*sustainability*

MDPI

*Article*

# Heavy Metal Pollution and Risk Assessment of Vegetables and Soil in Jinhua City of China

**Yangbin Mao [1,†], Maomao Wang [1,†], Hewen Wei [2], Ning Gong [3], Feijuan Wang [1,*] and Cheng Zhu [1]**

[1] Key Laboratory of Specialty Agri-product Quality and Hazard Controlling Technology of Zhejiang Province, College of Life Sciences, China Jiliang University, Hangzhou 310018, China
[2] Jinhua Institute of Food and Drug Inspection and Testing, Jinhua 321000, China
[3] Yiwu Product and Commodity Quality Inspection Institute, Jinhua 322000, China
* Correspondence: wfj0311@cjlu.edu.cn
† These authors contributed equally to this work.

**Abstract:** To understand the heavy metal (Cd, Cr and Pb) pollution situation and exposure risk of the vegetables and soil in Jinhua City, soil–vegetable samples collected from three districts of Jinhua City were analyzed in detail, and the risks of heavy metal concentration in vegetable and soil were evaluated using the single pollution index, Nemerow pollution index, Hakanson potential ecological index and a health risk assessment. The results indicate that: (1) The soil in Jinhua City is mainly polluted by Cd, and the BCF of heavy metals in vegetables was leafy vegetables > rootstalk vegetables > solanaceous vegetables. (2) Heavy metals had slight pollution in the surrounding environment, and the ecological risk of soil heavy metals in the sampling area was generally at a low risk level. (3) Children are more likely to suffer from non-carcinogenic risks; Cr is the main source of this risk ($HQ_{Cr}$ = 0.74). More than 90% of vegetables in the sampling had cancer risk, adults are more likely to suffer from carcinogenic risks, and Cd is the main source of potential cancer risk (TCR = $4.34 \times 10^{-4}$). Therefore, in our study area, Cd is the main factor of soil pollution that can cause potential cancer risk through vegetable enrichment, and Cr is the main factor causing the non-carcinogenic risk of leafy vegetables.

**Keywords:** soil; vegetables; heavy metals; ecological risk assessment; health risk assessment

check for updates

**Citation:** Mao, Y.; Wang, M.; Wei, H.; Gong, N.; Wang, F.; Zhu, C. Heavy Metal Pollution and Risk Assessment of Vegetables and Soil in Jinhua City of China. *Sustainability* **2023**, *15*, 4241. https://doi.org/10.3390/su15054241

Academic Editor: Jun Wang

Received: 28 December 2022
Revised: 6 February 2023
Accepted: 20 February 2023
Published: 27 February 2023

**Copyright:** © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

## 1. Introduction

In recent years, heavy metal pollution in soil has attracted great attention from many countries and environmental organizations [1,2]. In January 2019, with the implementation of the Law of the People's Republic of China on the Prevention and Control of Soil Pollution, the "General survey of Soil Pollution in Production Areas of Agricultural Products" and "investigation of soil pollution in land used by enterprises in key industries" were carried out across the country. The results show that the soil heavy metal pollution in China is not optimistic, and the soil around industrial, agricultural, mining and other industries has been polluted to varying degrees [3,4]. The harm caused by soil pollution mainly includes three aspects. First, soil pollution can cause huge economic losses. Every year, heavy metal pollution reduces grain production by more than 10 million tons, directly causing economic losses of more than 20 billion yuan [5]. Second, soil pollution leads to a decline in the quality of crops. The concentrations of heavy metals such as Cd, Pb, Cr and Hg in the grains, vegetables and other products grown in most suburban soils in China exceeds the standard or is close to the critical value [6,7]. Third, soil pollution makes heavy metals accumulate in plants and accumulate in humans through the food chain, endangering human health and inducing a variety of diseases. Therefore, the implementation of effective soil ecological management has become an urgent problem in China and even the whole world.

As an important part of the human diet, vegetables contain carbohydrates, proteins, vitamins, minerals, fiber and other key substances required for human health, which can

reduce the risk of chronic diseases, so they are popular among consumers [8]. As a big consumer of vegetables, China also exports a large number of fruits and vegetables [9]. However, in recent years, various types of vegetables have frequently been contaminated with heavy metals. Gupta et al. [10] found that due to wastewater irrigation, Cd and Pb in edible parts of radish in suburbs in India were 17.79 mg/kg and 57.63 mg/kg, respectively, which is far beyond the safe threshold. In a heavy metal risk assessment of Romanian vegetables (*Solanum lycopersicum* and *Daucus carota*), it was found that the concentrations of Cd, Cu and Pb in these vegetables were high and far beyond the warning limits set by Romanian legislation [11]. Vasileios et al. sampled vegetables grown around a mining area in Germany and found that the heavy metal content in beans, carrots and lettuce all posed health risks to human body, in which Pb and Hg reached 13,789.0 mg/kg and 36.8 mg/kg, respectively. Similarly, the phenomenon of heavy metal pollution of vegetables also exists in China. Luo et al. [6] reported that uncontrolled e-waste processing operations caused serious pollution to soils and vegetables in Guangdong Province. The Cd concentration in lettuce grown around Guangdong Province was 0.38 mg/kg, and the Cd and Pb concentrations in the Taro were 0.32 mg/kg and 1.30 mg/kg, respectively. A study of crops in the villages around the Dabaoshan mining area in Guangdong Province found that mining and smelting could lead to serious Cd and Pb pollution in local rice and vegetables and posed a huge risk to the health of local residents [12]. Liu et al. [7] found Cd, Cu and Zn pollution in the local soil near an electronics factory in southeastern Zhejiang Province. According to human health risk assessment, eating vegetables surrounding sources of pollution brings non-carcinogenic and carcinogenic risks to residents. However, there have been few heavy metal pollution and risk assessments on vegetables and soil in Jinhua City. Therefore, it is urgent to investigate heavy metal pollution in vegetables and its risk assessment to human health.

