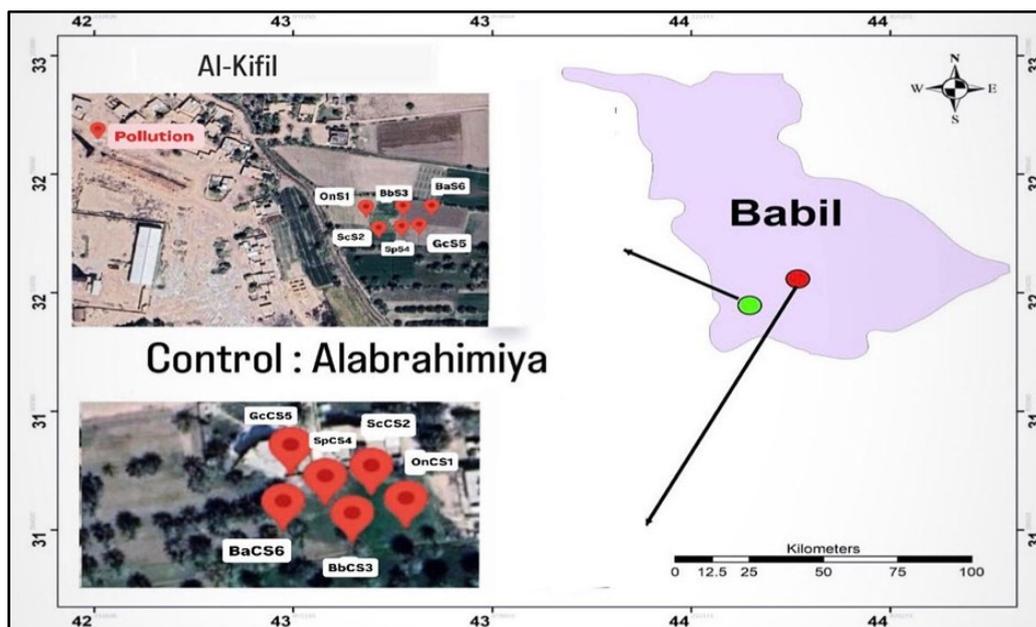


Figure 1. Map showing the GPS coordinates of the sampling locations in the study area

**Table 1.** Name and codes of the selected samples

No.	Sample Name	Plant Sample Code	Soil Sample Code
1.	Onion	OnS1	OnSS1
2.	Swiss chard	ScS2	ScSS2
3.	Broad beans	BbS3	BbSS3
4.	Spinach	SpS4	SpSS4
5.	Garden cress	GcS5	GcSS5
6.	Barley	BaS6	BaSS6

## 2.2. Collection and Preparation Samples

The concentrations of heavy metals in soil and plants were determined through a series of procedures, starting with the collection of samples from designated locations. The collected samples underwent preparation steps, including drying, grinding, sieving, and storage, followed by analysis using an Atomic Absorption Spectrometer to quantify the levels of Iron (Fe) and Lead (Pb) .

In this study, two sites were selected to investigate contamination by heavy metals: Al-Kifil as a polluted area and Al-Ibrahimiya as agricultural, used as a control for comparison. Soil and plant samples were collected from these sites in December 2024.

A total of 36 soil samples, along with their associated plant samples from two sites as the following plants (Onion, Swiss Chard, Broad Beans, Spinach, Garden Cress, and Barley), were prepared and analyzed to determine their physical and chemical properties and to measure the concentrations of Iron and Lead. Soil and plant samples were collected from an agricultural area covering approximately 1000 meters. Six soil-plant triplicated samples were taken from sites located about 500 meters from the pollution source. Additionally, six soil-plant triplicated samples were collected from an uncontaminated site, which served as the control area. The exact locations of all sampling points were determined using a GPS device. Plant samples were thoroughly washed with distilled water to remove any unwanted debris. Both soil and plant samples were then oven-dried at 75 °C to eliminate moisture completely. After drying, the samples were ground using a manual grinder to obtain a fine powder. The powdered samples were sieved using a 2 mm mesh to achieve a uniform and homogeneous texture free of impurities that could interfere with the analytical procedures.

