



Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: <https://atbuscienceforum.com.ng/index.php/jpas>



Determination of Lead and Cadmium Concentrations in Lettuce and Spinach Using Atomic Absorption Spectroscopy

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Abstract

The levels of lead (Pb) and cadmium (Cd) were determined in vegetables such as Allium's leaf vegetables that are commonly consumed by human beings, using Atomic Absorption Spectroscopy (AAS) at the Central Laboratory of the University of Baghdad. Because they have high consumption rates and can build up high amounts of heavy metals, lettuce (*Lactuca sativa*) and spinach (*Spinacia oleracea*) were selected. Due to variations in soil characteristics and the proximity to possible pollution sources (including traffic, industrial activities and agricultural activities), samples were collected from various parts of Al-Shatrah city. Three consecutive months (three experimental stages) of sampling of leaves, stems and roots was conducted for both plants. The data showed significant differences in the levels of both the elements among the different sampling locations and among the various sections where the plants were sampled. All the lead readings were above the national average and the highest reading was at City 1 (15 ppm), City 2 (13.4 ppm) and City 3 (12 ppm). Cadmium also was identified in some samples with the highest concentration (0.40 ppm and 0.27 ppm) in City 1 samples. Species dependent variability in the efficiency of heavy metal uptake was noticed, as cadmium content was higher in spinach as compared to lettuce. Various other factors affect the reported level of pollution, including soil properties, temperature, wind characteristics, etc., and anthropogenic factors (chemical fertilizer use, fuel burning and industrial emissions). The findings highlight the importance of continued environmental surveillance and sustainable agricultural practices to reduce the levels of heavy metals, and to ensure food security and safety, as well as the potential human health risks associated with consumption of contaminated leafy vegetables.

Keywords

Heavy Metal Contamination, Lettuce, Spinach, Lead (Pb), Cadmium (Cd), Atomic Absorption Spectroscopy (AAS).



1. Introduction

Leafy vegetables are a vital part of the human diet because of their high nutritional content and health advantages. Lettuce (*Lactuca sativa*) and spinach (*Spinacia oleracea*) are two of these plants that are popular around the world and are thought to be abundant in vitamins, minerals, and bioactive substances. These vegetables are rich in antioxidants, folate, iron, and vitamins A, C, and K, all of which are crucial for preserving human health and lowering the risk of chronic illnesses (Berkheiser, 2019; Whelan, 2020). One of the most popular leafy vegetables is lettuce, which comes in a variety of forms, including iceberg and romaine. It is distinguished by its high-water content, low calorie content, and potassium and folate content, which significantly improve cardiovascular health.

(Johnson, 2019). Similarly, the nutritional importance and ability of spinach to accumulate micronutrients from the environment make it more susceptible to environmental pollution (Alam & Ganguly, 2015; FAO, 2022). Heavy metal contamination of vegetables has become a global problem due to the rapid industrialisation, urbanisation, and increase in human activities. Due to their huge surface area and high ability to absorb harmful metals from the soil and atmosphere, leafy vegetables are especially sensitive. Lead (Pb) and cadmium (Cd) are two of the most harmful elements in the group of heavy metals due to their toxicity, persistence, and bioaccumulation in living organisms. Although leafy vegetables are rich in nutrients, they are highly vulnerable to environmental pollution - particularly the contamination, absorption

and accumulation of heavy metals such as lead (Pb) and cadmium (Cd).

They may be subject to human activities that can add these harmful substances into agricultural soils including industrial emissions, car exhaust, wastewater irrigation, mining and overusing of chemical fertilizers (Su et al., 2014; Triassi et al., 2015). When found in soil, these metals can be taken up by plant roots and accumulate in edible parts of plants and are a significant threat to human health. Recent research has shown that leafy vegetables, especially spinach and lettuce, tend to have greater potential to accumulate heavy metals than other vegetables. While more recent research (FAO, 2022; WHO, 2021) highlighted that extended exposure to these metals may result in serious health issues, Xiao-Dong et al. (2016) showed higher levels of Pb and Cd in commercially available vegetables.

The environmental influences, such as soil composition, temperature, rainfall, wind, and the source of pollution (such as traffic emissions, thermal power plants and industrial areas) determine the concentration of metals in agricultural soil to a large extent (Victoria, 2015; WHO, 2021). Moreover, the use of unwashed sewage sludge and contaminated irrigation water can also lead to soil and crop contamination with hazardous substances if these are not properly managed. Heavy metal contamination of leafy greens is a matter of public health and nutrition and therefore deserves attention.

