Agriculture and Food Sciences Research
Vol. 11, No. 2, 146-155, 2024
ISSN(E) 2411-6653/ ISSN(P) 2518-0193
DOI: 10.20448/aesr.v11i2.6228

Heavy metal accumulation in soil and leafy vegetables irrigated with domestic wastewater in Vietnam

Pham Thi Thom[1]
Nguyen Tuan Khoi[2]
Phan Le Na[3]

(Corresponding Author)

[1,2,3]*BacGiang Agriculture and Forestry University, Vietnam.*
[1]*Email: thompt87@wru.vn*
[2]*Email: khoint@bafu.edu.vn*
[3]*Email: napl@bafu.edu.vn*

Abstract

This study was conducted to evaluate the accumulation of heavy metals, including copper (Cu), lead (Pb), and cadmium (Cd), in soil and leafy vegetables irrigated with domestic wastewater. The surveyed vegetables included water spinach (Ipomoea aquatica), Chinese mustard greens (Brassica integrifolia), and Malabar spinach (Basella alba), grown over three consecutive seasons. Results showed that Cu accumulation in the vegetables ranged from 4.41 mg/kg to 5.62 mg/kg, Pb from 0.11 mg/kg to 0.13 mg/kg, and Cd from 0.02 mg/kg to 0.03 mg/kg. All values were below the safety limits set by Vietnam's National Technical Regulation (QCVN), with thresholds of 30 mg/kg for Cu, 0.3 mg/kg for Pb, and 0.2 mg/kg for Cd. Similarly, heavy metal accumulation in the soil remained within the permissible limits under QCVN standards. The analysis further indicated that seasonal variations had minimal impact on heavy metal concentrations, suggesting that consistent wastewater management practices contributed to maintaining soil and crop safety. In addition, the research highlighted that water spinach accumulated slightly higher levels of heavy metals compared to the other vegetables, likely due to its faster growth rate and higher water absorption capacity. Despite this, the concentrations remained well within safety thresholds, affirming the viability of these crops for safe consumption. The study concludes that using domestic wastewater for vegetable irrigation does not lead to heavy metal accumulation beyond safe thresholds, supporting sustainable and safe agricultural practices. However, continued monitoring and appropriate wastewater treatment remain essential to ensure long-term safety, particularly as environmental and anthropogenic factors evolve.

Keywords: Domestic wastewater irrigation, Environmental health risks, Food Safety and heavy metals, Heavy metal contamination, Leafy vegetable safety in Vietnam, Soil and plant health risks.

Citation | Thom, P. T., Khoi, N. T., & Na, P. L. (2024). Heavy metal accumulation in soil and leafy vegetables irrigated with domestic wastewater in Vietnam. *Agriculture and Food Sciences Research*, *11*(2), 146–155. 10.20448/aesr.v11i2.6228

History:
Received: 11 November 2024
Revised: 9 December 2024
Accepted: 12 December 2024
Published: 20 December 2024

Publisher: Asian Online Journal Publishing Group

Funding: This study received no specific financial support
Institutional Review Board Statement: Not applicable.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

Contents

Contribution of this paper to the literature

This study contributes to sustainable agriculture by demonstrating that domestic wastewater can be safely used for irrigating leafy vegetables without exceeding heavy metal safety thresholds. It highlights the potential for resource optimization, provides baseline data for safe wastewater reuse practices, and underscores the importance of monitoring to ensure long-term environmental and food safety.

1. Introduction

In the context of freshwater scarcity, the reuse of domestic wastewater in agriculture has emerged as a potential solution to meet irrigation demands and alleviate pressure on freshwater resources [1]. However, domestic wastewater may contain heavy metals such as copper (Cu), lead (Pb), and cadmium (Cd) [2] which are elements capable of accumulating in soil and crops [3] posing potential risks to agricultural product quality and human health if they exceed safe limits [4]. These heavy metals can be toxic in the environment, reducing crop yields and posing health risks if they enter the food chain [5]. Leafy vegetables, which are often consumed directly [6] present a particular concern regarding heavy metal accumulation from soil and irrigation water, necessitating rigorous assessment [7]. This study aims to evaluate the accumulation levels of Cu, Pb, and Cd in soil and leafy vegetables irrigated with domestic wastewater over three consecutive growing seasons. The selected vegetables include water spinach (Ipomoea aquatica), Chinese mustard greens (Brassica integrifolia), and Malabar spinach (Basella alba). The accumulation levels of Cu, Pb, and Cd in both the vegetables and soil will be compared to the safety limits set by Vietnam's National Technical Regulation (QCVN), thereby assessing the safety and feasibility of applying domestic wastewater in agriculture.

2. Content and Research Methodology

2.1. Research Content

This study assesses the accumulation of heavy metals in leafy vegetables and soil when irrigated with domestic wastewater. The vegetables examined include water spinach (Ipomoea aquatica), Chinese mustard greens (Brassica integrifolia), and Malabar spinach (Basella alba). Domestic wastewater is collected from ponds that receive discharge from surrounding households and then used to irrigate the vegetables in the experiment. The objective is to determine the heavy metal accumulation in both vegetables and soil over different planting seasons.

2.2. Research Methodology

2.2.1. Experimental Design

Subjects: Three types of leafy vegetables: water spinach, Chinese mustard greens, and Malabar spinach.

Experimental Period: Conducted over three planting seasons:

Season 1: Starting June 1, 2022.

Season 2: Starting August 10, 2022.

Season 3: Starting October 15, 2022.

Replications: Each vegetable type is grown in three replicates (3 plots per vegetable). Experimental plots are arranged randomly.

2.2.2. Sample Collection and Analysis

After each planting season, samples of both vegetables and soil are collected from the experimental plots. Random samples are taken from the three replicates of each vegetable type to calculate the mean values of the parameters.

Sample collection and preparation for vegetables follow TCVN 9016:2011.

Soil sampling, preservation, and preparation adhere to standards: TCVN 7538-2:2005 (ISO 10381-2:2002).

Heavy metal content in vegetable and soil samples is analyzed using atomic absorption spectroscopy (AAS) as per TCVN 6496:2009.

2.2.3. Data Analysis Method

Data are analyzed by calculating the mean values of parameters across replicates for each vegetable and season.

SPSS statistical software is used to assess the differences in heavy metal content between vegetable types and planting seasons.

Table 1 presents the analysis results of domestic wastewater samples utilized for vegetable irrigation.

Table 1. Analysis results of domestic wastewater samples used for vegetable irrigation.

Indicator	Parameter	QCVN 08-MT:2015/BTNMT
Temperature (°C)	24.42 ± 0.37	-
pH	7.52 ± 0.14	5.5-9
Total suspended solids (TSS) (mg/l)	482.6 ± 14.3	50
Electrical conductivity (EC) (mS/cm)	0.59 ± 0.01	-
Ammonium (NH_4^+-N) (mg/l)	5.12 ± 0.14	0.9
Phosphate (PO_4^{3-}-P) (mg/l)	1.58 ± 0.07	0.3
Dissolved Oxygen (DO) (mg/l)	3.08 ± 0.17	≥ 4
Turbidity (NTU)	79.2 ± 2.72	-
Cadmium (Cd) (mg/l)	0.032 ± 0.0005	0.01
Copper (Cu) (mg/l)	0.019 ± 0.0005	0.5
Lead (Pb) (mg/l)	0.03± 0.0006	0.05

Note: QCVN: Vietnam's national technical regulation.
BTNMT: Ministry of natural resources and environment.