It has been reported that the heavy metal content in vegetables is positively and significantly correlated with the heavy metal concentrations in planting soils [13]. Therefore, soil remediation has received great attention in recent years. The United States has invested a lot of money and introduced relevant laws and regulations to restore contaminated soil, such as "the Superfund Amendments and the Reauthorization Act (SARA)"and "the Resource Conservation and Recovery Act (RCRA)", to enhance soil remediation related technologies [14]. Zhang et al. [15] leached heavy metals with oxidizing agents such as sulfuric acid and sodium chlorate and then neutralized them with calcium hydroxide so that the heavy metals in the soil were quickly filtered out. Liu et al. [16] reduced the migration of heavy metals to plants or other environmental media by adding reagents to contaminated soil to form insoluble substances such as Fe-Mn plaque (oxides-bound) in plant roots. In addition, microorganisms such as *Bacillus subtilis*, *Pseudomonas aeruginosa* and *Penicillium* can also adsorb heavy metals in soil, reducing the availability concentrations of heavy metals in soil, and the metabolites of microorganisms can also improve soil fertility [17–19].

Jinhua City is located in the central part of Zhejiang Province, with a total GDP of 535.544 billion yuan in 2021. Its pillar industry is auto parts. Electroplating, coating and other processes in this industry are indispensable links in automobile manufacturing, and the resulting wastewater may cause heavy metal pollution. However, there are few studies on the pollution of heavy metals in soil and vegetables in Jinhua City. It is of great significance to strengthen the monitoring and evaluation of soil in Jinhua City for soil environmental quality and food safety. Therefore, this project selected Wucheng District (WC), Jindong District (JD) and Kaifa District (KF) of Jinhua City as the research area, collected soil and vegetable samples, analyzed the ecological risk of the target soil using the single pollution index, Nemerow pollution index, and Hakanson potential ecological risk assessment in combination with the concentrations of heavy metals in the soil and vegetables, and carried out human health risk assessment in order to provide theoretical reference for agricultural production in Jinhua City and guarantee resident dietary health.

## 2. Materials and Methods

### *2.1. Study Area*

Jinhua City is located in the eastern part of the hilly basin in central Zhejiang (119°14′ N–120°46′ N, 28°32′ E–29°41′ E), and it is the transportation hub in central Zhejiang [20]. Jinhua belongs to the subtropical monsoon season, with four distinct seasons, abundant heat, sufficient rainfall, and obvious dry and wet seasons. The average annual frost-free period is more than 250 days, and the annual precipitation is 1426.2 mm [21]. This environment is suitable for the growth of all kinds of vegetables, making Jinhua a traditional agricultural city.

### *2.2. Sample Collection*

Random sampling was carried out for JD, WC and KF in Jinhua City. There were 585 vegetable samples (1 kg edible part of each), including leafy vegetables (water spinach, spinach, pakchoi), rootstalk vegetables (lettuce and taro) and solanaceous vegetables (eggplant, tomato and pumpkin) (Figure 1 and Table 1). Simultaneously, 585 soil samples were collected at the vegetable sampling sites. When sampling, a five-point sampling method was adopted to collect vegetables and soil. Soil samples were taken in the immediate vicinity of the roots of the vegetable samples from 0–20 cm depth. Only the edible part of each vegetable was collected for analyses.

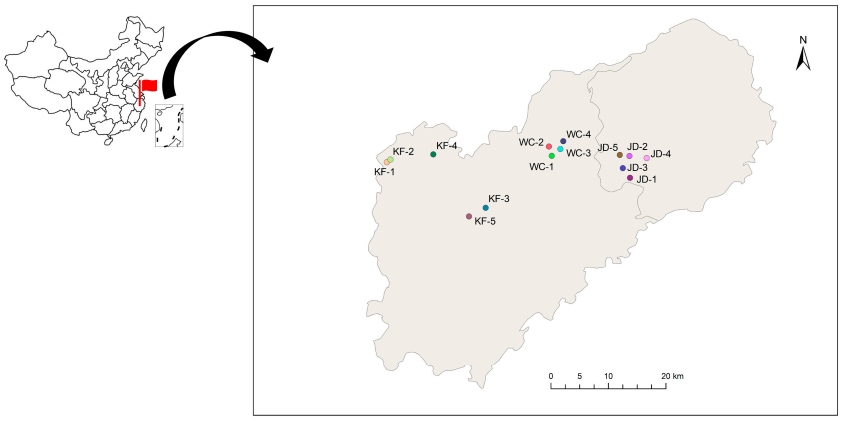



**Figure 1.** Map of the study area that shows the soil and vegetable sampling district in Jinhua City.

**Table 1.** Specific sampling information of Jinhua.

| Sampling Area | Specific Locations | Vegetable Sample | Soil |
|---|---|---|---|
| JD (Jing Dong) | District 1 | 80 | 80 |
| | District 2 | 55 | 55 |
| | District 3 | 70 | 70 |
| | District 4 | 5 | 5 |
| | District 5 | 15 | 15 |
| KF (Kai Fa) | District 1 | 45 | 45 |
| | District 2 | 20 | 20 |
| | District 3 | 50 | 50 |
| | District 4 | 40 | 40 |
| | District 5 | 35 | 35 |
| WC (Wu Cheng) | District 1 | 30 | 30 |
| | District 2 | 25 | 25 |
| | District 3 | 70 | 70 |
| | District 4 | 45 | 45 |

### *2.3. Experimental Method*

#### 2.3.1. Soil Processing and Testing Methods

All soil samples were air-dried indoors and sieved to pass through 18-mesh, 60-mesh and 100-mesh nylon sieves. Soil pH was determined with a pH meter (Mettler toledo) in 1:2.5 (soil: water, weight/volume, air-dried soil) suspensions. Soil organic matter (SOM) was determined using the $K_2Cr_2O_7$-$H_2SO_4$ oxidation method, and the organic carbon content was calculated according to the consumed $K_2Cr_2O_7$, then multiplied by the constant 1.724, which was the SOM content of the soil. Total and available heavy metal concentrations in the soils were carried out according to Massas et al. [22].