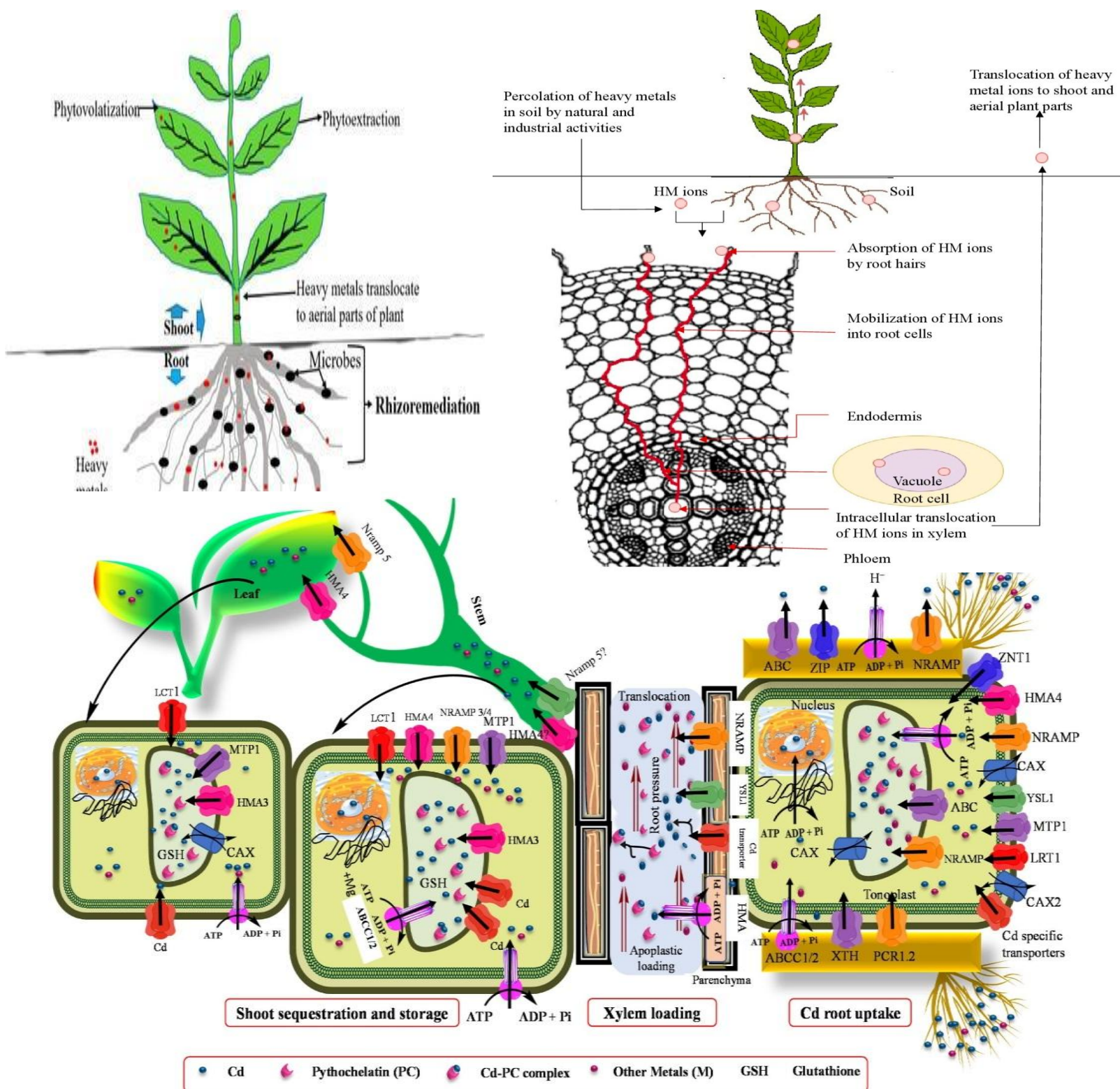


Figure (1) describes the mechanisms of foliar deposition of airborne heavy metals (Pb, Cd) and the absorption of heavy metals by the roots from contaminated soil.

The study only measured the concentration of lead (Pb) and cadmium (Cd) and only at selected sample locations. Further research is suggested on additional heavy metals and other agricultural fields.

2. Heavy Metals in Plants

Heavy metals are some of the most dangerous contaminants in the environment due to their toxicity, bioaccumulation and persistence. Rapid industrialization, urbanization and increased transportation activities have also contributed to

further environmental contamination particularly in urban and industrial settings (Su et al., 2014; Triassi et al., 2015). These contaminants can be found in the food chain and cause significant health risks as they can enter the soil, water and air and concentrate within the plant, ultimately within the edible parts of the plant.