3. Research Results

The wastewater analysis indicates several parameters exceeding the acceptable limits set by the Ministry of Natural Resources and Environment (QCVN 08-MT:2015/BTNMT), meaning they do not meet the required safety standards for irrigation. Specifically, TSS is at 482.6 mg/l, far above the permissible 50 mg/l. NH_4^+-N is measured at 5.12 mg/l, surpassing the limit of 0.9 mg/l, and PO_4^{3-}-P is 1.58 mg/l, exceeding the allowed 0.3 mg/l. Additionally, Cd at 0.032 mg/l is above the limit of 0.01 mg/l. DO at 3.08 mg/l falls below the required minimum of ≥4 mg/l. In contrast, Pb at 0.03 mg/l and Cu at 0.019 mg/l are within safe limits, meeting the standard requirements. These results highlight the need for treatment to reduce TSS, ammonium, phosphate, and cadmium levels to comply with safety standards before irrigation use.

Table 2 illustrates the impact of domestic wastewater irrigation on copper (Cu) accumulation in leafy vegetables.

Table 2. Impact of domestic wastewater on Cu accumulation in leafy vegetables.

Vegetable varieties	The first season	The second season	The third season	Average	Regulations according to QCVN
Water spinach	5.57 ± 0.26	5.36 ± 0.27	5.11 ± 0.1	5.35± 0.28	30
Chinese mustard greens	5.9 ± 0.28	5.6 ± 0.34	5.57 ± 0.21	5.62 ± 0.25	
Malabar spinach	4.43 ± 0.11	4.31 ± 0.22	4.48 ± 0.22	4.41 ± 0.18	

Note: (Unit: mg/kg dry vegetable).
QCVN: Vietnam's national technical regulation.

Excessive copper (Cu) accumulation in leafy vegetables poses serious health risks due to its potential toxicity [8]. While Cu is an essential micronutrient in small amounts, high concentrations can disrupt cellular processes by generating reactive oxygen species (ROS), damaging plant tissues and reducing crop yield [9]. In humans, chronic exposure to elevated Cu levels through food consumption may lead to symptoms such as gastrointestinal distress, liver dysfunction, and, in severe cases, liver diseases [10].

Studies show that leafy vegetables like spinach can absorb substantial amounts of Cu when grown in contaminated soils or irrigated with Cu-laden wastewater [11]. In regions with high levels of Cu contamination, concentrations in vegetables often exceed safe limits set by the World Health Organization (WHO), thus increasing the risk of bioaccumulation and adverse health effects [12].

This issue is especially concerning in areas where untreated wastewater is used for irrigation, emphasizing the need for stringent monitoring and improved agricultural practices to prevent Cu-related health hazards in the food supply [13].

The study on copper (Cu) accumulation in three types of leafy vegetables—water spinach (Ipomoea aquatica), Chinese mustard greens (Brassica integrifolia), and Malabar spinach (Basella alba)—was conducted over three growing seasons with these vegetables irrigated using domestic wastewater. Results indicate that Cu accumulation in all these vegetables remained below the permissible limits set by the National Technical Regulation on heavy metal limits in food (QCVN), which specifies a maximum threshold for copper at 30 mg/kg.

Figure 1 Compares copper (Cu) accumulation in leafy vegetables irrigated with domestic wastewater against Vietnamese safety standards.

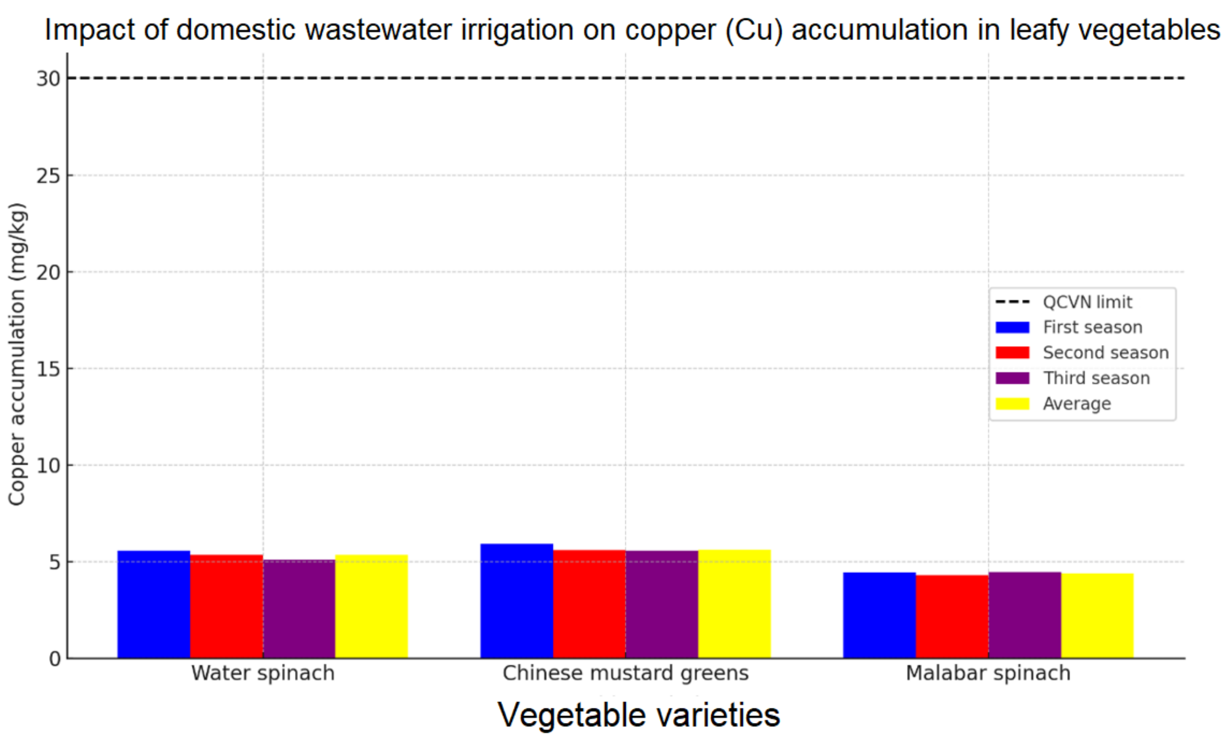

Figure 1. Comparison of Cu accumulation in leafy vegetables with Vietnamese standards.

Note: QCVN: Vietnamese national technical regulations.

Specifically, over the three growing seasons, water spinach exhibited an average Cu accumulation of 5.35 ± 0.28 mg/kg, Chinese mustard greens 5.62 ± 0.25 mg/kg, and Malabar spinach 4.41 ± 0.18 mg/kg. In individual seasons, Cu accumulation in water spinach ranged from 5.11 mg/kg to 5.57 mg/kg, in Chinese mustard greens from 5.57 mg/kg to 5.9 mg/kg, and in Malabar spinach from 4.31 mg/kg to 4.48 mg/kg. Chinese mustard greens showed the highest Cu accumulation, especially in the first season at 5.9 mg/kg, while Malabar spinach consistently had the lowest accumulation across all seasons, with an average of only 4.41 mg/kg.

Although there are some differences in Cu accumulation among the vegetable types, the variation is not substantial. Chinese mustard greens tend to absorb more Cu compared to water spinach and Malabar spinach, but all three vegetables maintained safe Cu accumulation levels, significantly below the maximum threshold of 30 mg/kg set by QCVN. This indicates that, under experimental conditions, the use of domestic wastewater for irrigating leafy vegetables does not lead to a significant increase in copper accumulation that would pose health risks to consumers.

Table 3. presents the impact of domestic wastewater on Pb accumulation in leafy vegetables.

Vegetable varieties	The first season	The second season	The third season	Average	Regulations according to QCVN
Water spinach	0.12 ± 0.006	0.13 ± 0.006	0.12 ± 0.01	0.12± 0.007	0.3
Chinese mustard greens	0.12 ± 0.006	0.13 ± 0.006	0.15 ± 0.006	0.13± 0.014	
Malabar spinach	0.12 ± 0.006	0.11 ± 0.006	0.11± 0.006	0.11± 0.007	

Note: (Unit: mg/kg dry vegetable).
QCVN: Vietnam's national technical regulation.