#### 2.3.2. Vegetable Processing and Testing Methods

We washed the vegetables with ultrapure water to remove dust, dried them and ground the edible parts into a homogenate, stored at 4 °C for later use. Vegetable samples (0.3 g, fresh weight) were digested with 6 mL $HNO_3$, the acid was driven out and then the total volume was diluted to 10 mL with ultrapure water [23]. Finally, the Cd, Cr and Pb concentrations in the samples were determined using an AA-7000.

### *2.4. Environmental and Risk Assessment*

(1) Pollution index

To evaluate heavy metal pollution levels, the pollution index was calculated [24].

$$\text{Pollution Index } (P_k) = \frac{C_k}{S_k} \quad (1)$$

where $P_k$ represents the pollution index of a heavy metal, $C_k$ is the actual measured value of heavy metals (mg/kg) and $S_k$ is the standard concentration of heavy metals in the study area (mg/kg). In this study, the background value of soil heavy metals in Zhejiang Province was used as the assessment standard of pollutants, which were Cd = 0.274 mg/kg, Cr = 60.6 mg/kg and Pb = 42.4 mg/kg. The $P_k$ of each heavy metal is classified in Table 2 [25].

**Table 2.** Heavy metal pollution index classification standard.

| Grade | $P_k$ | Pollution Degree | $P_N$ | Pollution Degree |
|---|---|---|---|---|
| 1 | $P_k < 1$ | Clean | $P_N \leq 0.7$ | Safe |
| 2 | $1 \leq P_k < 2$ | Light pollution | $0.7 < P_N \leq 1$ | Warning line |
| 3 | $2 \leq P_k < 3$ | Moderate pollution | $1 < P_N \leq 2$ | Light pollution |
| 4 | $P_k \geq 3$ | Heavy pollution | $2 < P_N \leq 3$ | Moderate pollution |
| 5 | / | / | $P_N \geq 3$ | Heavy pollution |

(2) Nemerow pollution index

A Nemerow pollution index ($P_N$) was applied to assess the general quality of the soil environments and was calculated as [26]:

$$P_N = \sqrt{\frac{P_{kave}^2 + P_{kmax}^2}{2}} \quad (2)$$

where $P_{kave}$ is the average $P_k$ value of each heavy metal and $P_{kmax}$ is the maximum $P_k$ (in this study) value of each heavy metal. The $P_N$ of each heavy metal is classified in Table 2.

(3) Ecological risk assessment

Swedish scientist Hakanson (1980) proposed an ecological risk assessment to evaluate heavy metal pollution in the soil of a study area. It is calculated as follows [27]:

$$E_k = P_k \times T_k \quad (3)$$

$$\text{RI} = \sum_{i=1}^{n} E_k^i \quad (4)$$

where $E_k$ is the potential ecological risk factor of the heavy metal and $T_k$ is the toxicity coefficient of the heavy metal. The toxicity coefficients of the three heavy metals were set according to the relevant literature and pollution characteristics of heavy metals: Cd = 30, Cr = 2, Pb = 5 [28]. RI is the potential ecological risk index of multiple heavy metals, and the pollution degree can be classified according to the calculation results (Table 3).

**Table 3.** Potential ecological hazard assessment indices per Hakanson.

| Grade | $E_k$/*RI* | Pollution Degree |
|---|---|---|
| 1 | $E_k < 30$, or $RI < 40$ | Slight negative impact |
| 2 | $30 \leq E_k < 60$, or $40 \leq RI < 80$ | Moderate negative impact |
| 3 | $60 \leq E_k < 120$, or $80 \leq RI < 160$ | Strong negative impact |
| 4 | $120 \leq E_k < 240$, or $160 \leq RI < 320$ | Very strong negative impact |
| 5 | $E_k \geq 240$, or $RI \geq 320$ | Severe negative impact |

(4) Bioconcentration factor

The bioconcentration factor (BCF) is an important quantitative indicator of crop contamination and has commonly been used for estimating the transfer capabilities of heavy metals from soil to crops. The BCFs of heavy metals from soil to vegetables in our research were calculated as follows [29]:

$$\mathrm{BCF} = \frac{C_{vegetable}}{C_{soil}} \quad (5)$$

where $C_{vegetable}$ and $C_{soil}$ (total concentration) are heavy metal concentration in vegetables and corresponding soil (mg/kg), respectively.

### *2.5. Health Risk Assessment*

(1) Exposure assessment

In this study, according to the health risk assessment model recommended by the U.S. Environmental Protection Agency (USEPA), the intake of heavy metals in four ways was quantitatively calculated [30]. CDI represents the daily intake of pollution elements that enter the body in different ways. The formula is as follows:

$$\mathrm{CDI}_{\mathrm{ingest-soil}} = \frac{C_k \times IRS \times EF \times ED \times CF}{BW \times AT} \quad (6)$$

$$\mathrm{CDI}_{\mathrm{dermal-soil}} = \frac{C_k \times SA \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \quad (7)$$

$$\mathrm{CDI}_{\mathrm{inhala-soil}} = \frac{C_k \times IR_{in} \times EF \times ED \times CF}{PEF \times BW \times AT} \quad (8)$$

$$\mathrm{CDI}_{\mathrm{veg}} = \frac{C_{veg} \times IR_{veg} \times EF \times ED}{BW \times AT} \quad (9)$$

The model parameter names and reference values are shown in Table 4 [30]:

**Table 4.** The meanings and values of health risk assessment parameters.

| | Parameter | Reference | Unit |
|---|---|---|---|
| EF | Exposure frequency | 350 | d/a |
| ED | Exposure time | Adult: 30; child: 7 | a |
| AT | Average time | Carcinogenic: 365 × 70; non-carcinogenic: 365 × ED | d |
| BW | Body weight | Adult: 60; child: 26 | kg |
| SA | Skin area | 1690 | $cm^2$ |

**Table 4.** *Cont.*

| | Parameter | Reference | Unit |
|---|---|---|---|
| AF | Adhesion factor | 0.07 | $mg/cm^2$ |
| ABS | Skin absorption rate | 0.001 | / |
| PEF | Particulate emancipate factor | $1.36 \times 10^9$ | $m^3/kg$ |
| CF | Conversion factor | $1 \times 10^{-6}$ | kg/mg |
| IRS | Soil particle intake rate | 50 | mg/d |
| $IR_{in}$ | Soil particle intake | 16 | $m^3/d$ |
| $IR_{veg}$ | Vegetable intake | Adult: 244; child: 186 | g/d |
| $C_k$ | Concentrations of heavy metals in soil | This study | mg/kg |
| $C_{veg}$ | Concentrations of heavy metals in vegetable | This study | mg/kg |

(2) Non-carcinogenic risk assessment

The target hazard quotient (HQ) method is used to assess the non-carcinogenic risk caused by the consumption of polluted crops [31,32]:

$$\mathrm{HQ} = \frac{CDI}{RFD} \tag{10}$$

$$\mathrm{HI} = \sum_{i=1}^{n} HQ_k \tag{11}$$

RFD is the chronic reference dose of heavy metal, and $HQ_k$ represents the non-carcinogenic risk index of different elements. According to the database of USEPA, the reference values for Cd, Cr and Pb are 0.001, 0.003 and 0.0035 mg/kg, respectively [30]. When HQ > 1, it is proposed that heavy metal elements will cause certain non-carcinogenic risks to the human body. HI indicates the superposition of the non-carcinogenic risk indexes of all pollution elements when there are multiple heavy metal pollution elements in the environment. When HI > 1, the environment is considered to have potential non-carcinogenic risk to the human body.

(3) Carcinogenic risk assessment

Carcinogenic risk assessment can be evaluated by the following linear equations [33]:

$$\mathrm{CR} = \mathrm{CDI} \times \mathrm{SF} \tag{12}$$

$$\mathrm{TCR} = \sum_{i=1}^{n} CR_k \tag{13}$$

CR represents the potential carcinogenic risk, SF represents the slope factor of heavy metal elements, and the SF value for Cd, Cr and Pb are 6.1, 0.5 and 0.0085, respectively [34]. $CR_k$ represents the cancer risk factors of different elements, and TCR represents the sum of the carcinogenic risks of all polluting elements. When CR or TCR are less than $10^{-6}$, it is generally considered that the carcinogenic risk in the environment can be ignored. When it is between $10^{-6}$ and $10^{-4}$, the carcinogenic risk is within the acceptable range. When it is greater than $10^{-4}$, the carcinogenic risk in the environment is unacceptable.

### *2.6. Statistics Analysis*

All experiment data were analyzed by Excel 2019 and SPSS 21, and all charts were delineated by Origin 16.0.

## 3. Results

### *3.1. Soil Physicochemical Properties and Heavy Metal Concentrations*

In the study area, the pH value of the soil was 3.99–8.72, with an average value of 6.09. The pH values of the three sampling areas were WC > JD > KF (Table 5). According to the grading standard of soil pH, the proportion of acidic soil was 64.96%, so the soil in this region was acidic as a whole. The mass concentration of SOM was $1.74 \times 10^4$–$8.06 \times 10^4$ mg/kg, and the average value was $3.61 \times 10^4$ mg/kg. The SOM value of the three sampling areas was in the order of WC > KF > JD (Table 5). The results presented in Table 6 indicate that the total concentrations of Cd, Cr and Pb in the soil of

the sampling area were 0.19–0.68, 11.73–88.56 and 12.52–58.01 mg/kg, respectively. According to China's Risk Control Standard for Soil Contamination of Agricultural Land (GB 15618-2018), the concentrations of Cr and Pb were both lower than the corresponding screening value, while the concentration of Cd was higher than the national standard (Cd > 0.3 mg/kg), and the Cd pollution rate reached 93.16% (Figure 2a). In the three sampling areas, the pollution degree of Cd was WC > KF > JD, which might be closely related to the industrial development around the WC area. The Cd concentration in the atmosphere around this industrial area is generally high, and it enters the soil through rainfall or precipitation, resulting in a high Cd concentration in the WC area [4]. The concentrations of availability of Cd, Cr and Pb in soil were 0.05, 10.29 and 2.80 mg/kg, accounting for 10.83%, 32.98% and 10.30% of the corresponding total heavy metals, respectively (Table 5). According to the risk assessment method of element availability state proposed by Valerie (2002), the availability of Cr in the soil in the study area was high, and there was a certain ecological risk, while Cd and Pb were mainly in the combined state, and the bioavailability was low.