### 2.2.1. Analysis and Digestion of Plant Samples

A 1 g portion of the plant sample, which had been thoroughly washed with distilled water to remove any external contaminants, oven-dried, and finely ground, was weighed and placed into a digestion tube. Subsequently, 20 mL of concentrated nitric acid (HNO<sub>3</sub>) was added to the tube. The mixture was gradually and gently heated until colored fumes appeared (indicate the release of nitrogen dioxide). This step breaks down easily oxidizable organic matter.. Heating was continued until the fumes subsided, indicating the completion of Pre-digestion step. After cooling, 5 mL of perchloric acid (HClO<sub>4</sub>) was added, followed by further gentle heating. The completion of Digestion is typically considered complete when the solution becomes clear/colorless, 25 mL of distilled water was added to the mixture, which was then filtered. The filtrate was transferred to a 50 mL volumetric flask and brought up to volume with distilled water. The concentrations of the target elements were then determined according to the standard method described <sup>[13]</sup>.

### 2.2.2. Analysis and Digestion of Soil Samples

A 1 g portion of oven-dried, sieved soil (< 2 mm mesh) was weighed to obtain a fine powder. Subsequently, 20 mL of concentrated nitric acid (HNO<sub>3</sub>) was added to the sample. The mixture was then heated to oxidize the organic matter. Red fumes evolved during the digestion process; once the red fumes

subsided, 5 mL of perchloric acid (HClO<sub>4</sub>) was added and heating was continued until white fumes appeared, indicating complete digestion. The digested solution was allowed to cool, and 25 mL of distilled water was added. The mixture was then filtered and transferred into a 50 mL volumetric flask. The final volume was brought up to 50 mL with distilled water. The concentrations of the target heavy metals were subsequently determined using Atomic Absorption Spectrophotometry (AAS), following standard method described [13].

## 2.3. Chemical and Physical Properties

### 2.3.1. Organic Matter

Organic matter refers to the fraction of soil composed of partially or fully decomposed plant and animal residues, serving as an important source of nutrients and enhancing the physical and chemical properties of the soil [14]. The percentage of organic matter was calculated using the following equations:

$$M=10/V_{blank} \quad (1)$$

where:

$M$  : Calibration factor.  $V_{blank}$  : Volume of titrant used for the blank (mL)

$$\%OC \text{ (oxidized)} = \frac{0.3 \times M \times [V_{sample} - V_{blank}]}{W1} \quad (2)$$

where:

$\%OC \text{ (oxidized)}$ : Percentage of oxidized organic carbon in the sample (%)

0.3 = The milliequivalent weight of carbon in grams. Since 1 milliequivalent of Carbon is 0.003g, multiplying by 100 to get a percentage results in the 0.3 factor Walkley-Black Method – EPA [13].

$V_{sample}$  : Volume of titrant used for the soil sample (mL)

$V_{blank}$  : Volume of titrant used for the blank (mL)

$W1$ : Oven-dry weight of the soil sample (g)

$$\% OC \text{ (total)} = \% OC \text{ (oxidized)} \times 1.334 \quad (3)$$

where:

$\%OC \text{ (total)}$  = Total organic carbon content (%) after recovery correction

1.334 = Recovery correction factor (Walkley–Black method)

$$\%OM = \% OC \text{ (total)} \times 1.724 \quad (4)$$

where:

$\%OM$  = Percentage of organic matter in the soil (%)

1.724 Van Bemmelen factor (converts organic carbon to organic matter).

### 2.3.2. Electrical Conductivity (EC)

A measure of the soil-water extract's ability to conduct electricity, used as an indicator of soil salinity. In this study soil and water were mixed at a 1:1 ratio, shaken, and EC was measured with an EC meter [15].

### 2.3.3. pH

A measure of the acidity or alkalinity of the soil-water extract on a scale from 0 to 14. In this study, soil and water were mixed at 1:1 ratio, shaken and pH was measured with a pH meter [15].

### 3. Results and Discussion

#### 3.1. Measurement of Heavy Metals (Fe and Pb) Concentration in Soil and Plant

Table (2) presents the concentrations of lead in plant samples which collected from Al-Ibrahimiya area (control site) and Al-Kifil area near the Al-Iatimad factory as a pollution source.

According to table (2) the concentration of the nonessential elements such as toxic lead (Pb) levels in the plant samples had been ranged from the highest value at  $8.8204 \pm 0.5301$  ppm in plant of Swiss Chard into the lowest at  $1.9211 \pm 0.1401$  ppm in plant of Barley. It is evident that Pb levels in all plant samples from Al-Kifil site exceeded significantly the permissible limit of 0.3 ppm [16].