Lead (Pb) accumulation in leafy vegetables and domestic wastewater poses significant health and environmental risks [14]. Pb is a toxic heavy metal with no known biological function in plants or humans [15]. Its presence in soil and water sources, often due to industrial activities and urban runoff, leads to absorption by plants, especially leafy vegetables, through both roots and foliage exposed to contaminated water and atmospheric particles [16]. When Pb concentrations exceed the World Health Organization's safety limits, its consumption through contaminated vegetables can result in serious health consequences, including neurological damage, kidney dysfunction, and developmental issues, particularly in young children [1].

In domestic wastewater, Pb can accumulate from various sources, including plumbing, industrial discharge, and household products [2]. When this wastewater is used for irrigation without adequate treatment, it increases Pb levels in the soil, which plants readily absorb [3]. This cycle not only impacts food safety but also threatens soil health, as Pb can persist in the environment, leading to long-term ecological contamination [17]. These risks highlight the critical need for managing Pb in wastewater and ensuring it does not enter the agricultural food chain [18].

Table 3 assessed the accumulation of lead (Pb) in leafy vegetables, including water spinach, Chinese mustard greens, and Malabar spinach, when irrigated with domestic wastewater over three growing seasons. The results indicate that Pb levels in all vegetable samples remained within the safety limits set by the National Technical Regulation (QCVN) for heavy metal limits in food, with a maximum threshold for Pb at 0.3 mg/kg.

Figure 2 compares Pb accumulation in leafy vegetables irrigated with domestic wastewater to Vietnamese safety standards.

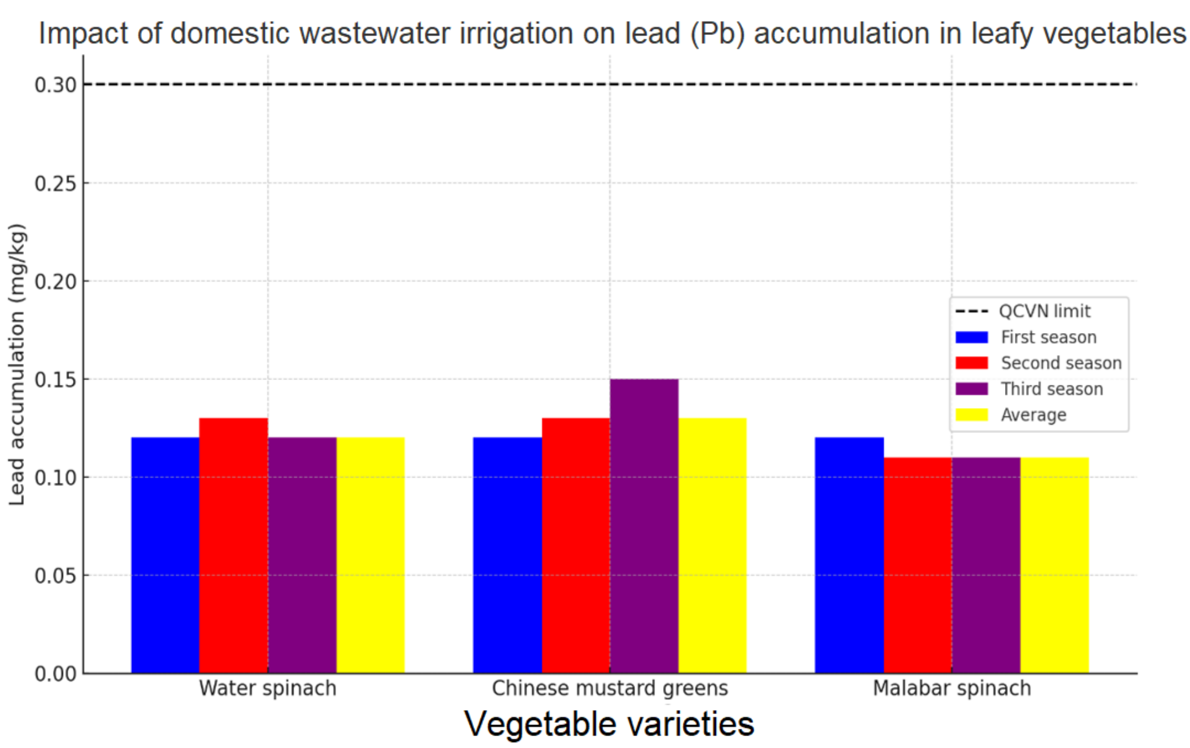

Figure 2. Comparison of Pb accumulation in leafy vegetables with Vietnamese standards.

The Pb content in water spinach fluctuated slightly across the seasons, with values of 0.12 ± 0.006 mg/kg in the first and third seasons and 0.13 ± 0.006 mg/kg in the second season, averaging 0.12 ± 0.007 mg/kg. Chinese mustard greens exhibited slightly higher Pb accumulation than water spinach, ranging from 0.12 ± 0.006 mg/kg in the first season, 0.13 ± 0.006 mg/kg in the second, and peaking at 0.15 ± 0.006 mg/kg in the third season, with an average of 0.13 ± 0.014 mg/kg. For Malabar spinach, Pb levels were more stable and lower than in the other vegetables, ranging from 0.11 ± 0.006 mg/kg in the second and third seasons to 0.12 ± 0.006 mg/kg in the first season, averaging 0.11 ± 0.007 mg/kg.

A comparison across the three vegetables shows that Chinese mustard greens had the highest Pb accumulation, particularly in the third season at 0.15 mg/kg, while Malabar spinach had the lowest accumulation across all seasons. However, these differences are minimal, and all values are well below the maximum threshold of 0.3 mg/kg set by QCVN.

These results indicate that, although domestic wastewater may contain Pb, the accumulation levels in leafy vegetables grown under the study conditions remain safe and do not exceed permissible limits.

Table 4 demonstrates the impact of domestic wastewater irrigation on Cd accumulation in leafy vegetables.

Table 4. Impact of domestic wastewater on Cd accumulation in leafy vegetables.

Vegetable varieties	The first season	The second season	The third season	Average	Regulations according to QCVN
Water spinach	0.03 ± 0.006	0.03 ± 0.006	0.03 ± 0.006	0.03 ± 0.005	0.2
Chinese mustard greens	0.03 ± 0.006	0.03 ± 0.006	0.03 ± 0.006	0.03 ± 0.005	
Malabar spinach	0	0.03 ± 0.006	0.03 ± 0.006	0.02 ± 0.004	

Note: (Unit: mg/kg dry vegetable).
QCVN: Vietnam's national technical regulation.

The accumulation of cadmium (Cd) in leafy vegetables and domestic wastewater poses serious health hazards to humans [19]. Cd is a toxic heavy metal that, unlike essential nutrients, serves no beneficial role in biological systems [20]. When Cd enters the food chain through contaminated leafy vegetables, it can lead to severe health issues [21]. Long-term ingestion of Cd-contaminated foods can result in kidney damage, osteoporosis, and even cancer due to Cd's high toxicity and tendency to accumulate in the body over time [22].

In domestic wastewater, Cd often originates from industrial waste, batteries, and household products [23]. When such wastewater is used for irrigation, Cd can be transferred to the soil and then taken up by plants, especially leafy vegetables, which are prone to heavy metal accumulation [24]. This cycle not only increases Cd concentrations in edible crops but also creates persistent contamination in agricultural soil [25]. The risks associated with Cd accumulation underline the necessity for effective wastewater treatment and regular monitoring to protect public health and ensure safe food production [26]. In the study on cadmium (Cd) accumulation in three types of leafy vegetables—water spinach, Chinese mustard greens, and Malabar spinach—irrigated with domestic wastewater over three growing seasons, results consistently showed that Cd accumulation levels remained within the safe limits set by the National Technical Regulation (QCVN), which specifies a maximum threshold for Cd at 0.3 mg/kg. Figure 3 compares Cd accumulation in leafy vegetables irrigated with domestic wastewater against Vietnamese safety standards.