**Table 5.** Soil pH and SOM in the study area.

| | pH | | | SOM (mg/kg) | | |
|---|---|---|---|---|---|---|
| | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** |
| JD | 6.02 | 4.29 | 8.52 | $3.11 \times 10^4$ | $1.74 \times 10^4$ | $6.53 \times 10^4$ |
| KF | 5.80 | 3.99 | 7.37 | $3.89 \times 10^4$ | $1.88 \times 10^4$ | $8.06 \times 10^4$ |
| WC | 6.49 | 4.28 | 8.72 | $3.94 \times 10^4$ | $1.90 \times 10^4$ | $7.61 \times 10^4$ |
| Total area | 6.09 | 3.99 | 8.72 | $3.61 \times 10^4$ | $1.74 \times 10^4$ | $8.06 \times 10^4$ |

**Table 6.** Characteristics of soil heavy metal concentrations in the study area.

| | Total | | | Valid State | | |
|---|---|---|---|---|---|---|
| | **Cd** | **Cr** | **Pb** | **Cd** | **Cr** | **Pb** |
| GB 15618-2018 | 0.3 | 150 | 70 | / | / | / |
| Mean (mg/kg) | 0.44 | 35.63 | 32.42 | 0.05 | 10.29 | 2.80 |
| Median (mg/kg) | 0.43 | 31.62 | 30.60 | 0.05 | 9.68 | 2.56 |
| SD (mg/kg) | 0.10 | 14.24 | 11.53 | 0.03 | 3.15 | 1.31 |
| Min (mg/kg) | 0.19 | 11.73 | 12.52 | 0.00 | 5.88 | 0.66 |
| Max (mg/kg) | 0.68 | 88.56 | 58.01 | 0.13 | 21.68 | 7.02 |
| c.v. (%) | 23.50 | 39.97 | 35.56 | 55.31 | 30.66 | 47.11 |

Note: GB 15618-2018, Risk control standard for soil contamination of agricultural land; valid state: the availability concentrations of heavy metal in soil; c.v.: coefficient of variation.

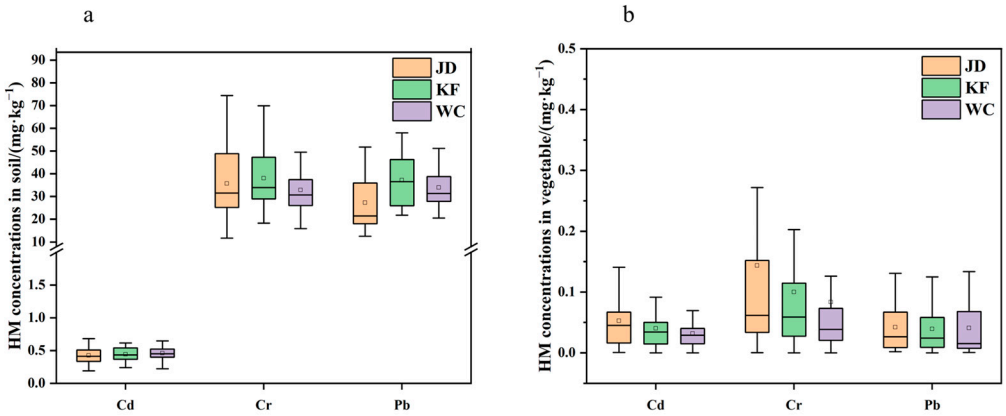



**Figure 2.** Box plot of heavy metal concentrations in vegetable and planting soil. (**a**) Planting soil, (**b**) vegetable. Note: HM, heavy metal.

The coefficient of variation can reflect the spatial dispersion of heavy metal elements. The larger the coefficient of variation, the greater the influence of external factors on the concentrations of heavy metals in soil. It is generally believed that the coefficient of variation is 15–36%, which is considered moderate variation; more than 36% is considered high variation [35]. The coefficients of variation of total Cd, Pb and available Cr in the soil were 23.50%, 35.56% and 30.66%, respectively, considered moderate variation; the rest can be considered high variation (Table 6). This indicates that the concentrations of heavy metal in the soil in the study area fluctuate greatly, and there might be point source pollution, which is closely related to the living environment and lifestyle of residents in the area.

### *3.2. Heavy Metal Concentrations in Vegetables*

Our results show that the average concentrations of Cd, Cr and Pb in leafy vegetables, rootstalk and solanaceous vegetables were 0.043, 0.112 and 0.041 mg/kg, respectively. In the three sampling areas, the concentrations of Cd, Cr and Pb in vegetables were the highest in the JD area (Cd = 0.052, Cr = 0.143, Pb = 0.042 mg/kg), and the Cd concentration of vegetables in the JD area exceeded the national standard (GB15201-94) (Figure 2b). The reason was that the bioavailability of Cd, Cr and Pb in the JD area was the highest among the three sampling areas (Figure 3). We speculated that the bioavailability of the heavy metals in the soil was related to the concentrations of the heavy metals in the vegetables. Table 7 shows that the concentration of Cr in the three categories of vegetables was the highest, which might be due to the high relative concentration and bioavailability of Cr in the soil. The accumulation trend of Cd, Cr and Pb in all kinds of vegetables was as follows: leafy vegetables > rootstalk vegetables > solanaceous vegetables. The difference in Pb among the three types of vegetables was great, and the concentration of Pb in leafy vegetables was more than six times that of solanaceous vegetables. The reason was that leaves accelerated the enrichment of Pb in vegetables through respiration and transpiration, made it easier for dust and industrial waste gas in the air to enter plant. Therefore, as the main pollutant in automobile exhaust, Pb was more likely to be enriched in leafy vegetables [36].

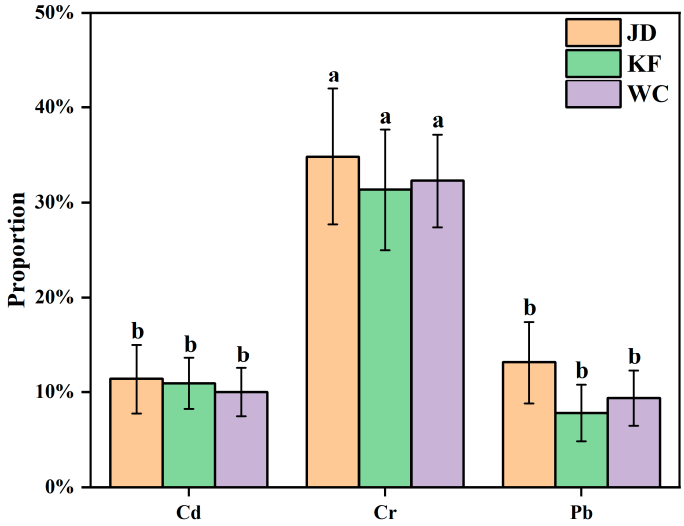



**Figure 3.** The proportions of available state of heavy metal in the soil. Note: Different lowercase letters (a,b) indicate significant difference ($p < 0.05$).