In the control of Al-Ibrahimiya, the Pb concentrations ranged from  $0.3841 \pm 0.0302$  ppm in plant of Broad Beans into  $0.0821 \pm 0.0103$  ppm in plant of Swiss Chard. The Pb level in all samples of control was within the safe limit, as in the following table (2) and figure (2).

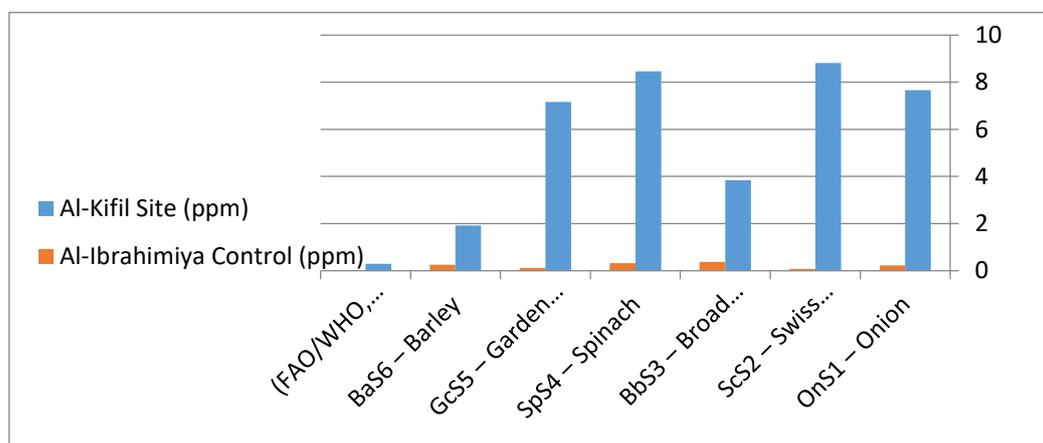
This reflects the great variation and difference in lead absorption and high uptake by each plant from its soil, for example, when comparing both Swiss chard and broad beans, from both the control site and the contamination site. There is a 100% probability that any crop harvested from the Al-Kifil site will exceed international safety standards for this heavy metal (Lead).

From the results of table (2), the gap between the two sites is extreme. For example, in Swiss Chard at the Al-Kifil site is over 100 times higher than the control. This means there is a 99% probability that the contamination at the Al-Kifil site is real and caused by external factors (pollution), rather than random variation.

The concentrations at the Al-Kifil site were significantly higher ( $p < 0.05$ ) than the Al-Ibrahimiya control site across all plant species, with Swiss Chard showing the highest accumulation at nearly 30 times the FAO/WHO permissible limit.

**Table 2.** Lead Concentration in plant samples in studied Areas

Sample ID-Plant Types	Al-Kifil Site (ppm)	Al-Ibrahimiya Control (ppm)
OnS1 – Onion	$7.6651 \pm 0.3501$	$0.2211 \pm 0.0401$
ScS2 – Swiss Chard	$8.8204 \pm 0.5301$	$0.0821 \pm 0.0103$
BbS3 – Broad Beans	$3.8412 \pm 0.1811$	$0.3841 \pm 0.0302$
SpS4 – Spinach	$8.4611 \pm 0.5621$	$0.3243 \pm 0.0321$
GcS5 – Garden Cress	$7.1642 \pm 0.4101$	$0.1244 \pm 0.0412$
BaS6 – Barley	$1.9211 \pm 0.1401$	$0.2501 \pm 0.1301$
(FAO/WHO, 2011) Limit		0.3



**Figure 2.** Distribution of Lead concentrations in studied plants samples

From table (3), the lead concentration of soil samples at Al-Kifil had been ranged from the highest at  $99.8332 \pm 4.6331$  ppm in soil of spinach to the lowest at  $11.8202 \pm 0.5011$  ppm in soil of barley. It is evident that Pb levels in some samples, like spinach, onion, and broad beans, exceeded the limit 70 ppm [17]; this results in a *p*-value far below the standard 0.05 threshold.