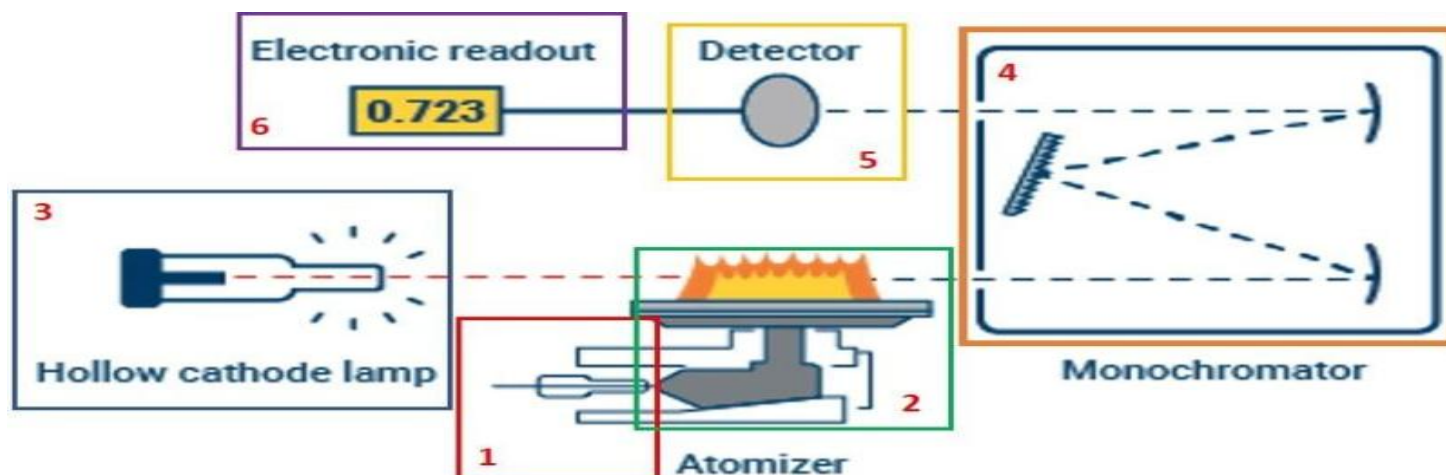


Figure (2) The Atomic Absorption Spectroscopy (AAS) device used to measure Pb and Cd concentrations

One popular analytical method for finding trace metals is Atomic Absorption Spectroscopy (AAS). It measures the amount of light that unbound atoms in the gaseous state absorb. The element-specific wavelengths emitted by the hollow cathode lamp enable precise measurement of Pb and Cd in plant samples (Skoog et al., 2014).

3. Description

One popular analytical method for identifying and measuring trace metals in biological and environmental materials is atomic absorption spectroscopy (AAS). The method measures how much light is absorbed by unbound atoms in their gaseous state. Lead (Pb) and cadmium (Cd) concentrations in plant tissues may be precisely determined thanks to AAS analysis, which uses a hollow cathode lamp to produce element-

specific wavelengths that are absorbed by metal atoms (Skoog et al., 2014).

3.1. Lead (Pb) is a non-essential

Lead (Pb) is a heavy metal, essential to human health, and very harmful. The environmental lead contamination has been highly elevated due to anthropogenic activities such as fuel combustion, industrial emissions, and pollution from traffic (WHO, 2021). After being absorbed by plants, lead builds up in different tissues and can find its way into the human food chain when contaminated vegetables are consumed (Uzu et al., 2010). Long-term exposure to lead is associated with serious health problems, including neurological problems, kidney disease, anemia, and cardiovascular disease (ATSDR, 2010). A previous study found that levels of exposure are much

higher among people than in ancient populations, due to increased environmental contamination.

(Mukunda, 2008; Budd et al., 1998).

3.2. Cadmium (Cd)

Even at low quantities, cadmium (Cd), another extremely hazardous heavy metal, causes major dangers to human health and the environment. It is thought to enter the environment primarily through industrial processes, phosphate fertilizers, wastewater irrigation and burning of fossil fuels (Su et al., 2014). Important trace elements tend to be excreted from the body, whereas Cadmium accumulates in the liver and kidneys. Cadmium (Hassan, 2012; Uzu et al., 2010).

exposure has been linked to kidney failure, bone loss, enzyme disruption and many chronic diseases (Angelonia & Bini, 2017; WHO, 2021). Cadmium inhibits growth, causes physiological and metabolic disturbances and reduces crop production.

3.3. Pathways of Metal Uptake in Plants

Heavy metals may enter plant tissues in two primary ways—foliar deposition of airborne particles or uptake by the roots from contaminated soil. Airborne particles with metals such as Pb and Cd can settle on leaf surfaces and be taken up through the stomata or infiltrate the interior parts of the leaf, whereas metals in the soil are taken up by roots and transported to aerial plant parts.



Figure (3) Sampling Locations and Environmental Impact (3D Map Style)

The selected sampling sites are located at different distances from the pollution sources such as power plants, industrial zones and road traffic. These environmental conditions greatly affect the variability of heavy metal levels in plants. (Triassi et al., 2015).

1. To determine the levels of lead (Pb) and cadmium (Cd) in favourite leafy vegetables such as spinach (*Spinacia oleracea*) and lettuce (*Lactuca sativa*).
2. To determine the effects of environmental factors (dust storms, temperature changes, human activity) on the accumulation of heavy metals.
3. To compare the amount of lead and cadmium that can build up in a plant such as spinach and lettuce.
4. To identify suitable mitigation strategies to reduce heavy metal contamination in crops and farmlands.