**Table 7.** Statistics of heavy metal concentrations in different vegetable samples.

| Type | Program | Cd | Cr | Pb |
|---|---|---|---|---|
| Leafy vegetables (n = 250) | Mean (mg/kg) | 0.053 | 0.193 | 0.070 |
| | Min (mg/kg) | 0.002 | 0.000 | 0.061 |
| | Max (mg/kg) | 0.155 | 1.633 | 0.216 |
| Rootstalk vegetables (n = 105) | Mean (mg/kg) | 0.043 | 0.103 | 0.043 |
| | Min (mg/kg) | 0.006 | 0.000 | 0.004 |
| | Max (mg/kg) | 0.240 | 0.347 | 0.119 |
| Solanaceous vegetables (n = 230) | Mean (mg/kg) | 0.029 | 0.053 | 0.011 |
| | Min (mg/kg) | 0.000 | 0.000 | 0.000 |
| | Max (mg/kg) | 0.091 | 0.194 | 0.032 |

The accumulation of heavy metals in the soil–vegetable system was further assessed using BCF, and it was found that the average BCF values of heavy metals in all samples collected from the study area was less than 1. However, the BCF of Cd was the highest among the three types of vegetables for a single heavy metal element, indicating that all types of vegetables have strong enrichment capacity for Cd (Figure 4a). Moreover, different vegetables have different enrichment capacities for Cd, in the order leafy vegetables > rootstalk vegetables > solanaceous vegetables, which is consistent with the results of Li et al. [37]. The BCF of Cr and Pb were both low, and the enrichment capacity trend was also leafy vegetables > rootstalk vegetables > solanaceous vegetables. Finally, among the three sampling areas, the heavy metal BCF value of vegetables in the JD area was significantly higher than that in the other areas (Figure 4b). This suggests that regional differences had a crucial impact on the BCF capacity of heavy metals in vegetables, which is consistent with the findings of Mao et al. [38]. Studies have shown that the availability of heavy metals in soils in southern China exceeds 60%, while it is only 30% in northern China [39]. Therefore, the difference in available stage of the heavy metals in the different regions led to the differences in heavy metal BCF in the vegetables.

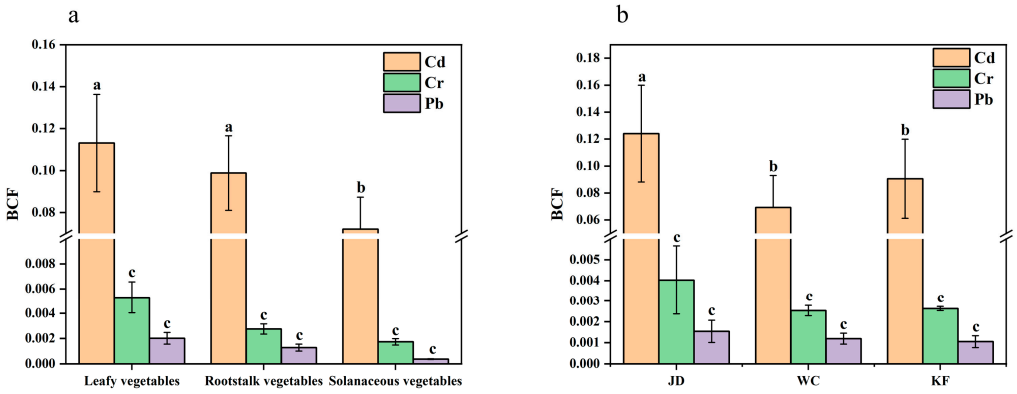



**Figure 4.** BCF of heavy metals in vegetables in Jinhua. (**a**) Different vegetable species; (**b**) different regions. Note: Different lowercase letters (a–c) indicate significant difference ($p < 0.05$).

### *3.3. Correlation Analysis*

As the carrier of vegetable growth, soil can provide various nutrients for vegetables. Therefore, the concentration of heavy metals in vegetables is closely related to the physical and chemical properties of soil and the concentration of heavy metals. As shown in Figure 5, Pb in soil was significantly correlated with Cd and Cr ($p < 0.01$), and Cd was significantly correlated with Cr ($p < 0.05$). Therefore, we speculated that the pollution sources of the three heavy metals in the sampling area of Jinhua City were similar. In general, except Cd, there was no significant correlation between the heavy metal concentration in the vegetables and the corresponding total amount of heavy metal in the soil. However, Cd, Cr and Pb in the vegetables demonstrated a very significant positive correlation with the corresponding availability of heavy metals in soil ($p < 0.01$). This indicates that soil-available heavy

metals were the main source of the heavy metals in the vegetables. Compared with other heavy metals, Cd concentration in the vegetables was significantly correlated with the total amount of soil Cd and the available Cd in soil, which indicates that Cd is more easily absorbed by crops. This is related to the low solid–liquid partition coefficient of Cd in soil, so it is easier for it to enter the soil solution and be absorbed by crops [39]. It was reported that soil pH and SOM were two of the key factors affecting the availability of heavy metals. When soil pH increases, the heavy metal ions in soil form relatively stable forms such as carbonate and phosphate, thereby reducing the availability of heavy metals in the soil. SOM can adsorb heavy metals and reduce the proportion of water-soluble heavy metals to reduce the toxicity of the heavy metals [40]. However, in this study, there was no significant correlation between soil pH and the available state concentration of heavy metals in soil. Although SOM was significantly positively correlated with the total amount of Cd, Cr and Pb in the soil ($p < 0.01$), it had no significant correlation with the available state concentration of each heavy metal, which might be caused by changes in other physicochemical properties of soil during vegetable planting.