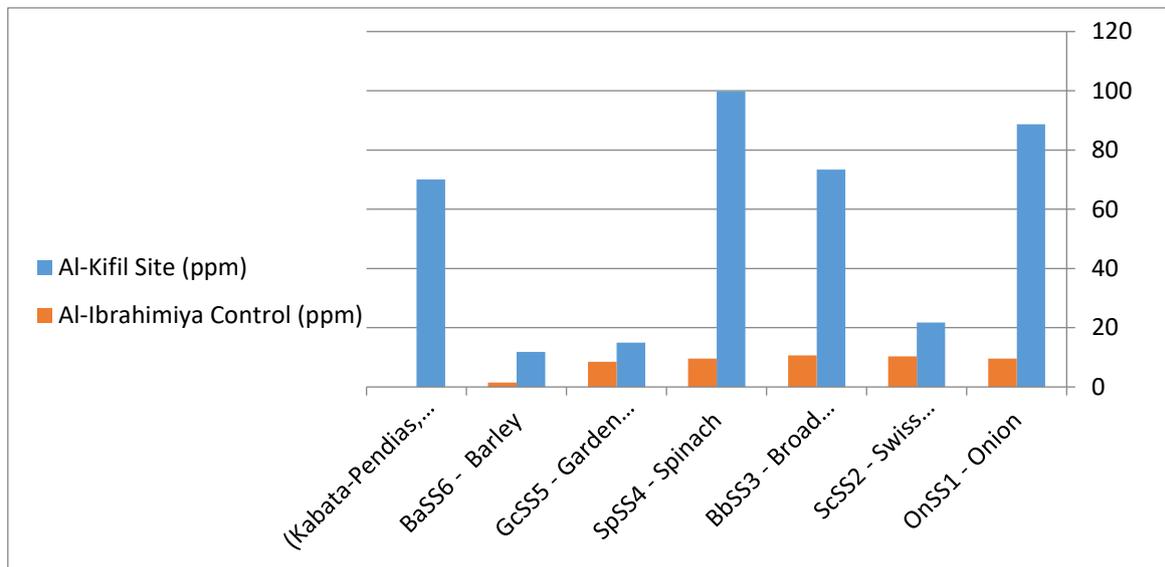
In the control of Al-Ibrahimiya, the Pb concentrations ranged from  $10.6601 \pm 0.4301$  ppm in soil of broad beans to  $1.5332 \pm 0.0701$  ppm in soil of barley, where the Pb level in all samples of control was within the safe limit, as in table (3) and figure (3). The contamination ratio of Pb in soil in Al-Kifil is 7 to 10 times more contaminated than Al-Ibrahimiya control.

The consistency indicated by the low standard deviations (e.g.,  $99.8332 \pm 4.6331$ ) indicates that the pollution is uniform and widespread across the study site. While some soils (like Garden cress, Swiss chard, or Barley) are technically below the 70 ppm soil limit, the resulting plants are all dangerously above the 0.3 ppm food limit. This suggests that even moderately contaminated soil in this region leads to toxic crops.

**Table 3.** Lead Concentration in soil samples of agricultured plants in studied Areas

Sample ID-Soil of plant types	Al-Kifil Site (ppm)	Al-Ibrahimiya Control (ppm)
OnSS1 – Onion	$88.6511 \pm 3.9001$	$9.5321 \pm 0.3401$
ScSS2 – Swiss Chard	$21.7712 \pm 1.1001$	$10.3321 \pm 0.3833$
BbSS3 – Broad Beans	$73.3731 \pm 3.1403$	$10.6601 \pm 0.4301$
SpSS4 – Spinach	$99.8332 \pm 4.6331$	$9.5421 \pm 0.4302$
GcSS5 – Garden Cress	$14.9711 \pm 0.5712$	$8.5332 \pm 0.2812$
BaSS6 – Barley	$11.8202 \pm 0.5011$	$1.5332 \pm 0.0701$

(Kabata-Pendias, 2001) 70



**Figure 3.** Distribution of Lead concentrations in soil samples of agricultured plants

From table (4), the concentrations of Iron (Fe) in plant samples in Al-Kifil had been ranged between the highest value  $87.4486 \pm 2.7024$  ppm in Spinach into the lowest  $24.9082 \pm 0.6002$  ppm in Broad Beans, it is evident that Fe in some samples such as (Spinach and Swiss Chard) were exceeded the limit of 50 ppm [18].