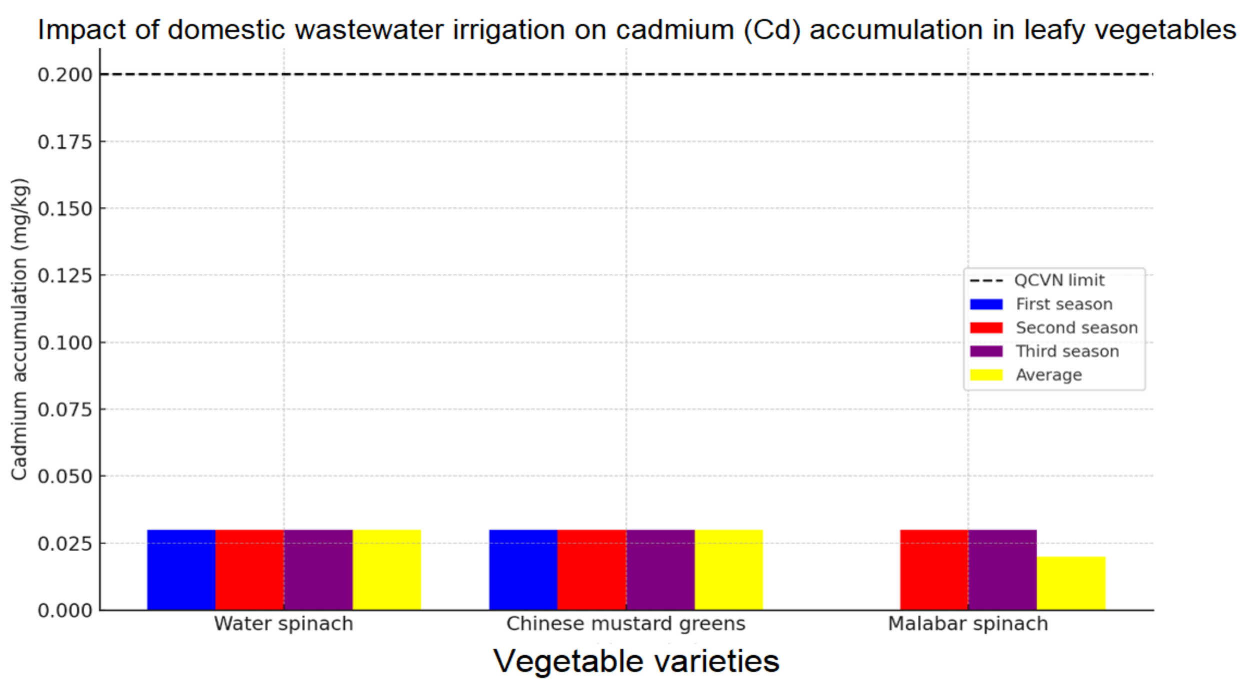

Figure 3. Comparison of Cd accumulation in leafy vegetables with Vietnamese standards.

Water spinach showed stable Cd accumulation across the three seasons, with values of 0.03 ± 0.006 mg/kg in each season and an average of 0.03 ± 0.005 mg/kg. Similarly, Chinese mustard greens also exhibited steady Cd levels, ranging around 0.03 ± 0.006 mg/kg in each season, averaging 0.03 ± 0.005 mg/kg. Malabar spinach, however, showed a slight variation, with no detectable Cd accumulation in the first season (0 mg/kg), increasing to 0.03 ± 0.006 mg/kg in the second and third seasons, resulting in a three-season average of 0.02 ± 0.004 mg/kg.

Comparing the vegetables, both water spinach and Chinese mustard greens showed similar Cd accumulation across all seasons, while Malabar spinach had significantly lower levels in the first season. Nonetheless, this difference holds little significance for food safety, as all values were well below the QCVN safety threshold of 0.3 mg/kg.

Table 5. Shows the impact of domestic wastewater irrigation on Cu accumulation in soil.

Vegetable varieties	The first season	The second season	The third season	Average	Regulations according to QCVN
Water spinach	23.62 ± 1.13	24.15 ± 0.49	23.81 ± 1.09	23.86 ± 0.85	100
Chinese mustard greens	23.62 ± 1.13	24.08 ± 0.43	23.88 ± 0.98	23.86 ± 0.81	
Malabar spinach	23.69 ± 0.49	24.21 ± 0.38	23.83 ± 0.46	23.91 ± 0.45	

Note: (Unit: mg/kg).
QCVN: Vietnam's national technical regulation.

Copper (Cu) accumulation in agricultural soil poses significant risks to both plant health and human safety. In soil, excessive Cu levels can lead to phytotoxicity, disrupting key plant processes like photosynthesis and enzyme activity, ultimately reducing crop yield and quality [27]. Cu's high affinity for binding to soil particles also means it can persist in the environment, gradually building up to toxic levels in areas subjected to repeated Cu exposure from fertilizers or wastewater irrigation [28].

For plants, Cu toxicity often manifests in stunted growth, leaf discoloration, and reduced root development, as high Cu concentrations interfere with nutrient absorption [29]. When leafy vegetables are grown in Cu-contaminated soil, they tend to absorb and accumulate Cu in their tissues, which can be transferred to humans through consumption [30]. Long-term exposure to elevated Cu levels in food has been associated with gastrointestinal distress, liver toxicity, and, in severe cases, neurological impacts [31].

These potential health effects highlight the need for careful Cu management in agricultural soils to protect both environmental and public health [32].

Table 5 presents data on the impact of domestic wastewater on copper (Cu) accumulation in soil used to grow leafy vegetables, including water spinach, Chinese mustard greens, and Malabar spinach, over three planting seasons. The results indicate that Cu accumulation in soil ranged from 23.62 ± 1.13 mg/kg to 24.21 ± 0.38 mg/kg, with average values between 23.86 ± 0.85 mg/kg and 23.91 ± 0.45 mg/kg. Compared to the Vietnamese National Technical Regulation (QCVN), which sets the maximum allowable Cu level in soil at 100 mg/kg, all Cu accumulation values in the soil for the three vegetables remained well below this limit, with averages significantly lower than the regulated threshold.

Figure 4 illustrates Cu accumulation in soil irrigated with domestic wastewater compared to QCVN standards.

