Assessment of Lead and Cadmium contamination in Vegetables: A Study from Faridabad

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Abstract
The study aimed to examine heavy metal accumulation in 5 vegetable and the soil under the crop. Five types of vegetables were collected from farmland contaminated with heavy metals, including lead and cadmium. The samples were collected after harvest and analysed for heavy metal quantities. The findings revealed significant variations in heavy metal concentrations across the edible parts of different vegetables. The accumulation of heavy metals presented a serious concern. The values of lead for all the soil samples ranging from S1 to S5 were observed to be 1.78, 1.8, 1.77,1.80 and 1.82 %. While in vegetables the values from V1 to V5 were observed to be 0.03, 0.07,0.07, 0.06 and 0.03 %. Similarly, the values for Cadmium in all the soil samples ranging from S1 to S5 were observed to be 1.52, 2.90, 1.71,1.75 and 1.81 %. And Cadmium in all the vegetable samples ranging from V1 to V5 were observed to be 0.04, 0.09,0.06, 0.08 and 0.04 %. So overall estimation depicted an active uptake of heavy metals from soil to vegetable crops, which poses a greater need for remediation methods.
Keywords: Heavy metal, vegetables, accumulation, health risk, vegetable; target hazard quotient (THQ)
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1. Introduction

Vegetables are a cornerstone of human nutrition, providing essential vitamins, minerals, fibres, and antioxidants that promote good health and help prevent various diseases. They are vital sources of macro nutrients and micro nutrients, playing a critical role in human diets across the globe **(FAO, 2016).** Vegetables are also known for their ability to buffer acids produced during digestion, offering an alkaline response that supports overall metabolic health **(Zhao et al., 2016)**. Additionally, their high fibre content aids in digestive health, while specific compounds in vegetables help fight oxidative stress and inflammation **(Jin et al., 2017)**. However, despite their significant nutritional benefits, vegetables are increasingly at risk of contamination by heavy metals due to environmental pollution. Heavy metals such as cadmium (Cd), lead (Pb), arsenic (As), copper (Cu), and zinc (Zn) can accumulate in plant tissues, particularly when the soil and water used for irrigation are contaminated **(Alloway, 2013).** These metals are absorbed through plant roots from contaminated soil or water, and can accumulate in the edible parts of vegetables, posing a direct health risk to consumers **(Li et al., 2018)**. Even low concentrations of these contaminants in soil and water can lead to dangerous levels of heavy metals in the food chain, thereby affecting human health. Even in cases where soil contamination levels are relatively low, heavy metals can accumulate significantly in the edible parts of vegetables due to the roots' easy absorption of the metals from the soil.The rate at which different plants accumulate metals varies, with some vegetables absorbing metals at much higher rates than others. The widespread use of wastewater for irrigation, industrial activities, and poor waste disposal practices have exacerbated the contamination of soil and water with toxic metals in many regions **(Sharma et al., 2020).** Recent studies show that vegetables irrigated with wastewater are more susceptible to accumulating these toxic metals. For instance, leafy vegetables like spinach tend to accumulate higher levels of metals, such as Cu and Zn, due to their higher bio-concentration factors (BCF) compared to other plant species **(Khan et al., 2008; Foti et al., 2010).** A BCF greater than 0.5 indicates that the plant absorbs metals at higher levels than what is present in the surrounding soil. For example, plants like coriander and brinjal exhibit higher BCF values for metals like Mn, Zn, and Cu, while others, such as tomatoes, absorb metals at lower rates **(Liu et al., 2009; Ali et al., 2013).**

As a result, this contamination not only threatens the quality of vegetables but also increases the risk of chronic diseases such as kidney dysfunction, neurological disorders, and cardiovascular diseases among populations that rely on locally grown produce **(Sultana et al., 2020).** While high levels of zinc can weaken the immune system and lower HDL levels, which can have a negative effect on general health, copper can cause acute gastrointestinal distress and liver damage. The ingestion of vegetables contaminated with heavy metals can pose significant non-carcinogenic health risks. Prolonged exposure to metals like Zn, Cu, and Pb can result in neurological, renal, and cardiovascular problems **(Goyer, 2001; Jarup, 2003).** Due to their lifetime accumulation and persistence in the body, heavy metal elements such as lead (Pb), cadmium (Cd), arsenic (As), and others present serious toxic risks to human health. Lead (Pb) can cause elevated blood lead levels, impair children's cognitive development, and aggravate conditions like cardiovascular disease, nephropathy, and hypertension. Chronic exposure to cadmium (Cd) can cause immune system dysfunction, nephrotoxicity, osteotoxicity, and acute toxicity in the liver and lungs. Skin cancer and angiosarcoma are closely associated with the metalloid arsenic (As). While zinc (Zn) and copper (Cu) are vital nutrients for humans, too much of either can be detrimental. Skin cancer and angiosarcoma are closely associated with the metalloid arsenic (As). While zinc (Zn) and copper (Cu) are vital nutrients for humans, too much of either can be detrimental. This study intends to ascertain the levels of lead and cadmium in frequently consumed vegetables considering these worries. By assessing the levels of these contaminants in vegetables, this study will help develop safer farming methods for long-term food security and offer important information on the possible health risks associated with eating vegetables.

