Evaluation of Heavy Metal Contamination in Soils of Vegetable Cultivation Bases in Zunyi City

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Abstract ［**Objectives**］ To analyze the current status of heavy metal contamination in soils of vegetable cultivation bases located in Huichuan District, Zunyi City. ［**Methods**］ Soil samples from various depths within the vegetable cultivation bases of Guanba Village, Sidu Village, and Banqiao Village in Huichuan District, Zunyi City, were selected as the subjects of this study. The concentrations of five heavy metals, including lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), and chromium (Cr), were measured at different soil depths. The Nemerow comprehensive pollution index method was employed to assess heavy metal contamination, and the analysis was conducted in accordance with the farmland environmental quality evaluation standards for edible agricultural products. ［**Results**］ The concentrations of Cd and As at the sample collection sites were relatively elevated. The pollution level of Cd reached grade III or above, indicating moderate contamination in certain topsoil areas. Most As concentrations corresponded to grade II and grade III pollution levels. In contrast, Hg, Pb, and Cr concentrations remained within the safety standards established for agricultural products. However, Cd and As levels predominantly surpassed these safety thresholds. Notably, Guanba Village and Sidu Village exhibited significant pollution levels, warranting comprehensive investigations into the sources of contamination. ［**Conclusions**］ This study offers valuable insights for advancing the sustainable development of local agriculture and for the prevention and management of soil contamination.

Key words Heavy metal contamination, Nemerow index, Vegetable

0　Introduction

　　The extent of heavy metal contamination in soil is directly associated with crop yield and quality, influencing the safety and market value of agricultural products. Moreover, it impacts the health of the soil ecosystem, sustainable agricultural development, and human health and well-being, serving as a critical factor that either restricts or facilitates high-quality agricultural advancement[1]. The vegetable cultivation area in Zunyi City constitutes a substantial proportion of the total in Guizhou Province[2]. Elevated concentrations of heavy metals in the soil can lead to their uptake by plants, subsequently entering the food chain and posing risks to human health. Different vegetable species exhibit significant variability in their capacity to absorb heavy metal elements from the soil[3]. Currently, research has predominantly focused on the vertical distribution of heavy metals within soil profiles[4-6]. By thoroughly investigating the characteristics of soil layers, these studies have analyzed the pollution status of various heavy metals[7-8].

　　The cultivation base located in Huichuan District, Zunyi City, is a rare contiguous dam area spanning 666.7 ha within Guizhou Province. It also serves as a core dam area that Huichuan District has developed to high standards through resource integration. Currently, research on soil heavy metal contamination in the vegetable cultivation base in Zunyi City remains limited. This study selected soil samples from different layers within vegetable cultivation bases located in Guanba Village, Sidu Village, and Banqiao Village in Huichuan District, Zunyi City, Guizhou Province as the research subjects. Soil samples were collected at depths of 0 − 10, 10 − 20, and 20 − 30 cm. The concentration characteristics of heavy metals in the soil were analyzed, and the pollution levels were assessed using the Nemerow index method. Furthermore, in conjunction with the farmland environmental quality evaluation standards for edible agricultural products, a comprehensive analysis was conducted to provide a scientific basis for promoting sustainable agricultural development and soil pollution prevention and control in the region.

1　Materials and methods

1.1　Collection of soil samples　Huichuan District is situated in the northern region of Zunyi City, Guizhou Province. It lies on the slope where the Yunnan − Guizhou Plateau transitions into the Hunan Hills and the Sichuan Basin, with an elevation generally ranging from 1 100 to 1 500 m. Soil samples were collected from vegetable cultivation bases located in Guanba Village, Sidu Village, and Banqiao Village, all situated within Huichuan District, Zunyi City, Guizhou Province. A five-point sampling method was employed to select three sampling locations within the cultivation bases, where soil was sampled at depths of 0 − 10, 10 − 20, and 20 − 30 cm. The collected soil samples were transported to the laboratory, air-dried naturally in a well-ventilated and cool environment, and subsequently passed through a 100-mesh sieve for further analysis.