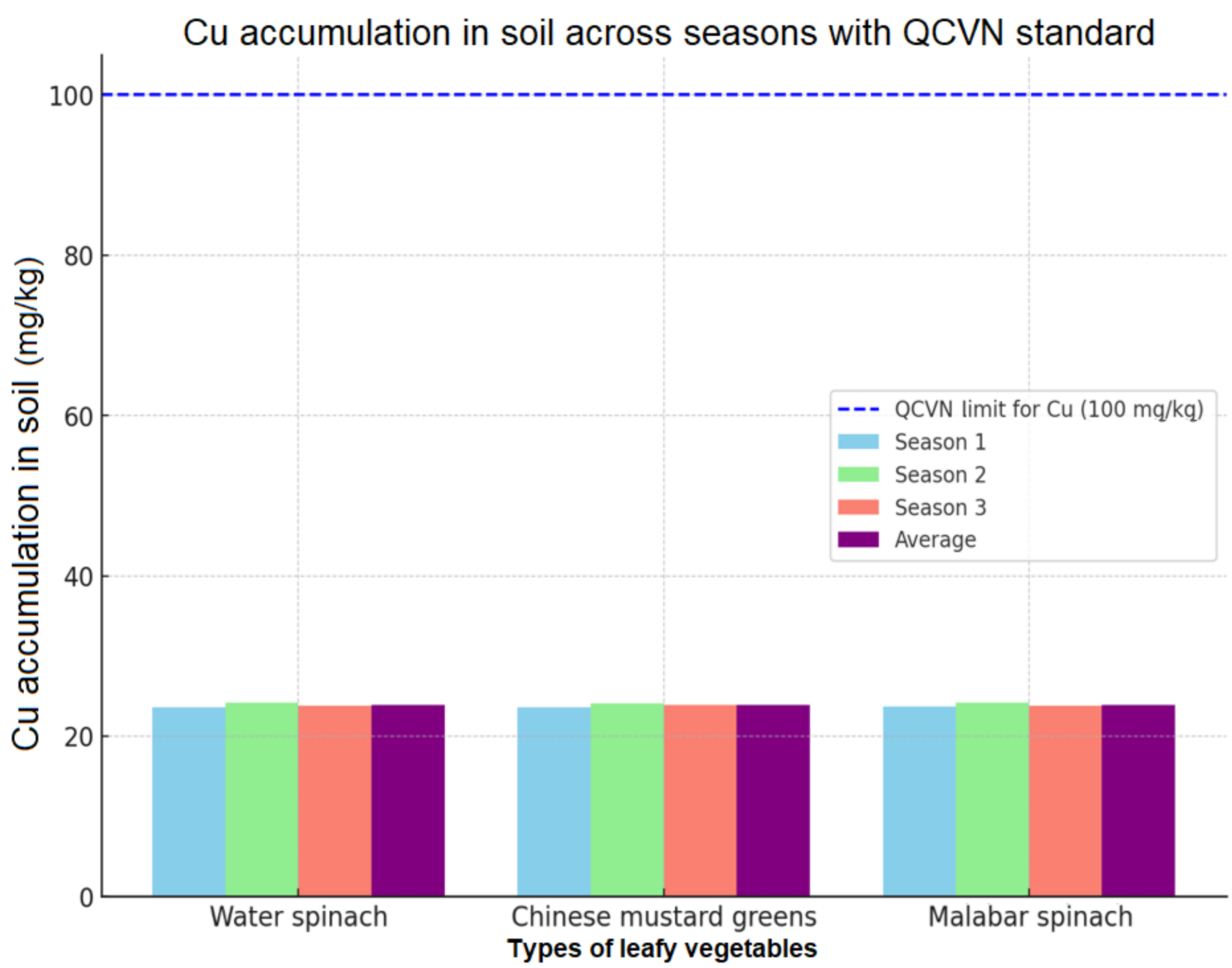

Figure 4. Cu accumulation in soil with domestic wastewater irrigation compared to QCVN.

Note: QCVN: Vietnam's national technical regulation.

Cu accumulation showed minor seasonal fluctuations, with standard deviations ranging from 0.38 mg/kg to 1.13 mg/kg, indicating stability in the accumulation process. Malabar spinach showed the least variation, while water spinach and Chinese mustard greens exhibited slightly higher fluctuations but remained within safe levels. These results demonstrate that using domestic wastewater for soil irrigation does not lead to excessive Cu accumulation, ensuring safety for the soil ecosystem and crop health.

Table 6 details the impact of domestic wastewater irrigation on Pb accumulation in soil.

Table 6. Impact of domestic wastewater on Pb accumulation in soil.

Vegetable varieties	The first season	The second season	The third season	Average	Regulations according to QCVN
Water spinach	1.9 ± 0.07	1.86± 0.11	1.92± 0.04	1.89 ± 0.07	70
Chinese mustard greens	1.93 ± 0.16	1.62 ± 0.17	1.76 ± 0.2	1.77 ± 0.2	
Malabar spinach	1.82 ± 0.12	1.8 ± 0.08	1.88 ± 0.13	1.83 ± 0.11	

Note: (Unit: mg/kg).
QCVN: Vietnam's national technical regulation.

Lead (Pb) accumulation in agricultural soil, particularly from the use of untreated domestic wastewater for irrigation, presents severe risks to both crops and human health [33]. Pb is a highly toxic heavy metal with no essential role in biological processes, and its persistence in soil means it can build up over time, especially when wastewater containing Pb residues is repeatedly used for irrigation [33]. In soil, Pb binds tightly to particles, making it challenging to remove and allowing it to be absorbed by plant roots [34]. When vegetables absorb Pb from contaminated soil, they become vectors of Pb exposure for humans, who may ingest the metal through their diet [35].

Ingesting Pb-contaminated vegetables can lead to a range of health problems, from developmental delays and neurological damage in children to kidney dysfunction and cardiovascular issues in adults [36]. Because Pb is not readily excreted from the body, it accumulates over time, causing long-term health impacts, particularly when exposure occurs regularly [37]. This risk underlines the importance of proper wastewater treatment and soil monitoring to ensure safe levels of heavy metals in agricultural soils and prevent Pb from entering the food chain [38].

Pb accumulation in the soil ranged from 1.62 mg/kg to 1.93 mg/kg, with an average of 1.89 ± 0.07 mg/kg for water spinach, 1.77 ± 0.2 mg/kg for Chinese mustard greens, and 1.83 ± 0.11 mg/kg for Malabar spinach. Compared to the Vietnamese National Technical Regulation (QCVN) limit of 70 mg/kg for Pb in soil, all Pb accumulation values were significantly below the safety threshold.

Figure 5 illustrates Pb accumulation in soil irrigated with domestic wastewater compared to QCVN standards.