5. Materials and Methods

5.1 Sample Collection

Lettuce (*Lactuca sativa*) and spinach (*Spinacia oleracea*) samples were collected from three different locations that vary in degree of environmental contamination. The selected locations were different in terms of proximity to traffic pollution, industry and agriculture.

5.2 Preparing the Sample

Plant material (leaves, stems, roots) was thoroughly washed with distilled water, dried in air, and dried in oven at 70°C till a constant weight. The samples were dried, then crushed and sieved through 75 μm mesh screen.

The sample analysis was done by burning 2 g of each sample at 600°C for 6 hours followed by acid digestion using nitric acid (HNO_3 , 1N) as reported by Su et al. (2014).

4. Research Goals

The aim of this study is to evaluate the potential health risk from heavy metal pollution of leafy vegetables. The study's particular goals are:

5.3 Analysis of Metals

Atomic Absorption Spectroscopy (AAS) was used to measure the amounts of Pb and Cd. The World Health Organization (WHO, 2021) recommended values were compared with the values obtained.

5.4 Design of Experiments

The comparison of temporal changes in the accumulation of heavy metals was performed by sampling in three consecutive months corresponding to three experimental stages.

5.5 Statistical Analysis

One-way ANOVA was applied to the statistical analysis in order to find significant difference between plants species and sampling areas. Data was presented as Mean $\pm$ Standard Deviation (Mean $\pm$ SD) and differences were considered significant if $p < 0.05$. The results of this study highlight that to reduce contamination from heavy metals and to guarantee the quality and safety of agricultural crops, there is a need to adopt a thorough monitoring system and sustainable environmental management.

6. Outcomes

The results of the statistical analysis showed that the accumulation of both elements (Pb and Cd) was significantly different ($p < 0.05$) among the plant species and sampling locations. The statistical analysis showed that the concentrations of the elements (Pb and Cd) increased significantly ($p < 0.05$) among sampling sites and plant species.

Table No (1): Heavy Metal Concentration (ppm) in Lettuce and Spinach

Plant	Location	Leaves (Pb)	Roots (Pb)	Leaves (Cd)	Roots (Cd)
Lettuce	City 1	14.0	6.0	0.26	0.40
Lettuce	City 2	12.0	11.0	0.22	0.13
Lettuce	City 3	10.0	6.0	0.25	0.15
Spinach	City 1	15.5	7.2	0.35	0.45
Spinach	City 2	13.1	9.5	0.28	0.21
Spinach	City 3	11.4	7.0	0.30	0.18

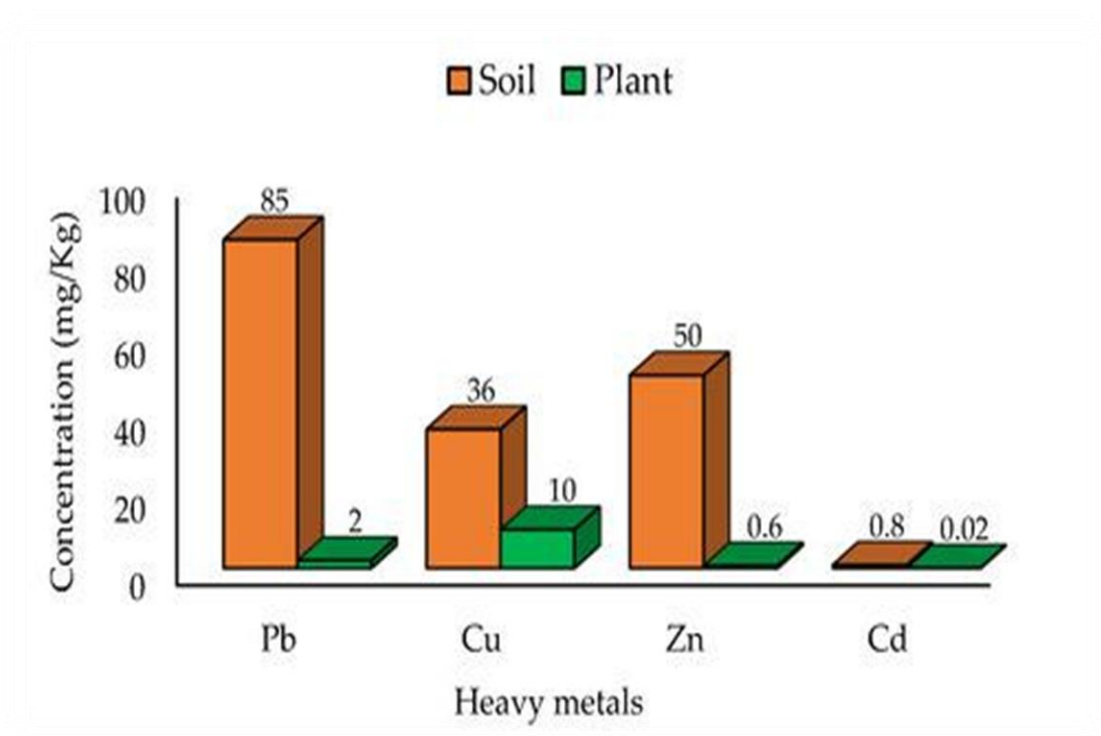


Figure (4) illustrates the comparative accumulation of Pb and Cd in lettuce and spinach samples collected from different polluted regions.