1.2　Evaluation methods

1.2.1　Calculation method of individual pollution index method. The calculation formula is expressed as follows:

$$P_i = C_i / S_i \tag{1}$$

where P_i represents the pollution index of the heavy metal element i; C_i denotes the measured concentration of the heavy metal element i, expressed in mg/kg; and S_i corresponds to the standard concentration of the heavy metal element i, also in mg/kg.

1.2.2 Calculation method of Nemerow comprehensive pollution index method. The calculation formula is presented as follows:

$$P_N = \sqrt{\frac{P_{max}^2 + P_{ave}^2}{2}} \qquad (2)$$

where P_N denotes the comprehensive pollution index of the sampling site; P_{max} represents the maximum value among the average values of the individual pollution indices; and P_{ave} signifies the average value of the individual pollution index.

1.3 Evaluation criteria

1.3.1 Classification criteria of Nemerow comprehensive pollution index[9]. The classification criteria for the Nemerow comprehensive pollution index are presented in Table 1.

Table 1　Classification criteria of Nemerow comprehensive pollution index

Grade	P_N	Pollution level
I	$P_N \leqslant 0.7$	Clean (Safe)
II	$0.7 < P_N \leqslant 1.0$	Still clean (approaching the warning limit)
III	$1.0 < P_N \leqslant 2.0$	Mild pollution
IV	$2.0 < P_N \leqslant 3.0$	Moderate pollution
V	$P_N > 3.0$	Heavy pollution

NOTE　P_N denotes the Nemerow pollution index.

1.3.2 Farmland environmental quality evaluation standards for edible agricultural products[10]. The farmland environmental quality evaluation standards for edible agricultural products are presented in Table 2.

Table 2　Farmland environmental quality evaluation standards for edible agricultural products

Environmental quality grade	Individual or comprehensive quality index of soil	Grade
1	$\leqslant 0.7$	Clean
2	$0.7 - 1.0$	Still clean
3	> 1.0	Exceeding the standard

2　Results and analysis

2.1　Soil heavy metal concentration　Table 3 presents the heavy metal concentration in the soil from various vegetable cultivation bases in Huichuan District, Zunyi City. The concentration of heavy metals is a critical factor in evaluating soil quality. Unregulated emissions from industrial, agricultural, and other sources have led to significant soil contamination by heavy metals, which primarily exist as cations. These metals are persistent in the soil environment, as they do not undergo natural degradation. Over time, their accumulation poses substantial risks to both agricultural productivity and human health[11].

Table 3　Overview of soil heavy metal concentration in different vegetable cultivation bases in Huichuan District, Zunyi City　mg/kg

Heavy metal		0 – 10 cm			10 – 20 cm			20 – 30 cm		
		A	B	C	A	B	C	A	B	C
Hg	Average value	0.265	0.323	0.263	0.293	0.332	0.249	0.344	0.255	0.236
	Standard deviation	0.065	0.012	0.018	0.074	0.023	0.056	0.045	0.042	0.030
Pb	Average value	18.176	16.489	23.997	22.377	17.574	18.800	19.831	18.537	23.788
	Standard deviation	0.910	0.679	2.110	1.409	1.180	0.590	0.757	0.756	0.990
Cd	Average value	0.647	0.373	0.537	0.660	0.337	0.468	0.550	0.343	0.433
	Standard deviation	0.038	0.005	0.015	0.021	0.034	0.017	0.017	0.019	0.009
Cr	Average value	69.390	58.022	72.337	69.523	61.649	74.942	67.462	62.186	77.059
	Standard deviation	2.381	1.590	1.316	0.561	2.802	2.057	1.998	1.463	1.907
As	Average value	32.709	27.918	20.584	33.603	29.521	32.831	24.390	22.493	27.383
	Standard deviation	1.202	2.041	0.671	1.130	1.130	0.550	0.280	3.503	1.611

NOTE　A. denotes Guanba Village; B. denotes Sidu Village; and C. denotes Banqiao Village. The same below.