2. Materials and Methods

2.1. Sample location and collection

The quality test survey of the vegetable and soil samples was conducted in July, 2024. 1kg representative sample per location from each at 5 different locations were collected from Faridabad, Haryana. (Figure 1.) All the samples were collected in polyethene pouches and put with proper labels clearly representing the location, date, and sample code. Details of different collection site along with the sample codes are given in Table 1.

Figure-1. Soil samples collected in polythene bags

Table 1. Details of collection sites

S. no.	Location
1.	Khedi gujran
2.	Kabulpur
3.	Sector 56
4.	Sector 89
5.	Old Faridabad

Table 2. Details of soil samples along with sample codes

S. no.	Soil	Vegetable
1.	S1	V1 (lady finger)
2.	S2	V2 (potato)
3.	S3	V3 (cucumber)
4.	S4	V4 (green chilly)
5.	S5	V5 (round guard)

2.2 Site Description

Faridabad district of Haryana State

Faridabad has an average elevation of 198 meters and is situated at 28.40°N 77.32°E. It is one of Haryana's main industrial centres and is about 30 kilometers from Delhi. Faridabad is located in the National Capital Region (NCR) and has a total area of about 742.9 square kilometers. Numerous industries and its proximity to Delhi have resulted in serious environmental problems, such as air and soil pollution. Despite its industrial significance, there is still a dearth of thorough research on soil contamination leading to vegetable deposition and its effects on the environment in Faridabad, which makes it an important topic for targeted investigation.

2.3 Sample preparation

5 different vegetable samples were gathered during the harvesting stage for the heavy metal investigation study, and soil samples under the vegetables too were collected between 0 - 15 cm and thoroughly mixed to create a composite sample: The 500 g of edible vegetable parts were gathered, thoroughly cleaned with fresh water to get rid of any dirt that stuck, and then rinsed with deionized water. A homogenous mass was then achieved by grinding roughly 10 g of each sample in a mortar. After that, the samples were placed in tiny, airtight polythene bags and stored in the refrigerator for further analysis. ICP-MS analysis was conducted at Oatman's testing agency, Faridabad.

The details of all the characteristics under study along with the method of analysis is provided in Table 3.

Table 3. Details of characteristics analysed in each sample

S. no.	Characteristics	Method of analysis

1.	**pH**	pH Meter IS:3025
2.	**Conductivity**	Conductivity meter IS: 14767:2000
3.	**Lead**	ICP-MS
4.	**Cadmium**	

3. Results and Discussion

The experimental values of all the physico-chemical parameters are presented in Table 4. and Figure 3 to 7. Colour of the soil sample was observed by visual analysis.

Table 4. Results of all physico-chemicals characteristics on all the sample lots

Sample	pH	Conductivity µmohs/s	Lead %	Cadmium %
S1	8.19	3.45	1.78	1.52
S2	8.12	3.45	1.80	2.90
S3	8.15	3.45	1.77	1.71
S4	8.18	3.45	1.80	1.75
S5	8.20	3.45	1.82	1.81
V1	7.27	-	0.03	0.04
V2	6.80	-	0.07	0.09
V3	7.27	-	0.07	0.06
V4	7.29	-	0.06	0.08
V5	7.34	-	0.03	0.04

3.1. pH

The pH range of soil and vegetable samples is revealed in the study, demonstrating how it impacts the bioavailability and accumulation of heavy metals. (Table 4. ; Figure 3,4.) In contrast to vegetable samples, which ranged from 6.44 to 7.34 and were primarily neutral to slightly alkaline, soils showed an alkaline nature with pH values between 8.12 and 8.20. Due to increased metal precipitation and adsorption onto soil colloids, alkaline soil conditions generally decrease the solubility and bioavailability of heavy metals **(Deyholos et al., 2023)**. These pH levels are consistent with these findings. Depending on the mobility of metals, such as cadmium (Cd) and lead (Pb), vegetables' neutral to slightly alkaline pH may facilitate moderate translocation and bioaccumulation in the context of heavy metal uptake. When accumulated in edible crops, Cd and Pb, which are known to have higher bioavailability in neutral conditions, present a serious health risk **(Liu et al., 2024).**