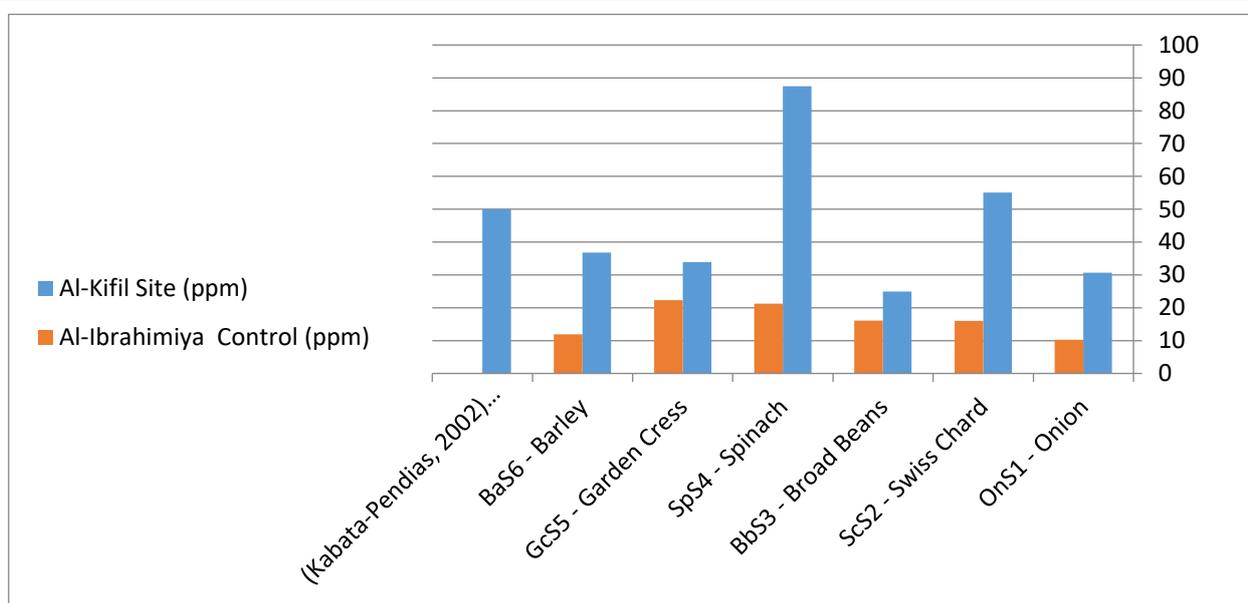
In Al-Ibrahimiya, Fe levels ranged from  $22.3204 \pm 0.4468$  ppm in Garden Cress to  $10.2964 \pm 0.1791$  ppm in Onion, where the Pb in all samples of control was within the safe limit, as in table (4) and figure (4).

Every single plant type at the Al-Kifil site has a higher Fe ppm than the corresponding plant at the control site, suggesting a systematic environmental factor (for example, soil contamination or irrigation source).

Statistical validation confirms high data consistency; minimal standard deviations further accentuate the significant disparities between study sites. A p-value of < 0.05 indicates a 98.8% probability that the observed spike at Al-Kifil is attributable to site-specific contamination.

**Table 4.** Iron (Fe) Concentration in plant samples in studied areas

Sample ID – Plant Types	Al-Kifil Site (ppm)	Al-Ibrahimiya Control (ppm)
OnS1 – Onion	30.6802 ± 1.1994	10.2964 ± 0.1791
ScS2 – Swiss Chard	55.0475 ± 1.7156	16.0005 ± 0.5708
BbS3 – Broad Beans	24.9082 ± 0.6002	16.1339 ± 0.8552
SpS4 – Spinach	87.4486 ± 2.7024	21.2048 ± 1.1157
GcS5 – Garden Cress	33.9204 ± 1.3714	22.3204 ± 0.4468
BaS6 – Barley	36.7587 ± 1.1496	11.9385 ± 0.5765
(Kabata-Pendias, 2002) Limit		50