As presented in Table 3, the average Hg concentration ranged from 0.236 to 0.344 mg/kg, which is comparatively low relative to other heavy metals. Pb concentrations averaged between 16.489 and 23.997 mg/kg, with notably higher levels observed at depths of 0 – 10 and 20 – 30 cm in Banqiao Village. Cd exhibited average concentrations ranging from 0.337 to 0.660 mg/kg, demonstrating a tendency for enrichment in the soil surface layer. Cr concentration averaged between 58.022 and 77.059 mg/kg, with elevated concentrations detected at the 20 – 30 cm depth, indicating a pattern of downward accumulation. The concentrations of As ranged from 20.584 to 33.603 mg/kg, with significant variations observed across different sampling sites and soil depths. The standard deviations for Hg and Cd were relatively low, suggesting stable concentrations, whereas Pb, Cr, and As exhibited higher standard deviations, indicating greater variability in their concentrations.

2.2　Evaluation of heavy metal pollution in soil　The individual pollution index (P_i) was calculated using formula (1), followed by the computation of the Nemerow comprehensive pollution index (P_N) for heavy metals in the soil from various vegetable cultivation bases in Huichuan District, Zunyi City, employing formula (2). Based on the values presented in Table 1, the comprehensive pollution levels for Hg, Pb, Cd, Cr, and As were ascertained. The results are summarized in Table 4.

Table 4 Nemerow comprehensive pollution index（P_N）for heavy metals in the soil from various vegetable cultivation bases in Huichuan District, Zunyi City

Heavy metal	0 – 10 cm			10 – 20 cm			20 – 30 cm		
	A	B	C	A	B	C	A	B	C
Hg	0.13	0.14	0.15	0.14	0.14	0.12	0.11	0.12	0.10
Pollution grade	I	I	I	I	I	I	I	I	I
Pb	0.16	0.19	0.17	0.14	0.15	0.16	0.21	0.16	0.20
Pollution grade	I	I	I	I	I	I	I	I	I
Cd	2.20	2.24	1.86	1.25	1.19	1.18	1.82	1.58	1.46
Pollution grade	IV	IV	III	III	III	III	III	III	III
Cr	0.35	0.35	0.34	0.29	0.31	0.31	0.37	0.38	0.39
Pollution grade	I	I	I	I	I	I	I	I	I
As	1.11	1.14	0.82	0.97	1.01	0.81	0.70	1.10	0.94
Pollution grade	III	III	II	II	III	II	I	III	II

As presented in Table 4, the Nemerow pollution index（P_N）for Hg, Pb, and Cr in the soil samples from the study site was classified as grade I, indicating that pollution levels were within the clean (safe) range and posed no comprehensive pollution risk. In contrast, the P_N values for Cd exceeded 1 across most areas, corresponding to grade III mild pollution. Notably, surface soil pollution in Sidu Town was more pronounced, with a P_N value exceeding 2, thereby classified as grade IV moderate pollution. The P_N values of As ranged from 0.70 to 1.14, indicating varying levels of pollution. Three pollution levels were identified: grade I (clean and safe), grade II (still clean but approaching the warning limit), and grade III (mild pollution). Notably, all sampling sites in Sidu Village, were classified as grade III, indicating mild pollution. It is imperative to monitor the potential increase in As concentrations to prevent further environmental degradation. Consequently, continuous assessment of Cd and As accumulation is essential, alongside the implementation of appropriate measures to mitigate their concentrations.

Further analysis was performed based on the farmland environmental quality evaluation standards for edible agricultural products presented in Table 2. The individual pollution indices（P_i）for Hg, Pb, and Cr, as well as the Nemerow comprehensive pollution indices（P_N）, were all ≤0.7, indicating an environmental quality grade of clean, which did not exceed the safety standards for agricultural products. However, the concentrations of Cd and As frequently exceeded these safety standards, identifying them as key heavy metals requiring targeted pollution prevention and control measures. Notably, Guanba Village and Sidu Village exhibited significant pollution levels. To ensure the safe production of agricultural products, it is imperative to conduct pollution source investigations, implement dynamic monitoring, and undertake remediation and treatment efforts in these areas.

3　Conclusions

The analysis of the Nemerow comprehensive pollution index revealed that the concentrations of Cd and As were comparatively elevated. The pollution level of Cd reached grade III or above, indicating moderate contamination in certain topsoil samples. Most As measurements corresponded to grades II and III. In contrast, Hg, Pb, and Cr concentrations remained within the safety standards established for agricultural products. However, Cd and As frequently surpassed these regulatory thresholds. Notably, Guanba Village and Sidu Village exhibited significant pollution levels, warranting detailed investigations into the sources of contamination.

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