In order to reduce metal uptake into the food chain, this observation calls for more research into the effects of pH control and soil amendments. A key aspect is also highlighted by the correlation between soil and vegetable pH: the chemical dynamics of the rhizosphere can drastically alter the availability of metal ions. Even in alkaline soils, elements like microbial activity and root exudates are crucial for either immobilizing or mobilizing heavy metals. According to studies, by changing the pH of the soil and enhancing its buffering ability, certain remediation techniques, such as organic amendments and phytoremediation, can successfully address metal bioaccumulation problems **(Sanogo et al., 2023).**

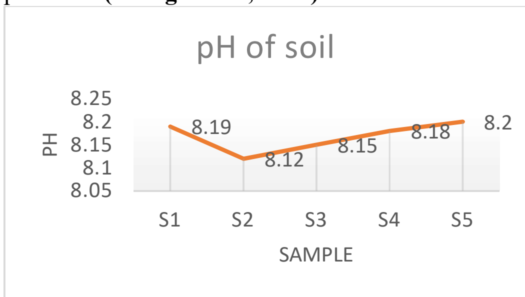

Figure-2. Graphical representation of pH variations in soil

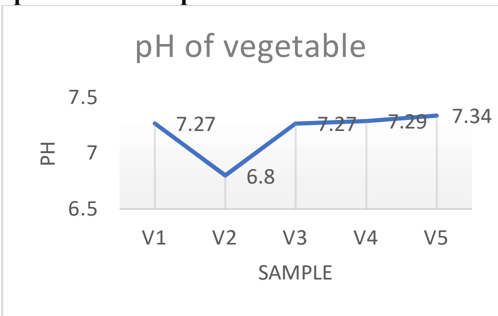

Figure-3. Graphical representation of pH variations in vegetables

3.2. Conductivity

The conductivity in all the soil samples were observed to be 3.45 **µmohs/s.**

Low salinity, which promotes plant growth and is unlikely to contribute to salinity-induced stress, is indicated by the consistent conductivity of 3.45 µmhos/cm across all soil samples. Depending on the metals' chemical forms and interactions within the soil matrix, low conductivity also indicates minimal soluble salts, which could restrict heavy metal mobility **(Smith et al., 2018).** This is consistent with the pH results, which show that alkaline environments (pH 8.12–8.20) may immobilize some metals by precipitating them as carbonates or hydroxides **(Jones & Clark, 2020).** Even with ideal soil conditions, external factors such as irrigation water or atmospheric deposition may cause heavy metal accumulation in vegetables instead of soil bioavailability **(WHO, 2017).** Therefore, all possible pathways of contamination must be taken into account in health risk assessments. For a thorough grasp of heavy metal dynamics in agroecosystems, future research should look into correlations between soil parameters, such as organic matter and cation exchange capacity.

3.3 Lead (Pb) in soil samples

The values for all the soil samples ranging from S1 to S5 were observed to be 1.78, 1.8, 1.77,1.80 and 1.82 %.

3.4 Lead (Pb) in vegetable samples

The values for all the vegetable samples ranging from V1 to V5 were observed to be 0.03, 0.07,0.07, 0.06 and 0.03 %

Significant contamination was indicated by the lead (Pb) concentrations in soil samples (S1 to S5), (Table 4. ; Figure 5,6.) which ranged from 1.77% to 1.82% and were significantly higher than natural background levels **(Alloway, 2013).** These high levels are a result of human activities that can lead to the buildup of heavy metals in the environment, such as fertilizers, contaminated water, and industrial emissions **(Kabata-Pendias, 2011).** The levels found in this study are concerning because the WHO and EPA state that soil concentrations higher than 0.1% may pose possible health and environmental hazards (EPA, 2007). However, despite the high soil concentrations, the lead concentration in vegetable samples (V1 to V5) ranged from 0.03% to 0.07%, which is significantly lower than the levels in the soil. This suggests that there is limited bioavailability for plant uptake. This may be because the soil's alkaline pH (pH 8.12–8.20) decreases lead's solubility and availability for plant absorption **(Cui et al., 2004).** Additionally, the ability of plants to absorb heavy metals varies; some crops are more resistant to the metals, while others act as accumulators **(Sajad et al., 2013).** Continuous exposure to even low levels of heavy metals through the consumption of contaminated produce can cause bioaccumulation in the human body, affecting vital organs like the kidneys and nervous system, even though the observed lead concentrations in vegetables were below the allowable limits set by food safety agencies (e.g., 0.3 mg/kg in the EU) **(WHO, 2011).** Therefore, long-term consumption, particularly in areas with high contamination, may still be concerning even though lead concentrations in vegetables may not present an immediate risk. It is important to consider that the differences in lead concentrations between soil and vegetables could also be influenced by other environmental factors such as irrigation practices, atmospheric deposition, and organic matter content, which could affect the uptake and mobility of heavy metals **(Liu et al., 2013).** Future studies should aim to investigate these factors further and explore soil remediation techniques to mitigate the risks associated with heavy metal contamination in food crops.