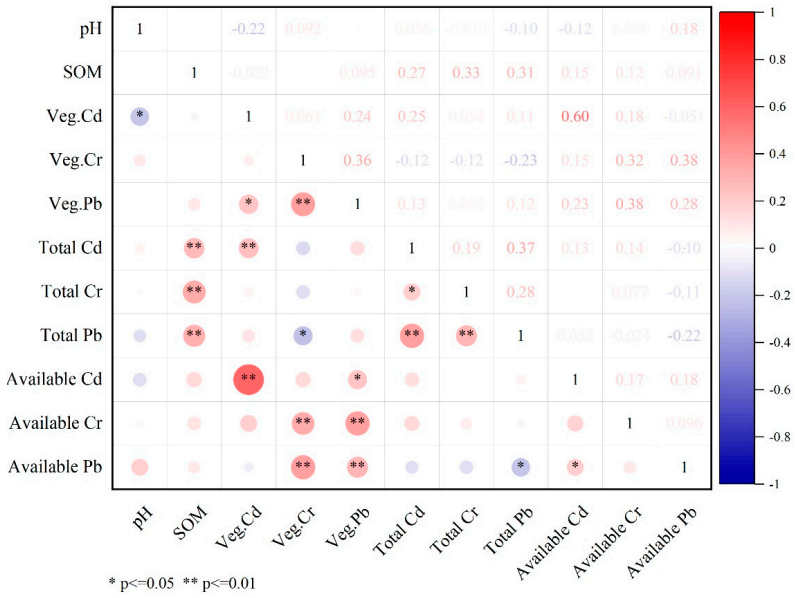



**Figure 5.** Correlation analysis between soil physicochemical properties and heavy metals in vegetables.

### *3.4. Ecological Risk Assessment of Heavy Metals in Soil*

Table 8 shows that the soil around Jinhua City was polluted by Cd, Cr and Pb to varying degrees. The $P_k$ of Cd, Cr and Pb in soil ranged from 0.80–2.49, 0.19–1.46 and 0.29–1.36, respectively. Overall, Cr and Pb were at a clean level, while Cd reached the level of slight pollution, with a pollution rate of 94.9%. It is worth noting that Cd in many soils reached a moderate pollution level. The $P_N$ of the three heavy metals was 1.89, which belonged to the light pollution level. According to $E_k$, the negative impact of Cd on the surrounding ecological environment was moderate ($E_k$ = 48.27), while the impact of Cr and Pb was small. Due to the influence of Cd, RI had a moderate negative impact on the surrounding environment (RI = 53.28). Therefore, the biggest threat of heavy metal pollution in Jinhua vegetable land is Cd, and Cr and Pb pose lower potential ecological risks to the surrounding environment.

**Table 8.** Risk index evaluation of heavy metal pollution in soil.

| Heavy Metal | $P_k$ | $P_N$ | $E_K$ | RI |
|---|---|---|---|---|
| Cd | 1.6 | 1.89 | 48.28 | 53.28 |
| Cr | 0.59 | | 1.18 | |
| Pb | 0.76 | | 3.82 | |

### *3.5. Human Health Risk Assessment*

#### 3.5.1. Non-Carcinogenic Risk

Studies show that when HI > 1, various pollution elements in the environment cause potential non-carcinogenic risks to the human body [41]. The non-carcinogenic health risks caused by the three heavy metals in our study area are shown in Figure 6. For the investigated samples, the contribution rates of the three heavy metals to HI were Cd (46.53%) > Cr (40.75%) > Pb (12.71%). Furthermore, the mean HIs of children and adults were 0.63 and 0.36, respectively. It can be seen that the average value of HI in children was higher than that in adults.

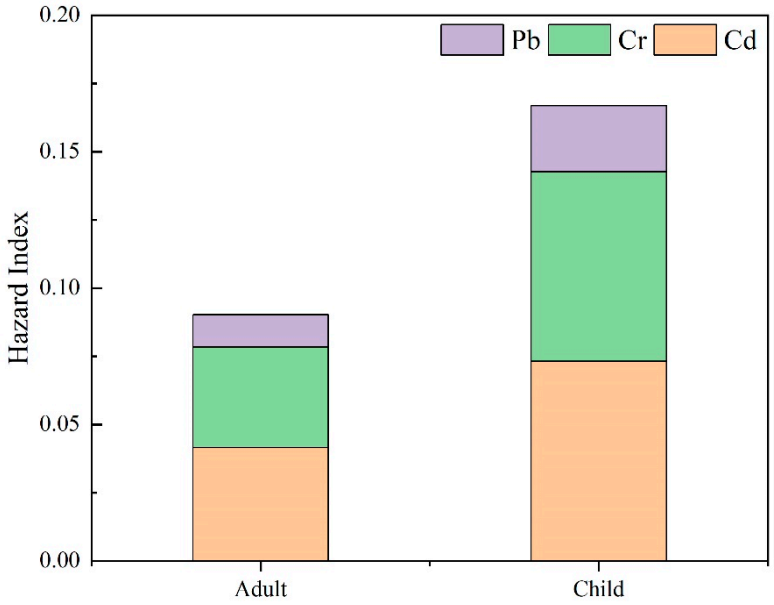



**Figure 6.** Non-carcinogenic risks of heavy metals in vegetables to adults and children.

Although the average HI of children and adults was less than 1 in this study, the impact on human health risks cannot be ignored. Figure 7 shows the specific HI of different vegetables to children was as follows: water spinach (1.20) > spinach (0.85) > pakchoi (0.68) > taro (0.64) > eggplant (0.48) > lettuce (0.44) > tomato (0.28) > pumpkin (0.05). Among them, the HI of children eating water cabbage was >1, which indicates that the accumulation of heavy metals in water spinach causes non-carcinogenic risk to children. Furthermore, our results state $HQ_{Cr}$ = 0.74, which indicates that Cr was the main factor causing the non-carcinogenic risk of water spinach. In addition, leafy vegetables were obviously more likely to pose a non-carcinogenic risk to the human body. Overall, from the perspective of the constituent elements of non-carcinogenic risks caused by various vegetables, Cd and Cr are the main factors that might cause non-carcinogenic risks in vegetables.