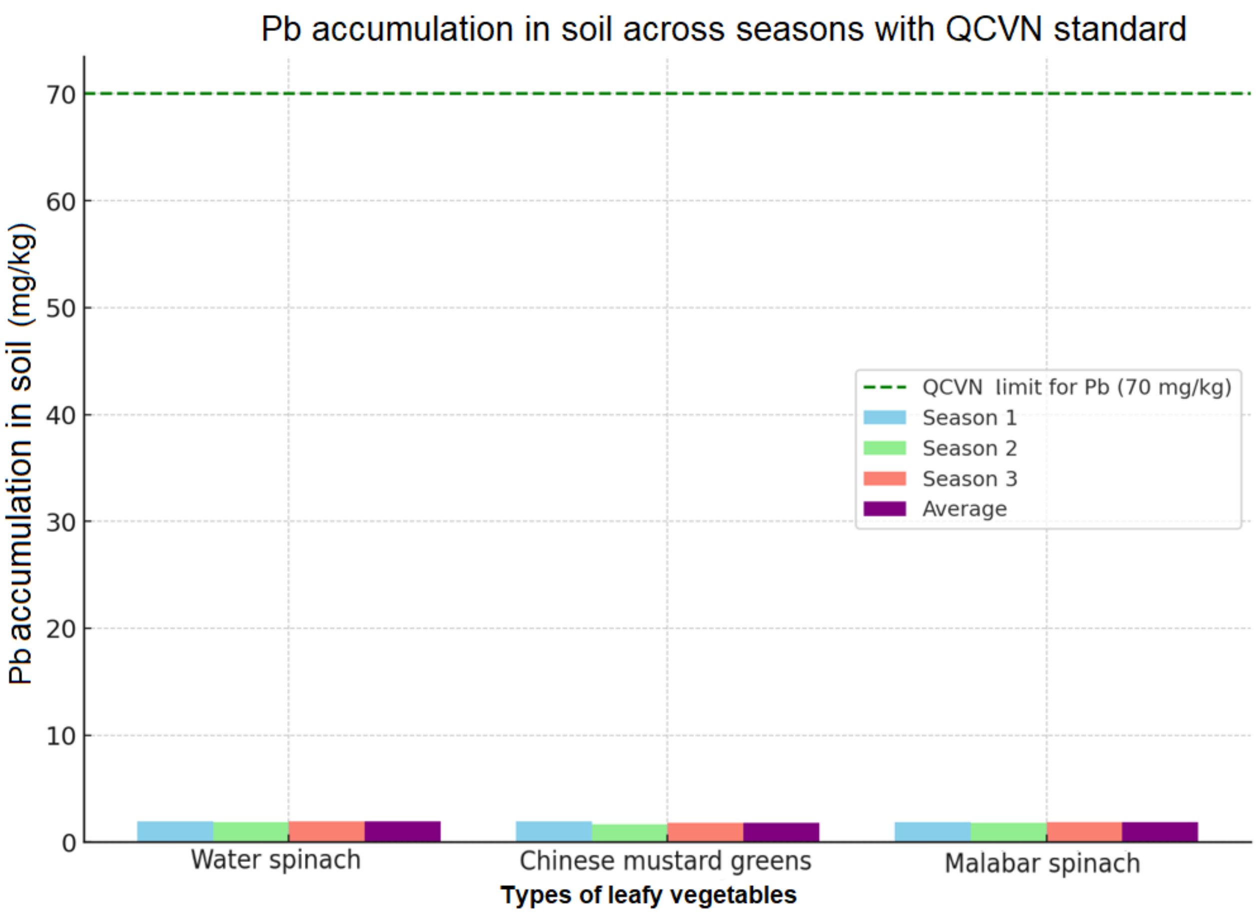

Figure 5. Pb Accumulation in soil with domestic wastewater irrigation compared to QCVN.

Note: QCVN: Vietnam's national technical regulation.

Seasonal fluctuations in Pb levels were minimal, with Chinese mustard greens showing the most variation and Malabar spinach the most stability. These results indicate that the use of domestic wastewater for irrigation does not result in significant Pb accumulation in soil, keeping Pb content well within the safe limits set by QCVN. Thus, domestic wastewater can be safely utilized in agricultural production without posing a risk of excessive Pb accumulation.

Table 7 presents the impact of domestic wastewater irrigation on Cd accumulation in soil.

Table 7. Impact of domestic wastewater on Cd accumulation in soil.

Vegetable varieties	The first season	The second season	The third season	Average	Regulations according to QCVN
Water spinach	0.1 ± 0.06	0.1 ± 0.06	0.2 ± 0.06	0.13 ± 0.05	1.5
Chinese mustard greens	0.2 ± 0.06	0.2 ± 0.06	0.2 ± 0.06	0.15 ± 0.07	
Malabar spinach	0.2 ± 0.06	0.1 ± 0.06	0.2 ± 0.06	0.17 ± 0.07	

Note: (Unit: mg/kg).
QCVN: Vietnam's national technical regulation.

Cadmium (Cd) accumulation in soil used for vegetable cultivation presents significant health and environmental risks, particularly when domestic wastewater is used for irrigation [39]. Cd is a toxic heavy metal with no beneficial role in plants or animals and is known for its persistence and bioaccumulation potential in soil [40]. Over time, soils irrigated with Cd-contaminated water sources, such as untreated wastewater, can accumulate Cd to levels that impact both plant health and the safety of food produced in these soils [41].

In plants, Cd disrupts growth by interfering with essential nutrient absorption and generating reactive oxygen species (ROS), which damage cellular structures [42]. Leafy vegetables, in particular, tend to absorb and concentrate Cd in their tissues, making them significant sources of Cd exposure when consumed [43]. Chronic ingestion of Cd through contaminated vegetables can lead to serious health issues in humans, including kidney damage, bone demineralization, and increased cancer risk [44]. The persistence of Cd in soils further compounds these risks, as it accumulates over time, presenting a continuous hazard for crops and consumers alike [45].

Cd levels ranged from 0.1 mg/kg to 0.2 mg/kg, with an average of 0.13 ± 0.05 mg/kg for water spinach, 0.15 ± 0.07 mg/kg for Chinese mustard greens, and 0.17 ± 0.07 mg/kg for Malabar spinach. Compared to the Vietnamese National Technical Regulation (QCVN), which sets a maximum permissible limit of 1.5 mg/kg for Cd in soil, all Cd accumulation values remained well below this threshold. Seasonal variations in Cd content were minimal, indicating stable accumulation levels in soil irrigated with domestic wastewater.
Figure 6 depicts Cd accumulation in soil irrigated with domestic wastewater compared to QCVN standards.

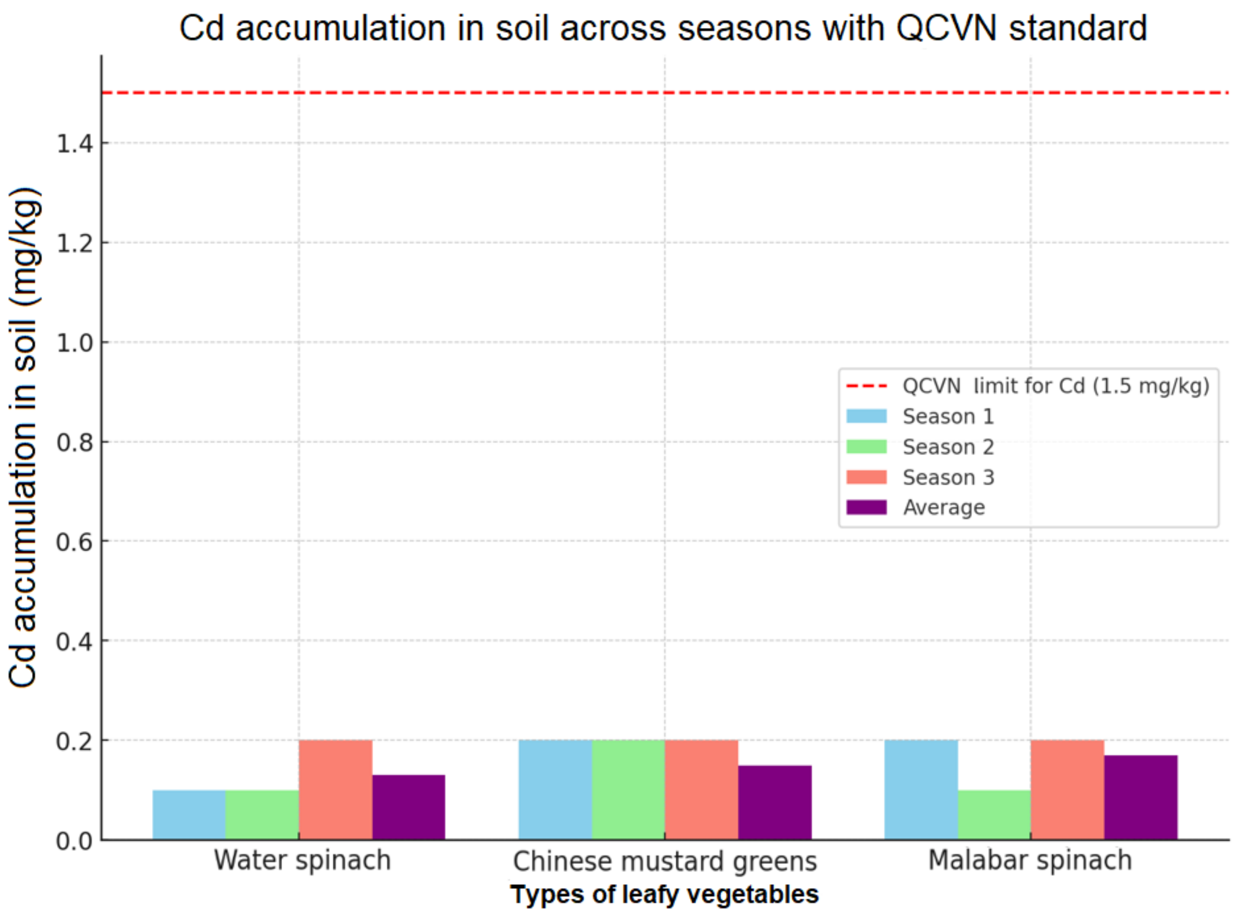

Figure 6. Cd accumulation in soil with domestic wastewater irrigation compared to QCVN.
Note: QCVN: Vietnam's national technical regulation.