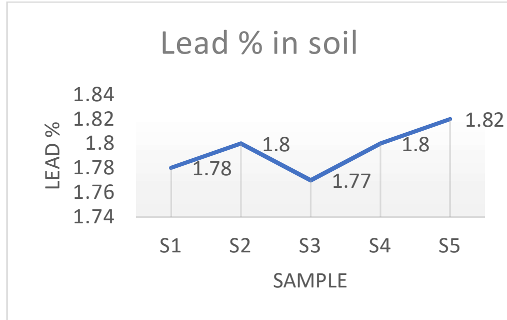

Figure-4. Graphical representation of lead% in soil

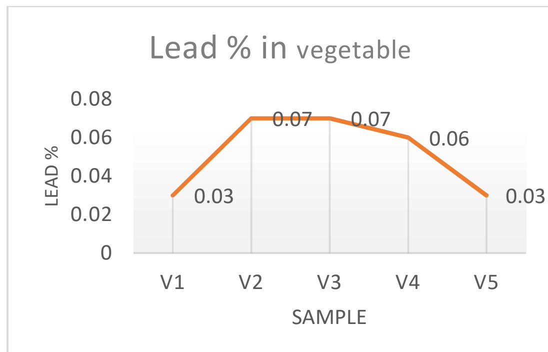

Figure-5. Graphical representation of lead% in vegetables

3.5 Cadmium (Cd) in soil samples

The values for Cadmium in all the soil samples ranging from S1 to S5 were observed to be 1.78, 1.8, 1.77,1.80 and 1.82 %.

3.6 Cadmium (Cd) in vegetable samples

The values for Cadmium in all the vegetable samples ranging from V1 to V5 were observed to be 0.03, 0.07,0.07, 0.06 and 0.03 %.

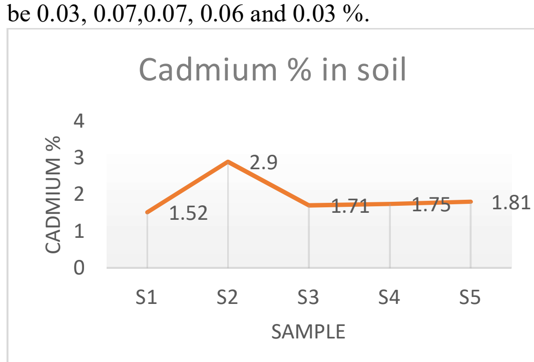

Figure 6. Graphical representation of cadmium% in soil

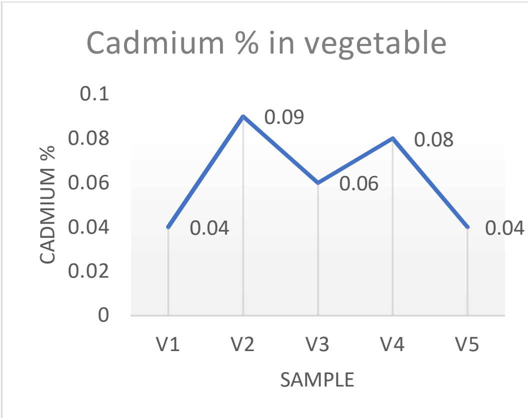

Figure-7. Graphical representation of cadmium% in vegetables

The cadmium (Cd) levels in soil and vegetable samples provide key insights into contamination and health risks. High soil cadmium concentrations (1.77% to 1.82%) suggest human activities like industrial operations or contaminated fertilizers **(Alloway, 2013; Zhang et al., 2015)**. (Table 4.; Figure 6,7.) These levels pose serious risks if contamination persists. In contrast, vegetable cadmium concentrations (0.03% to 0.07%) were lower, indicating limited uptake, possibly due to alkaline soil pH (pH 8.12–8.20), which reduces bioavailability **(Kabata-Pendias, 2011)**. Some plant species also reduce cadmium uptake **(Wang et al., 2016)**. Though below the permissible limits for food **(FAO/WHO, 2001),** cadmium bioaccumulates in human tissues, causing kidney, liver, and bone damage, with chronic exposure linked to diseases like cancer **(WHO, 2011; Jarup, 2003)**. Addressing contamination through better soil management, reduced fertilizer use, and regular monitoring is essential to ensure food safety and minimize health risks **(Chen et al., 2016).**

4. Conclusion

This According to this study, the pH of the soil influences how well heavy metals like lead (Pb) and cadmium (Cd) are absorbed by vegetables; even at low levels, high soil concentrations can be harmful to human health. Reducing the use of contaminated fertilizers and managing the soil are essential for lowering these risks.

Future prospects

Future studies should examine how to remediate soil and how environmental elements like irrigation affect the absorption of heavy metals. To guarantee food safety, enhanced agricultural methods and routine monitoring are crucial.

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