**Figure 4.** Distribution of Iron concentrations in studied plant samples

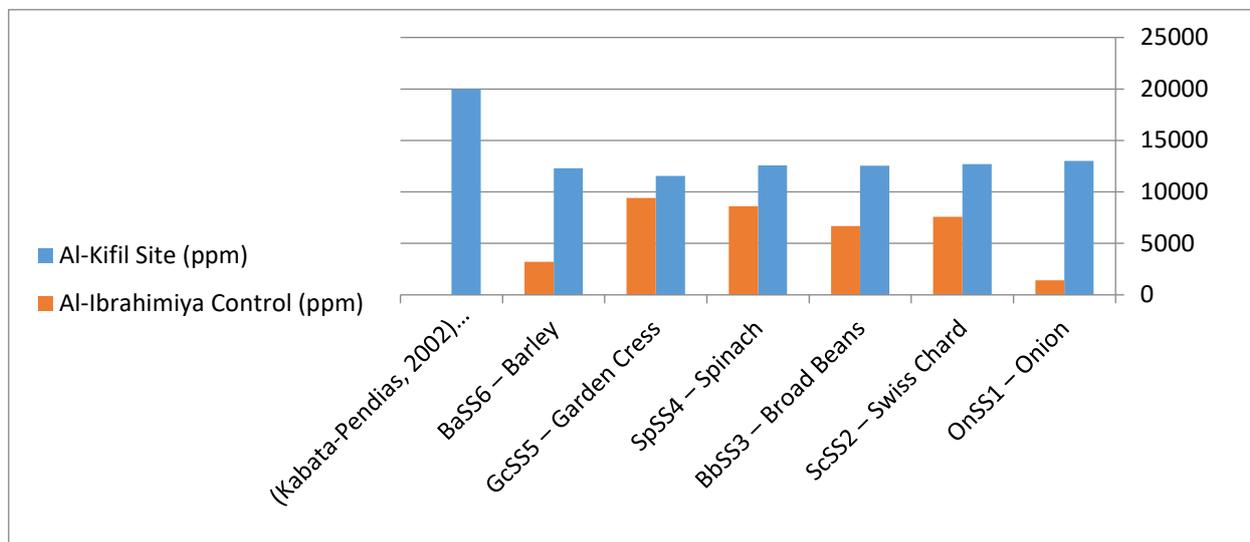
According to table (5), the concentration of iron (Fe) in soil samples at Al-Kifil ranged between the highest value of 13010.6±447.3 ppm in soil of Onion and the lowest of 11544.6±441.5 ppm in soil of Garden Cress. It is evident that Fe in all samples did not exceed the limit <sup>[18]</sup>. In the control site, Fe levels ranged from 9404.7±292.4 ppm in Garden Cress to 1411.8±270.3 ppm in the soil of Onion.

Iron is an important essential nutrient element in agricultural soil. Total iron concentrations in soils are relatively high compared to other heavy metals because Iron is a naturally abundant element in the earth's crust. The elevated Iron levels in soil, up to 20000 ppm, are not considered an indicator of contamination but reflect the natural geological composition and nutritional requirements of the soil, as in table (5) and figure (5).

**Table 5.** Iron (Fe) Concentration in soil samples for agricultured plants in studied areas

Sample ID – Soils of plat types	Al-Kifil Site (ppm)	Al-Ibrahimiya Control (ppm)
OnSS1 – Onion	13010.6 ± 447.3	1411.8 ± 270.3

ScSS2 – Swiss Chard	12703.8 ± 452.1	7573.0 ± 470.4
BbSS3 – Broad Beans	12535.5 ± 435.2	6685.1 ± 243.7
SpSS4 – Spinach	12571.3 ± 455.9	8605.7 ± 291.8
GcSS5 – Garden Cress	11544.6 ± 441.5	9404.7 ± 292.4
BaSS6 – Barley	12290.9 ± 442.2	3217.5 ± 113.2
(Kabata-Pendias, 2002) Limit		20000



**Figure 5.** Distribution of Iron concentrations in soil samples of agricultured plants

### 3.2. Chemical and Physical Properties of Soils

According to table 6, the soil pH values ranged from 5.93 at Al-Kifil into 7.11 at control of Al-Ibrahimiya. These values fall within the normal range for the control, while at Al-Kifil was still remain slightly below the global recommended limit of 6.0–8.5 <sup>[19]</sup>.

The relatively low pH observed at Al-Kifil site indicates a tendency of the soil towards acidity, which can increase the solubility and mobility of the studied heavy metals, thereby enhancing their transfer to plants and increase the uptake ratio.

Salinity (EC) values ranged from 3.65 dS/m at Al-Kifil site into 4.51 dS/m at control of Al-Ibrahimiya area, where the Al-Kifil value within the recommended limit of 4 dS/m <sup>[19]</sup>. Lower salinity levels can facilitate the translocation of heavy metals to plants and reduce competition among cations. In control of Al-Ibrahimiya, EC slightly exceeded the recommended threshold, which may reduce the mobility of heavy metals through chemical interactions and cation competition ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^{+}$ ) <sup>[20]</sup>.

Regarding organic matter, the control recorded the highest content at 4.01%, slightly above the recommended range. Organic matter has a dual role: it enhances soil fertility while, in some cases, limiting the mobility of heavy elements. It acts as a chemical and environmental shield, reducing the transfer heavy metals to plants, and consequently decreasing their entry into the food chain.

