Pollution monitoring and assessment of heavy metals in leafy vegetable: A case study of a typical industrial district

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Abstract

Long-term consumption of contaminated leafy vegetables poses potential health risks, particularly in areas affected by heavy metal (HM) pollution. To assess the status of vegetable contamination in China and provide a foundation for the experimental sampling of this study, HM data for vegetables published between 2017 and 2021 in the China National Knowledge Infrastructure and Web of Science databases were reviewed. Based on the accumulation characteristics of HMs in vegetables reported in the literature, this study analyzed the total amount of HMs in leafy vegetables from Qingshan District, a typical industrial area. The results showed that the average concentrations of HMs in the four vegetables did not exceed the limits set by national food safety standards. However, at certain sampling points, the HM levels in amaranth were close to or even exceeded the permissible limits, indicating a potential risk of Cd contamination in amaranth. The single-factor pollution indicated that the four HMs across the four vegetables were all classified as "uncontaminated." Notably, amaranth and water spinach exhibited relatively higher single-factor pollution indices for Cd, while vegetable shoots and Chinese cabbage showed higher single-factor pollution indices for Hg.

Keywords

Qingshan District; Heavy metal; Literature review; Citespace; Leafy vegetables.

1. INTRODUCTION

With the rapid industrialization in China, heavy metal (HM) contamination in soil has become an increasingly serious issue. HM in the soil accumulates in living organisms through the food chain [1], and studies have shown that prolonged exposure to these metals can adversely affect human health [2], leading to a range of diseases. Dietary intake is the primary route through which HM enters the human body [3]. Vegetables, as an essential part of the daily diet, provide key nutrients such as micronutrients and dietary fiber, which are vital for human health. Consequently, the quality and safety of vegetables are directly linked to public well-being. The HM contamination of vegetables has garnered significant attention [4], and addressing this issue is now a matter of urgent priority.

Leafy vegetables, such as lettuce, spinach, and cabbage, are particularly susceptible to HM accumulation in polluted environments due to their shallow root systems, short growth cycles, and high absorption capacity [5]. These vegetables are an integral part of the daily diet, providing essential vitamins, minerals, and other nutrients that support human health. However, when grown on contaminated land near industrial areas or irrigated with water

containing heavy metals, they inevitably absorb and accumulate harmful substances, posing potential health risks. Therefore, it is crucial to examine the extent of heavy metal contamination in leafy vegetables from chemical zones to safeguard food safety and protect public health.

2. DATA AND METHODS

2.1. Data Source

Data on the content of As, Cd, Pb, and Hg in vegetables, published between 2017 and 2021, were collected from the CNKI and WOS databases. The focus was primarily on vegetables, including Chinese cabbage, rapeseed, cauliflower, broccoli, celery, parsley, spinach, lettuce, and water spinach. The literature was selected and screened according to the following criteria: studies published between 2017 and 2021 that clearly identified the type of vegetables; exclusion of pot experiment studies, studies conducted in mining or industrially contaminated areas, and studies with unclear sampling locations; studies that reported at least the arithmetic mean of HM concentrations; and studies where the wet weight content of As, Cd, Pb, and Hg in vegetables had been measured or could be extrapolated. In total, 119 studies were included.

2.2. Research Method

2.2.1. Research Method

CiteSpace software is used to make a statistical analysis of the existing literature in the field of vegetable contamination in China. CiteSpace is a software that can conduct data mining and visual analysis of literature, which can reflect the development trend of a discipline or knowledge field in a certain period and form the evolution process of all cutting-edge research in this field, discover and display the new trend and new dynamics of scientific development.

2.2.2. Monitoring and Analytical Methods

(1) Overview of the study area

Qingshan District (also known as the Chemical District) is in the northeastern part of central Wuhan, along the southern bank of the Yangtze River. To the west, it borders Wuchang District; to the south, it adjoins Hongshan District; and to the east and north, it is bounded by the Yangtze River, across from the core area of Wuhan Yangtze River New City. Qingshan District is well known for its heavy industry, including iron and steel production, as well as its chemical industry.