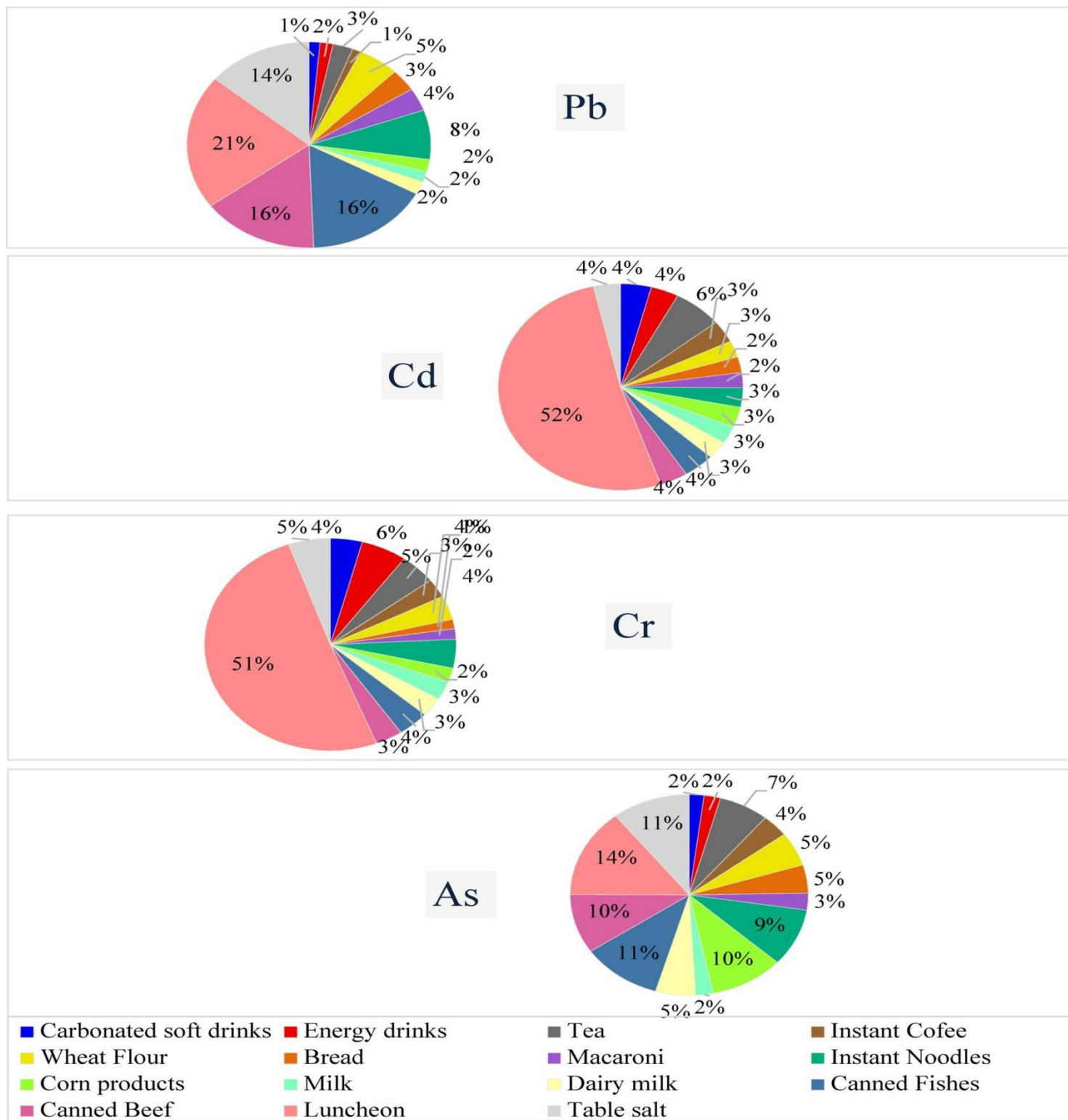


Figure (5) The findings suggest that while both plants have higher levels of lead in contaminated areas, spinach accumulates more cadmium than lettuce. This demonstrates how heavy metal intake varies depending on the species (Xiao-Dong et al., 2016).

Table No (2) Comparison with WHO Limits

Metal	WHO Limit (ppm)	Observed Range
Pb	0.3	10 - 15.5
Cd	0.2	0.13 - 0.45

Three replicates' mean $\pm$ standard deviation is used to express the values. The differences at $p < 0.05$ were considered significant.