These results demonstrate that using domestic wastewater for irrigation does not lead to excessive Cd accumulation in soil, ensuring no harm to the soil environment or crops. Therefore, domestic wastewater use in agriculture can be considered sustainable and safe concerning heavy metal accumulation in soil.

4. Conclusion

The research results indicate that the accumulation levels of Cu, Pb, and Cd in soil and leafy vegetables irrigated with domestic wastewater are within the safety limits specified by Vietnam's National Technical Regulation (QCVN). Specifically, Cu accumulation in vegetables ranged from 4.41 mg/kg to 5.62 mg/kg, Pb from 0.11 mg/kg to 0.13 mg/kg, and Cd from 0.02 mg/kg to 0.03 mg/kg, all significantly below the QCVN safety thresholds of 30 mg/kg for Cu, 0.3 mg/kg for Pb, and 0.2 mg/kg for Cd.

Similarly, in soil, Cu accumulation ranged from 23.86 mg/kg to 23.91 mg/kg, Pb from 1.77 mg/kg to 1.89 mg/kg, and Cd from 0.13 mg/kg to 0.17 mg/kg, all well within the regulatory limits established by QCVN. These findings demonstrate that using domestic wastewater for leafy vegetable irrigation does not lead to excessive heavy metal accumulation in vegetables or soil, ensuring safety for crops and soil ecosystems.

This study thus confirms the feasibility of reusing domestic wastewater in agriculture. Utilizing domestic wastewater not only helps reduce the pressure on freshwater resources but also maintains sustainability and safety in agricultural production.

References

[1] H. Waheed, N. Ilyas, N. Iqbal Raja, T. Mahmood, and Z. Ali, "Heavy metal phyto-accumulation in leafy vegetables irrigated with municipal wastewater and human health risk repercussions," *International Journal of Phytoremediation*, vol. 21, no. 2, pp. 170-179, 2019. https://doi.org/10.1080/15226514.2018.1540547

[2] H. Kim, T. Jang, S. Kim, and S. Park, "Impact of domestic wastewater irrigation on heavy metal contamination in soil and vegetables," *Environmental Earth Sciences*, vol. 73, pp. 2377-2383, 2015. https://doi.org/10.1007/s12665-014-3581-2

[3] S. Anwar, M. F. Nawaz, S. Gul, M. Rizwan, S. Ali, and A. Kareem, "Uptake and distribution of minerals and heavy metals in commonly grown leafy vegetable species irrigated with sewage water," *Environmental Monitoring and Assessment*, vol. 188, pp. 1-9, 2016. https://doi.org/10.1007/s10661-016-5560-4

[4] M. K. Souri, N. Alipanahi, and G. Tohidloo, "Heavy metal content of some leafy vegetable crops grown with waste water in southern suburb of Tehran-Iran," *Vegetable Science*, vol. 43, no. 2, pp. 156-162, 2016.

[5] K. Rehman *et al.*, "Comparison of proximate and heavy metal contents of vegetables grown with fresh and wastewater," *Pakistan Journal of Botany*, vol. 45, no. 2, pp. 391-400, 2013.

[6] F. Tariq, "Heavy metals concentration in vegetables irrigated with municipal wastewater and their human daily intake in Erbil city," *Environmental Nanotechnology, Monitoring & Management*, vol. 16, p. 100475, 2021. https://doi.org/10.1016/j.enmm.2021.100475

[7] A. S. Qureshi, M. I. Hussain, S. Ismail, and Q. M. Khan, "Evaluating heavy metal accumulation and potential health risks in vegetables irrigated with treated wastewater," *Chemosphere*, vol. 163, pp. 54-61, 2016. https://doi.org/10.1016/j.chemosphere.2016.07.073

[8] W.-Y. Chiou and F.-C. Hsu, "Copper toxicity and prediction models of copper content in leafy vegetables," *Sustainability*, vol. 11, no. 22, p. 6215, 2019. https://doi.org/10.3390/su11226215

[9] P. B. Tchounwou, C. G. Yedjou, A. K. Patlolla, and D. J. Sutton, "Heavy metal toxicity and the environment," *Experientia Supplementum (2012)*, vol. 101, pp. 133-164, 2012. http://doi.org/10.1007/978-3-7643-8340-4_6

[10] R. S. Lokhande, P. U. Singare, and D. S. Pimple, "Toxicity study of heavy metals pollutants in waste water effluent samples collected from Taloja industrial estate of Mumbai, India," *Resources and Environment*, vol. 1, no. 1, pp. 13-19, 2011.

[11] M. Javed and N. Usmani, "Accumulation of heavy metals in fishes: A human health concern," *International Journal of Environmental Sciences*, vol. 2, no. 2, pp. 659-670, 2011.

[12] J. Y. Uriu-Adams and C. L. Keen, "Copper, oxidative stress, and human health," *Molecular Aspects of Medicine*, vol. 26, no. 4-5, pp. 268-298, 2005. https://doi.org/10.1016/j.mam.2005.07.015

[13] Z. Leblebici, M. Kar, and L. Başaran, "Assessment of the heavy metal accumulation of various green vegetables grown in Nevşehir and their risks human health," *Environmental Monitoring and Assessment*, vol. 192, pp. 1-8, 2020. https://doi.org/10.1007/s10661-020-08459-z

[14] H. Azar and M. Vajargah, "Investigating the effects of accumulation of lead and cadmium metals in fish and its impact on human health," *Journal of Aquaculture & Marine Biology*, vol. 12, no. 2, pp. 209-213, 2023. https://doi.org/10.15406/jamb.2023.12.00376

[15] B.-J. Park, J.-h. Lee, and W.-I. Kim, "Influence of soil characteristics and arsenic, cadmium, and lead contamination on their accumulation levels in rice and human health risk through intake of rice grown nearby abandoned mines," *Journal of the Korean Society for Applied Biological Chemistry*, vol. 54, pp. 575-582, 2011. https://doi.org/10.3839/jksabc.2011.087

[16] S. Khalid *et al.*, "Influence of groundwater and wastewater irrigation on lead accumulation in soil and vegetables: Implications for health risk assessment and phytoremediation," *International Journal of Phytoremediation*, vol. 19, no. 11, pp. 1037-1046, 2017. https://doi.org/10.1080/15226514.2017.1319330

[17] M. K. Souri, M. Hatamian, and T. Tesfamariam, "Plant growth stage influences heavy metal accumulation in leafy vegetables of garden cress and sweet basil," *Chemical and biological Technologies in Agriculture*, vol. 6, no. 1, pp. 1-7, 2019. https://doi.org/10.1186/s40538-019-0170-3

[18] Z. I. Khan *et al.*, "Assessment of trace metal and metalloid accumulation and human health risk from vegetables consumption through spinach and coriander specimens irrigated with wastewater," *Bulletin of Environmental Contamination and Toxicology*, vol. 101, pp. 787-795, 2018. https://doi.org/10.1007/s00128-018-2448-8

[19] A. Latif *et al.*, "Heavy metal accumulation in vegetables and assessment of their potential health risk," *Journal of Environmental Analytical Chemistry*, vol. 5, no. 234, pp. 2380-2391, 2018. https://doi.org/10.4172/2380-2391.1000234

[20] Z. Zakaria *et al.*, "Understanding potential heavy metal contamination, absorption, translocation and accumulation in rice and human health risks," *Plants*, vol. 10, no. 6, p. 1070, 2021. https://doi.org/10.3390/plants10061070