(2) Sample collection and pre-treatment

In this study, amaranth, Chinese cabbage, vegetable shoots, and water spinach were collected from each of the 28 investigation sites during the spring of 2022. At least 0.5 kg of each vegetable was collected, and the samples were placed in colorless polyethylene ziplock bags for transport to the laboratory. The wilted parts of the vegetables were removed, and the edible portions were retained and weighed. The vegetables were then washed with purified water and placed in an oven at 100°C for 15 minutes to prevent greening, followed by low temperature drying at 70°C. After drying, the samples were mechanically ground using a pulverizer and grinder (Seiko JGY-150A, see Appendix). The powdered samples were then sealed in plastic bags for subsequent testing. The heavy metal concentrations in vegetables were determined using the Thermo ICAP-Q. The sample digestion process was as follows: 0.1 g of the sample was accurately weighed and placed into a pre-cleaned polytetrafluoroethylene digestion vessel. To this, 15 ml of nitric acid and 2 ml of hydrochloric acid were added. The vessel was sealed, and the microwave digestion program was then run. Once digestion was complete, the sample was transferred to a clean polyester plastic bottle and diluted with ultrapure water to a final volume of 50.00 g. A blank control sample was processed in the same manner.

(3) Evaluation of the degree of contamination of vegetables

The level of vegetable contamination was analyzed using the single factor index method (P$_i$).

$$P_i = C_i / S_i \qquad (1)$$

Where P$_i$ is the single-factor pollution index. The larger the value of P$_i$, the more severe the pollution. According to the value of P$_i$, the pollution status can be classified into five levels [6]: when P$_i$ ≤ 0.7, it means safe and uncontaminated; 0.7< P$_i$ ≤ 1 is the alert line; 1< P$_i$ ≤ 2, it means mildly contaminated; 2< P$_i$ ≤ 3, it means seriously contaminated; P$_i$ > 3, it means heavily contaminated. C$_i$ represents the measured concentration of heavy metals in vegetables (mg/kg), and S$_i$ is the evaluation standard value (mg/kg) for each heavy metal, as specified in the GB 2762-2017.

3. RESULTS AND DISCUSSION

3.1. Characterization of Heavy Metal Accumulation in Chinese Vegetables

To assess the overall status of vegetable pollution in China in recent years and provide a basis for the experimental sampling in this study, this paper collected data on heavy metal contamination in vegetables from the CNKI and WOS databases, covering the period from 2017 to 2021. The concentrations and statistical characteristics of As, Cd, Pb, and Hg in vegetables from various regions of China were summarized in Table 1. For leafy vegetables, the average concentrations of As and Cd were below the limits set by the GB 2762-2017. However, the average concentrations of Pb and Hg were slightly above the prescribed thresholds. The results of the single-factor pollution index evaluation were presented in Table 2. Regarding As contamination in leafy vegetables, 96% of the samples were uncontaminated, 1% reached the warning line level, 1% exhibited lightly contamination, 1% were severely contaminated, and 1% were heavily contaminated. For Pb, 83% of the leafy vegetable samples were uncontaminated, 7% reached the warning line level, 3% were lightly contaminated, 3% were severely contaminated, and 3% showed heavy contamination. Concerning Cd, 79% of the leafy vegetable samples were uncontaminated, while 7% reached the warning line level. Additionally, 9% of the samples exhibited light contamination, 2% showed severe contamination, and 4% were heavily contaminated. For Hg, 83% of the samples were uncontaminated, 2% reached the warning line level, 2% showed light contamination, 2% were severely contaminated, and 10% were heavily contaminated.

It has been proved that leafy vegetables were more likely to be enriched with HMs, especially Pb because leafy vegetables can not only absorb heavy metal elements in the soil through their roots but also absorb HMs in atmospheric dust through their leaves [7]. The study of Hou Shengnan et al. (2018) also showed that the HM content in leafy vegetables was greater than that of root and fruit [8]. Therefore, in the subsequent experiments of this study, special attention should be paid to leafy vegetables based on the specific cultivation of vegetables in the farmland of Beihu, to analyze their health risks and make reasonable judgments.

Table 1. Leafy vegetables statistical tables

Testing Program	Number of cases	Limit value/ (mg/kg)	Average value/ (mg/kg)	Standard deviation / (mg/kg)	Minimum value/ (mg/kg)	Maximum value/ (mg/kg)	P25/ (mg/kg)	P50/ (mg/kg)	P75/ (mg/kg)
As	70	0.5	0.0986	0.3421	0.0018	2.76	0.0118	0.025	0.044
Pb	120	0.3	0.5449	4.3321	0.0003	47.5	0.0263	0.0504	0.145
Cd	129	0.1	0.0935	0.2795	0	2.44	0.0139	0.029	0.0585
Hg	40	0.01	0.0131	0.0312	0.0002	0.128	0.0009	0.0021	0.0059