7. Interpretation

The results revealed that most of the samples tested were contaminated with Pb and Cd in levels exceeding the limits in particular in heavily polluted and industrial sites. Cadmium accumulation ability was observed to be higher in spinach than lettuce suggesting that the species uptake and translocate different metals differently. The findings, consistent with previous studies of the accumulation of heavy metals in leafy vegetables, are posted here. (Xiao-Dong et al., 2016; WHO, 2021).

8. Recommendations

2. Establish environmental monitoring stations in polluted areas of agriculture.
2. Encourage the application of organic fertilizers in preference to excessive use of chemicals.
3. Use plants that can absorb heavy metals from contaminated soils to implement phytoremediation procedures.
4. Promote awareness about food safety and environmental pollution and the importance of food safety for human health.
6. Ensure that levels of heavy metals in agricultural products are monitored periodically to assure compliance with global safety standards.

9.Future Perspectives

Other heavy metals such as chromium (Cr), arsenic (As) and mercury (Hg) in different vegetable species are suggested to be further investigated. The samples could be increased and advanced analysis tools used to

provide more detailed information on food safety and environmental contamination.

10. Discussion

The results of this study revealed that high concentrations of lead (Pb) and cadmium (Cd) existed in some of the study areas in the collected samples of spinach (*Spinacia oleracea*) and lettuce (*Lactuca sativa*). Observed quantities were found to be above the limits set by World Health Organization (WHO, 2021) and indicating a possible public health threat. Lead concentration may have been caused by deposition of lead from burning leaded petrol, industrial pollution and leafy tissues (City 1) - Sites with large amounts of traffic and industry will have higher concentrations. These results are in line with earlier research that found industrial and automotive processes to be the main causes of lead pollution in the environment.

(Hassan, 2012; Triassi et al., 2015). Moreover, the higher concentration of Pb in the leaves compared with the roots may suggest that the uptake of heavy metal via airborne dust particles and atmospheric pollution is more likely to take place in the leaves rather than in the roots (Uzu et al., 2010). In addition, the amount of Cd deposition in spinach samples was higher than in lettuce samples. This difference could be attributed to variation in transpiration rates, species-specific metal uptake processes, and/or physiological characteristics which facilitate metal uptake and translocations processes. Xiao-Dong et al. (2016) also found a considerable variation in the

amount of toxic metal uptake by leafy vegetables. The distribution of heavy metals was also influenced by environmental factors, such as soil composition, soil temperature, wind directions, and precipitation at the different study sites.

The notion of human activities as a significant source of pollution is corroborated by higher levels of contamination in proximity to pollution sources (Su et al., 2014; Victoria, 2015). In addition, soil contamination with Cd could have been due to the application of chemical fertilizers and possibly contaminated irrigation water (Angelone & Bini, 2017). The temporal variations observed over the three sampling periods suggest that seasonal and climatic factors can affect the accumulation of heavy metals. Higher concentrations may be associated with dust storms and dry weather which encourage air deposition on plant surfaces. From a health standpoint, eating tainted leafy vegetables on a regular basis could cause harmful metals to bioaccumulate in the body (WHO, 2021; ATSDR, 2010).

Chronic exposure to Cd has been associated with renal damage and bone abnormalities, while chronic exposure to Pb has been associated with neurological disorders, kidney malfunction and cardiovascular diseases. The high levels of these compounds detected in this study therefore poses serious concerns in public health and food safety. The overall findings of this study corroborate with the global studies that indicate the increase in concentration of heavy metals in agricultural systems with the degradation of environment and the industrialization. Our results emphasize the importance of conducting environmental monitoring, pollution control, sustainable agricultural management, and remediation

measures to minimize the accumulation of pollutants within the crops.

The current study puts into perspective the impact of environmental pollution on food safety and public health and gives current data regarding the contamination of leafy vegetables with heavy metals in Al-Shatrah city. The results from the present study highlight the need for sustainable agriculture and environmental monitoring programmes to reduce the contamination of heavy metals and the risk to human health. The results of the study highlight the need for sustainable agriculture and monitoring programmes to reduce contamination by heavy metals and food safety. One of the most important problems that affect soil conditions and food security is environmental contamination resulting from industrialization, traffic and bad agricultural practices. Heavy metals may build up in food and pose a risk to an ecosystem and the occurrence of chronic diseases in the population that eats the polluted vegetable.

The main health effects of chronic human exposure to lead (Pb) and cadmium (Cd) are presented in Figure 5. Prolonged exposure to Pb and Cd may result in neurological abnormalities, renal damage and cardiovascular diseases. These metals accumulate in human tissues over time, and may cause long term damage (WHO, 2021). Regular consumption of contaminated food may result in bioaccumulation of toxic metals in the body of human beings. Long-term exposure to lead and cadmium may result in neurological effects, kidney dysfunction, cardiovascular effects and bone damage.