[21] H. Zhou *et al.*, "Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment," *International Journal of Environmental Research and Public Health*, vol. 13, no. 3, p. 289, 2016. https://doi.org/10.3390/ijerph13030289

[22] N. Gupta *et al.*, "Investigation of heavy metal accumulation in vegetables and health risk to humans from their consumption," *Frontiers in Environmental Science*, vol. 10, p. 791052, 2022. https://doi.org/10.3389/fenvs.2022.791052

[23] F. Mapanda, E. Mangwayana, J. Nyamangara, and K. Giller, "Uptake of heavy metals by vegetables irrigated using wastewater and the subsequent risks in Harare, Zimbabwe," *Physics and Chemistry of the Earth, Parts A/B/C*, vol. 32, no. 15-18, pp. 1399-1405, 2007. https://doi.org/10.1016/j.pce.2007.07.046

[24] S. Ahmed, M. M. Mahdi, M. Nurnabi, M. Z. Alam, and T. R. Choudhury, "Health risk assessment for heavy metal accumulation in leafy vegetables grown on tannery effluent contaminated soil," *Toxicology Reports*, vol. 9, pp. 346-355, 2022. https://doi.org/10.1016/j.toxrep.2022.03.009

[25] S. Gupta, S. Satpati, S. Nayek, and D. Garai, "Effect of wastewater irrigation on vegetables in relation to bioaccumulation of heavy metals and biochemical changes," *Environmental Monitoring and Assessment*, vol. 165, pp. 169-177, 2010. https://doi.org/10.1007/s10661-009-0936-3

[26] A. Hussain, M. Priyadarshi, and S. Dubey, "Experimental study on accumulation of heavy metals in vegetables irrigated with treated wastewater," *Applied Water Science*, vol. 9, pp. 1-11, 2019. https://doi.org/10.1007/s13201-019-0999-4

[27] Q. Li, S. Cai, C. Mo, B. Chu, L. Peng, and F. Yang, "Toxic effects of heavy metals and their accumulation in vegetables grown in a saline soil," *Ecotoxicology and Environmental Safety*, vol. 73, no. 1, pp. 84-88, 2010. https://doi.org/10.1016/j.ecoenv.2009.09.002

[28] S. Singh, M. Zacharias, S. Kalpana, and S. Mishra, "Heavy metals accumulation and distribution pattern in different vegetable crops," *Journal of Environmental Chemistry and Ecotoxicology*, vol. 4, no. 10, pp. 170-177, 2012. https://doi.org/10.5897/jece11.076

[29] Y. N. Jolly, A. Islam, and S. Akbar, "Transfer of metals from soil to vegetables and possible health risk assessment," *SpringerPlus*, vol. 2, pp. 1-8, 2013. https://doi.org/10.1186/2193-1801-2-385

[30] A. Zwolak, M. Sarzyńska, E. Szpyrka, and K. Stawarczyk, "Sources of soil pollution by heavy metals and their accumulation in vegetables: A review," *Water, Air, & Soil Pollution*, vol. 230, pp. 1-9, 2019. https://doi.org/10.1007/s11270-019-4221-y

[31] W. Hu, B. Huang, X. Shi, W. Chen, Y. Zhao, and W. Jiao, "Accumulation and health risk of heavy metals in a plot-scale vegetable production system in a peri-urban vegetable farm near Nanjing, China," *Ecotoxicology and Environmental safety*, vol. 98, pp. 303-309, 2013.

[32] K. S. Balkhair and M. A. Ashraf, "Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia," *Saudi Journal of Biological Sciences*, vol. 23, no. 1, pp. S32-S44, 2016. https://doi.org/10.1016/j.sjbs.2015.09.023

[33] D. Woldetsadik, P. Drechsel, B. Keraita, F. Itanna, and H. Gebrekidan, "Heavy metal accumulation and health risk assessment in wastewater-irrigated urban vegetable farming sites of Addis Ababa, Ethiopia," *International Journal of Food Contamination*, vol. 4, pp. 1-13, 2017. https://doi.org/10.1186/s40550-017-0053-y

[34] H. Yu *et al.*, "Comparative evaluation of groundwater, wastewater and canal water for irrigation on toxic metal accumulation in soil and vegetable: Pollution load and health risk assessment," *Agricultural Water Management*, vol. 264, p. 107515, 2022. https://doi.org/10.1016/j.agwat.2022.107515

[35] S. Kausar, S. Faizan, and I. Haneef, "Effect of wastewater irrigation on heavy metal accumulation, growth and yield of vegetables," *International Journal of Plant and Environment*, vol. 3, no. 01, pp. 65-76, 2017. https://doi.org/10.18811/ijpen.v3i.8448

[36] H. M. Jalil, S. Rezapour, A. Nouri, and N. Joshi, "Assessing the ecological and health implications of soil heavy metals in vegetable irrigated with wastewater in calcareous environments," *Agricultural Water Management*, vol. 272, p. 107848, 2022. https://doi.org/10.1016/j.agwat.2022.107848

[37] K. Tiwari, N. Singh, M. Patel, M. Tiwari, and U. Rai, "Metal contamination of soil and translocation in vegetables growing under industrial wastewater irrigated agricultural field of Vadodara, Gujarat, India," *Ecotoxicology and Environmental Safety*, vol. 74, no. 6, pp. 1670-1677, 2011. https://doi.org/10.1016/j.ecoenv.2011.04.029

[38] S. Raja, H. M. N. Cheema, S. Babar, A. A. Khan, G. Murtaza, and U. Aslam, "Socio-economic background of wastewater irrigation and bioaccumulation of heavy metals in crops and vegetables," *Agricultural Water Management*, vol. 158, pp. 26-34, 2015. https://doi.org/10.1016/j.agwat.2015.04.004

[39] D. Baldantoni, L. Morra, M. Zaccardelli, and A. Alfani, "Cadmium accumulation in leaves of leafy vegetables," *Ecotoxicology and Environmental Safety*, vol. 123, pp. 89-94, 2016. https://doi.org/10.1016/j.ecoenv.2015.05.019

[40] B. J. Alloway, A. P. Jackson, and H. Morgan, "The accumulation of cadmium by vegetables grown on soils contaminated from a variety of sources," *Science of the Total Environment*, vol. 91, pp. 223-236, 1990. https://doi.org/10.1016/0048-9697(90)90300-j

[41] L. Huang *et al*., "Cadmium uptake from soil and transport by leafy vegetables: A meta-analysis," *Environmental Pollution*, vol. 264, p. 114677, 2020. https://doi.org/10.1016/j.envpol.2020.114677

[42] Z. Xu *et al*., "Screening of leafy vegetable varieties with low lead and cadmium accumulation based on foliar uptake," *Life*, vol. 12, no. 3, p. 339, 2022. https://doi.org/10.3390/life12030339

[43] V. Onokebhagbe, A. Adeleye, and M. Nkereuwen, "Bioavailability of cadmium in soils, fertilizer sources and uptake by leafy vegetables: A review," *FUDMA Journal of Sciences*, vol. 3, no. 1, pp. 299-306, 2019.

[44] M. M. Ngugi, H. I. Gitari, C. Muii, and J. P. Gweyi-Onyango, "Cadmium mobility, uptake, and accumulation in spinach, kale, and amaranths vegetables as influenced by silicon fertilization," *Bioremediation Journal*, vol. 26, no. 2, pp. 113-127, 2022. https://doi.org/10.1080/10889868.2021.1924111

[45] Q. Xiao, S. Wang, and Y. Chi, "Accumulation and chemical forms of cadmium in tissues of different vegetable crops," *Agronomy*, vol. 13, no. 3, p. 680, 2023. https://doi.org/10.3390/agronomy13030680