The Al-Kifil site recorded an organic matter content of 3.19%, consistent with average values of 2–3% reported <sup>[21]</sup>. Such levels may contribute to increased solubility and transfer of heavy metals from soil to plants, as in table 6.

**Table 6.** Chemical and physical properties of Soils in studied areas

Parameter	Limit	Al-Kifil Site	Al-Ibrahimiya (Control)
pH	8.5-6.0	5.93	7.11

Salinity	4.0 dS/m	3.65	4.51
Organic Matter %	3-2 %	3.19	4.01

The current study is consistent with numerous research studies [4,9,10,11], and therefore scientists will inevitably have to look for efficient green treatment methods to remove the resulting pollution in a way that is consistent with the sustainable development goals [22,23].

### 3.3. Interpretation of the Results and Explanation of Their Outcomes

Based on the overall data provided, the interpretation of the findings regarding heavy metal accumulation at the Al-Kifil site compared to the Al-Ibrahimiya control would be [24-29]:

1. Mechanisms of Pb and Fe Uptake: The data shows a clear disparity in how plants absorb Lead (Pb) versus Iron (Fe).

Lead (Pb) is a non-essential, toxic element. Plants generally take it up through passive diffusion via the roots. However, the high concentrations in Al-Kifil plants (e.g., 8.82 ppm in Swiss Chard vs. the 0.3 ppm FAO limit) suggest that the protective barriers of the roots are being overwhelmed, or there is significant atmospheric deposition on the leaves.

Iron (Fe) unlike Lead, Iron is a micronutrient. Plants use active transport (Strategy I and II mechanisms) to acquire Fe. The extremely high soil Fe levels (up to 13,010 ppm) are within the natural limit of 20,000 ppm, but the plant uptake remains high, suggesting the plants are in a state of luxury consumption.

2. Influence of Soil Properties on Metal Mobility: The soil properties in table (6) explain why Al-Kifil shows such high metal bioavailability:

A. pH Levels: Al-Kifil has a pH of 5.93 (slightly acidic), while the control is 7.11 (neutral). Heavy metals like Pb and Fe become significantly more soluble and mobile in acidic soils. The lower pH at Al-Kifil facilitates the transition of these metals from soil particles into the soil solution, making them easier for roots to absorb.

B. Organic Matter (OM): Al-Kifil has higher OM (3.19%). While OM can sometimes bind metals, it also forms soluble organic complexes (chelates) that can actually enhance the mobility of Fe and Pb toward the plant roots.

C. Salinity (EC): The lower salinity at Al-Kifil (3.65 dS/m) compared to the control suggests less competition for ion exchange sites, potentially allowing heavy metal ions to be more readily available.

3. Plant-Specific Accumulation: The tables show that Spinach and Swiss Chard are the primary accumulators:

A. Morphology: Leafy vegetables have a large surface area-to-volume ratio. This makes them highly susceptible to foliar uptake of metals from dust, irrigation water, and root uptake.

B. Hyper-accumulation Tendencies: Members of the *Amaranthaceae* family (Spinach/Chard) are known biologically as heavy metal accumulators. They have high transpiration rates, which creates a pull that brings dissolved metals from the soil into the edible tissues.

C. Comparison: In contrast, Barley showed the lowest Pb levels (1.92 ppm), likely because cereals often have more selective barriers in their root-to-shoot translocation processes.

4. Practical implications and risk assessment of human health:

The Pb levels in all Al-Kifil crops are significantly above the safe limit for human consumption. Long-term ingestion of these vegetables poses risks of neurological damage and kidney dysfunction.

A. Agricultural Management: The soil at Al-Kifil is near the limit for Pb (88.6 ppm vs. 70 ppm limit). Farmers should avoid planting "accumulator" crops like Spinach and Chard in this area.

B. Remediation: There is an urgent need for soil liming to raise the pH, which would help immobilize the Lead and prevent it from entering the food chain.

When calculate the Transfer Factor (TF) for each plant to see which one is most efficient at moving metals from the soil to the leaves, we use the ratio of the concentration of the metal in the plant to the concentration of the metal in the soil:

$$TF = C_{\text{plant}} / C_{\text{soil}}$$

If a TF > 1 indicates that the plant is a hyper-accumulator, while a higher TF relative to other plants shows a greater efficiency in absorbing metals.