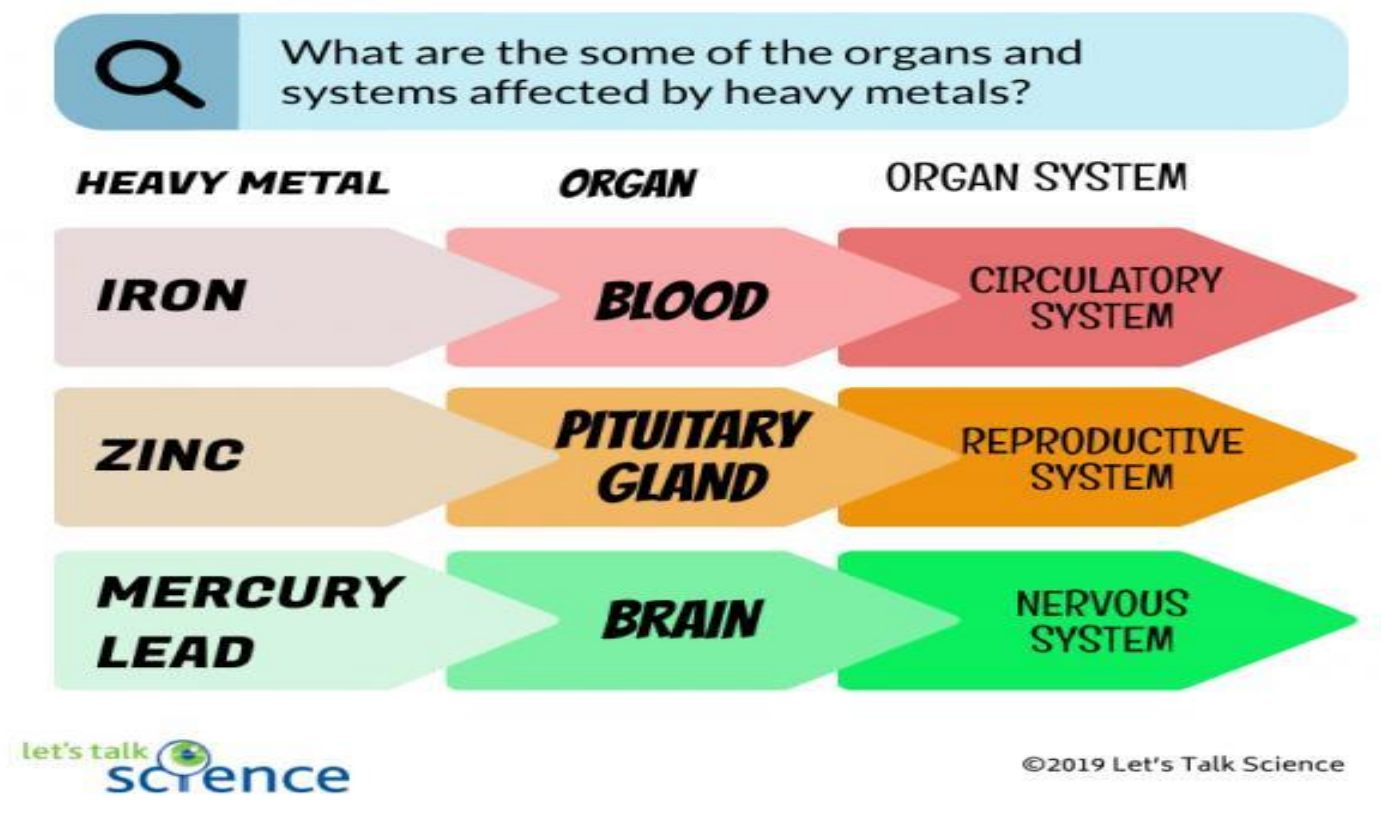


Figure (6) Some of the organs and systems affected by heavy metals

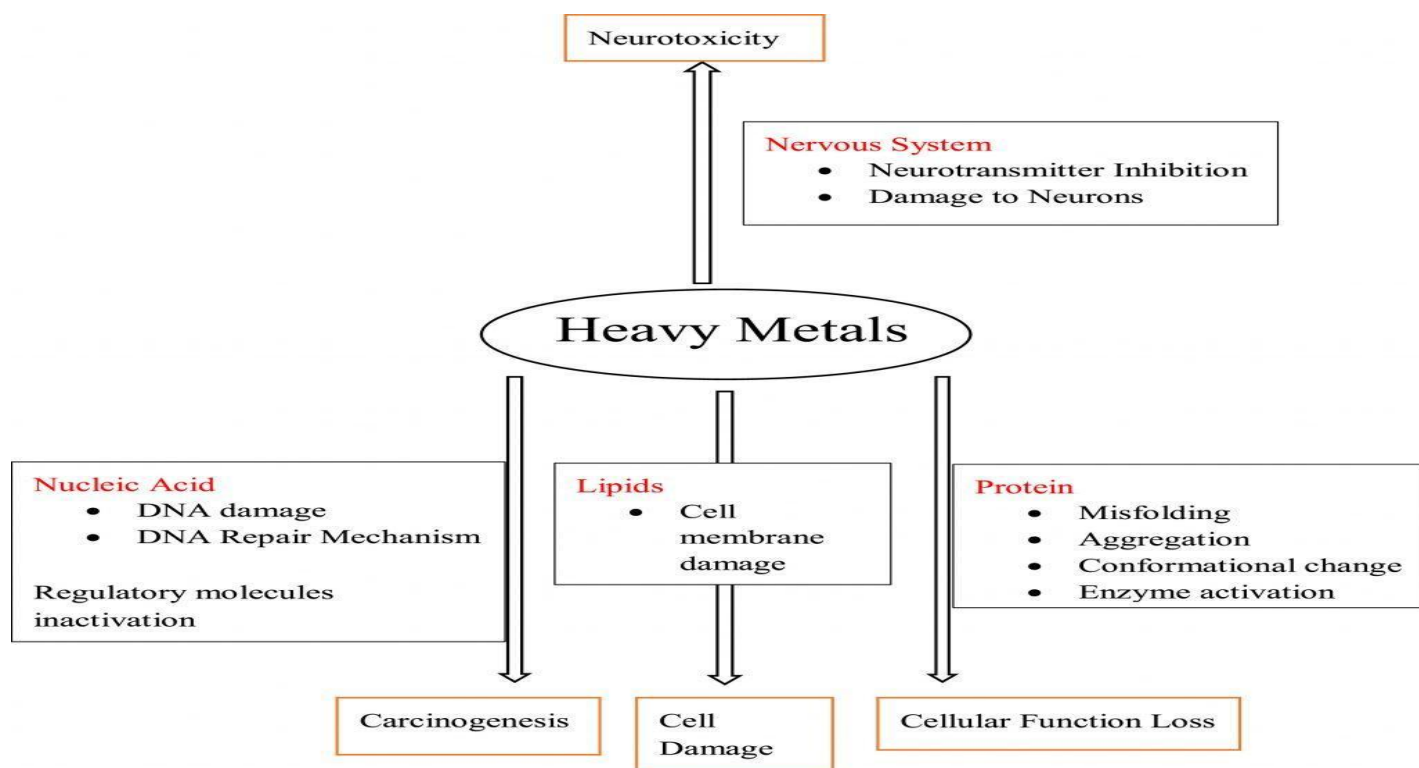


Figure (7) The higher level of heavy metal found in spinach could be related to its physiology such as bigger size of leaf area and transpiration rate which leads to more absorption and transportation of the contaminants.

11. Novelty of the Study

This study gives the up-to-date data on the level of contamination of leafy vegetables in Al-Shatrah with heavy metals. It brings attention to the importance of environmental sources and vehicle emissions and industrial processes to the buildup of lead and cadmium in spinach and lettuce. Additionally, the research is supportive of the agricultural regions to take care of food safety and raise environmental consciousness.

12. Health Risk Assessment

If the leaves are ingested over a prolonged period of time, toxic metals may accumulate in the human body over time. Chronic exposure to lead (Pb) and cadmium (Cd) may lead to significant health impacts such as damage to the immune system, nervous system, kidney, cardiovascular system and bone. Thus, it is crucial to regularly check food products for heavy metals in order to safeguard public health.

13. The Study limitations.

This investigation focused on only selected sample sites and the concentrations of both the content of lead and cadmium in lettuce and spinach. Further studies are needed with higher number of participants and various environmental conditions to provide a more thorough evaluation.

14. Conclusions

Based on the results of this study, some important inferences can be drawn regarding the level of heavy metal contamination in leafy vegetables:

1. Samples of spinach (*Spinacia oleracea*) and lettuce (*Lactuca sativa*) collected above the acceptable limits recommended by international standards for lead (WHO, 2021), particularly in areas where there are high levels of industrial and transportation activity.

2. The accumulation of Cd in the plant species, spinach and lettuce was also found to be higher in spinach than in lettuce.
3. The different parts of plants showed different concentration of heavy metals; more concentration was observed in the leaves which indicates that the larger portion of heavy metal is from atmosphere.
4. Environmental conditions such as soil properties, pollution sources, climate and farming practices have an important effect on the accumulation of heavy metals in plants.
5. The major sources of heavy metal pollution in the research zones were identified as anthropogenic sources, including over-fertilized use of chemical fertilizers, industrial emissions and fuel combustion.
6. Eating polluted leafy vegetables regularly may be very harmful since hazardous metals are known to bioaccumulate in the human body to cause chronic disorders.
7. The results highlight the importance of environmental monitoring, improved agricultural management, and sustainable practices to reduce heavy metal contamination and ensure food safety.

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