Table 2. Statistics of As, Pb, Cd and Hg contamination in leafy vegetables

	As	Pb	Cd	Hg
Number of cases	70	120	129	40
Uncontaminated	96%	83%	79%	83%
Warning line	1%	7%	7%	2%
Light pollution	1%	3%	9%	2%
Severe pollution	0%	3%	2%	2%
Heavy pollution	1%	3%	4%	10%
Percentage of total pollution	2%	9%	15%	15%

3.2. Heavy Metal Contamination of Vegetables in Qingshan District

(1) Characterization of total heavy metal content

As shown in Figure 1, the mean concentrations of the four heavy metals (As, Cd, Pb, and Hg) in amaranth were 0.030 mg/kg, 0.145 mg/kg, 0.048 mg/kg, and 0.002 mg/kg, respectively. In water spinach, the mean concentrations of these heavy metals were 0.140 mg/kg, 0.033 mg/kg, and 0.029 mg/kg for As, Cd, and Pb, respectively. For vegetable shoots, the mean concentrations of As, Cd, Pb, and Hg were 0.023 mg/kg, 0.038 mg/kg, 0.052 mg/kg, and 0.005 mg/kg, respectively. The order of Cd content across the four vegetables was water spinach > amaranth > vegetable shoots > Chinese cabbage, which indicated that As was more likely to be enriched in water spinach. The order of Cd content across the four vegetables was amaranth > vegetable shoots > water spinach ≈ Chinese cabbage. Notably, the Cd content in amaranth at certain sampling points was close to or even exceeded the regulatory limit, suggesting a potential risk of Cd contamination in amaranth. The order of Pb content was vegetable shoots > amaranth > Chinese cabbage > water spinach, indicating that Pb was more likely to accumulate in the vegetable shoots. The order of Hg concentration was vegetable shoots > water spinach ≈ Chinese cabbage > amaranth.
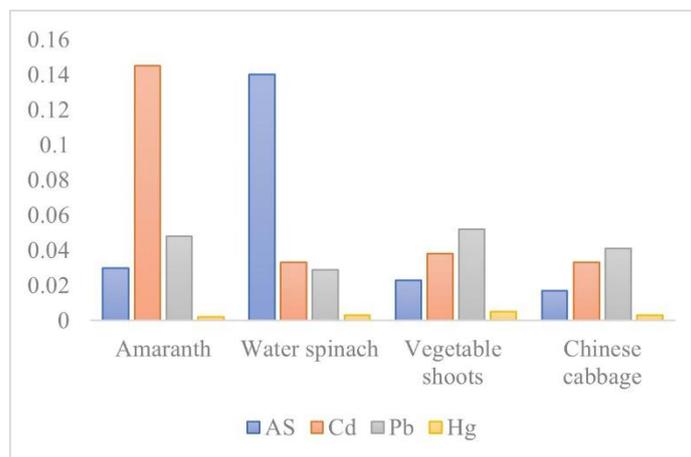
Figure 1. Distribution of heavy metals in vegetables

(2) Heavy metal pollution risk evaluation

The single-factor contamination indicted the four HMs in amaranth were Cd (0.73) > Hg (0.20) > Pb (0.16) > As (0.06); in water spinach were Cd (0.33) > Hg (0.30) > Pb (0.29) > As (0.28) ; in vegetable shoots were Hg (0.50) > Pb (0.29) > Cd (0.19) > As (0.05); and in Chinese cabbage were Hg (0.30) > Cd (0.17) > Pb (0.04) > As (0.03). The single-factor contamination levels of the four HMs in the four vegetables were all uncontaminated, with amaranth and water spinach having higher single-factor contamination indices for Cd, and vegetable shoots and Chinese cabbage having higher single-factor contamination indices for Hg, which should be emphasized for stem and leafy vegetables. In addition, for HMs (As, Pb, Hg,.) which those

originating from atmospheric deposition and soil dust, washing vegetables before consumption can reduce the health risk due to vegetable consumptio [9].

4. CONCLUSION

Based on a literature review and field sampling, this study examined the current status of heavy metal pollution in leafy vegetables from the Beihu area of Qingshan District. The research focused on vegetables grown by local farmers in this region. The findings indicated that heavy metal pollution was most severe in leafy vegetables, followed by fruit vegetables, with root vegetables showing the least contamination. The average levels of heavy metals in the four types of leafy vegetables sampled in Qingshan District were found to be within the limits set by national food safety standards. It is essential to promote the high-quality development of farmland and prioritize soil health management in the future.

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