From table (7), the analysis of the transfer factors would be as follows:

1. Lead (Pb) accumulation efficiency:

A. Highest efficiency of plants such as Garden cress (0.478) and Swiss chard (0.405) show the highest transfer factors for Lead. Even though Spinach had a higher absolute concentration in its leaves, Garden cress and Swiss chard are actually more efficient at extracting Pb relative to the amount available in their specific soil patches.

B. Low bioavailability: All TF values for Pb are <1, this suggests that while the plants are taking up dangerous amounts of Lead, the soil is still holding onto a large portion of it. If the soil pH drops further, these TF values could spike, making the crops even more toxic.

2. Iron (Fe) Accumulation Efficiency:

A. Extremely low TF: The TF values for Iron are very low (all <0.01), this is because the soil concentration of Fe is massive (approx. 12,000 ppm).

B. Selective uptake: Plants have a ceiling for Iron uptake because it is a nutrient, even though there is a massive supply in the soil, the plants' internal mechanisms (like the storage protein ferritin) work to prevent the plant from becoming toxic, though Spinach still managed to accumulate the most (TF: 0.0069).

However, the Swiss chard and Garden cress have become high-risk crops. The high TF for Swiss chard and Garden cress indicates they are bio-indicators of pollution, they act like sponges for Lead. In Al-Kifil, the combination of slightly acidic soil (pH 5.93) and the biological nature of these leafy greens makes them the most hazardous crops in the study. But if this land must be used for agriculture, the data suggests that Broad beans or Onions are safer choices than leafy greens, as they show lower efficiency in transferring Lead from the soil to the edible parts.

For the Fe-Pb synergy, the synergistic uptake of metals is facilitated by plant physiology and soil acidity (pH 5.93), which enhances the solubility of both Fe and Pb <sup>[30]</sup>.

**Table 7.** Transfer Factor (TF) for Lead (Pb) and Iron (Fe) at Al-Kifil site

Sample ID	Plant Type	Pb (Plant/Soil)	Fe (Plant/Soil)
OnS1	Onion	0.086	0.0023
ScS2	Swiss Chard	0.405	0.0043
BbS3	Broad Beans	0.052	0.0019
SpS4	Spinach	0.084	0.0069
GcS5	Garden Cress	0.478	0.0029
BaS6	Barley	0.162	0.0029

**Table 7.** (Continued)

## 4. Conclusion

The comparative assessment between the Al-Kifil site and the Al-Ibrahimiya control reveals a significant environmental contamination profile, particularly concerning Lead (Pb). The findings demonstrate that agricultural produce in the Al-Kifil area is heavily impacted by the presence of heavy metals, with Pb concentrations in all studied plant species exceeding the FAO/WHO (2011) permissible limit of 0.3 ppm.

The high bioavailability of these metals is closely linked to the soil's physicochemical properties. The slightly acidic nature of the Al-Kifil soil (pH 5.93) enhances the solubility and mobility of Pb and Fe, facilitating their transition from the soil matrix into the plant vascular system. Leafy vegetables—specifically Spinach and Swiss chard—exhibited the highest accumulation levels, acting as bio-accumulators. While Iron (Fe) levels are within natural soil limits, the excessive uptake in spinach (87.44 ppm) suggests a breakdown in the plant's regulatory mechanisms under the stress of contaminated conditions. Collectively, the data indicates that the Al-Kifil site represents a high-risk zone for heavy metal entry into the local food chain.

## 5. Recommendations

1. Immediate soil remediation (Liming): Application of agricultural lime is strongly recommended to raise the soil pH toward a neutral. This will significantly reduce the solubility of Pb, locking it in the soil and preventing root uptake.

2. Restricted crop selection: Farmers in the Al-Kifil region should be advised against cultivating leafy green vegetables (Spinach, Swiss Chard, Garden Cress) which show high (TF). Transitioning to crops with lower translocation rates is advisable until soil levels stabilize.

3. Phytoremediation programs: Implementation of a phytoremediation strategy using non-food hyper accumulators (e.g., *Helianthus annuus* or specific mustard varieties) to gradually extract Pb from the topsoil.

4. Continuous monitoring: Establish a periodic heavy metal monitoring program for both irrigation water and soil in the Al-Kifil area to identify the ongoing source of contamination (e.g., industrial discharge or vehicular emissions).

5. Public Health Awareness: Local communities should be informed of the risks associated with consuming leafy vegetables grown in the affected area to mitigate the long-term health impacts of heavy metal toxicity.

## 6. Acknowledgment

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## 7. Conflict of interest

The authors declare no conflict of interest.

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