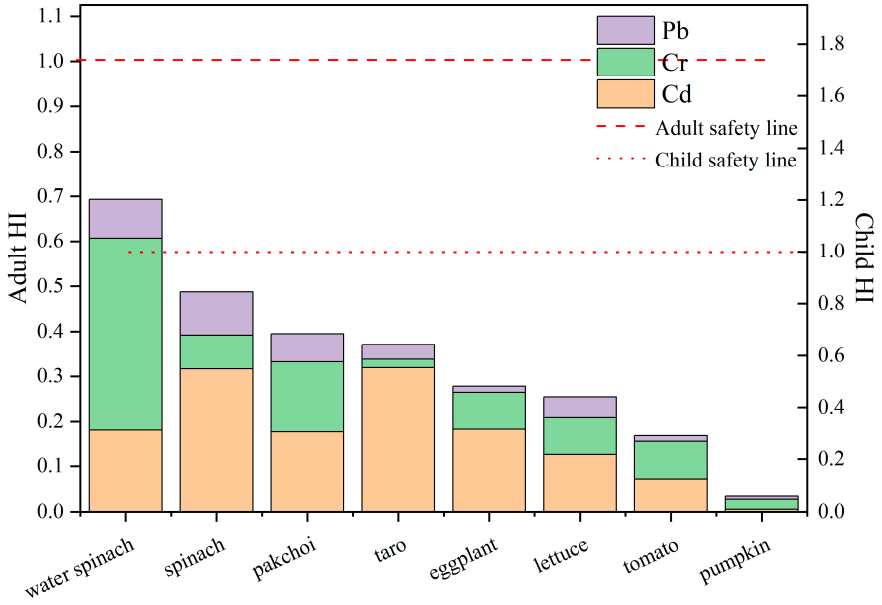



**Figure 7.** Non-carcinogenic risk assessment results of various vegetables.

According to the non-carcinogenic risk assessment results of the four different exposure routes (Table 9), the four exposure modes of ingestion (vegetables), respiratory inhalation, dermal contact, and direct intake (soil) did not cause non-carcinogenic risk to the human body. Overall, the non-carcinogenic risk caused by direct ingestion was the largest, and the health risk caused by respiratory inhalation was the smallest.

**Table 9.** Non-carcinogenic risk assessment results.

| | Adult | | | | Child | | | |
|---|---|---|---|---|---|---|---|---|
| | **Cd** | **Cr** | **Pb** | **HI** | **Cd** | **Cr** | **Pb** | **HI** |
| $HQ_{ingest\text{-}soil}$ | $8.22 \times 10^{-5}$ | $2.21 \times 10^{-3}$ | $1.73 \times 10^{-3}$ | $4.02 \times 10^{-3}$ | $8.13 \times 10^{-4}$ | $2.19 \times 10^{-2}$ | $1.71 \times 10^{-2}$ | $3.98 \times 10^{-2}$ |
| $HQ_{dermal\text{-}soil}$ | $8.34 \times 10^{-7}$ | $2.25 \times 10^{-5}$ | $1.75 \times 10^{-5}$ | $4.08 \times 10^{-5}$ | $1.92 \times 10^{-6}$ | $5.18 \times 10^{-5}$ | $4.04 \times 10^{-5}$ | $9.42 \times 10^{-5}$ |
| $HQ_{inhala\text{-}soil}$ | $8.29 \times 10^{-8}$ | $2.23 \times 10^{-6}$ | $1.74 \times 10^{-6}$ | $4.06 \times 10^{-6}$ | $1.91 \times 10^{-7}$ | $5.15 \times 10^{-6}$ | $4.02 \times 10^{-6}$ | $9.36 \times 10^{-6}$ |
| $HQ_{veg}$ | $1.66 \times 10^{-1}$ | $1.45 \times 10^{-1}$ | $4.54 \times 10^{-2}$ | $3.57 \times 10^{-1}$ | $2.92 \times 10^{-1}$ | $2.56 \times 10^{-5}$ | $7.98 \times 10^{-2}$ | $6.28 \times 10^{-1}$ |
| HQ | $1.66 \times 10^{-1}$ | $1.48 \times 10^{-1}$ | $4.71 \times 10^{-2}$ | $3.61 \times 10^{-1}$ | $2.93 \times 10^{-1}$ | $2.78 \times 10^{-1}$ | $9.69 \times 10^{-2}$ | $6.68 \times 10^{-1}$ |

### 3.5.2. Carcinogenic Risk

In this study, Cd, Cr and Pb were considered to be carcinogenic heavy metals [41]. It is generally believed that when the TCR is greater than $1 \times 10^{-4}$, the vegetable is considered to have potential carcinogenic risk. In the investigated vegetable samples, the mean TCRs for children and adults were $2.19 \times 10^{-4}$ and $5.33 \times 10^{-4}$, respectively (Figure 8). Therefore, both children and adults are at risk of cancer, and adults are at higher risk of carcinogenic effects when eating these vegetables. In addition, the contribution rates of the three heavy metals to TCR were Cd (81.43%) > Cr (17.54%) > Pb (1.08%). It can be seen that Cd was the main factor causing potential carcinogenic risk. Overall, the carcinogenic risk of Cd to adults ($TCR_{Cd} = 4.34 \times 10^{-4}$) and children ($TCR_{Cd} = 1.78 \times 10^{-4}$) was greater than $1 \times 10^{-4}$. This indicates that local residents face the carcinogenic risk caused by Cd at different ages.

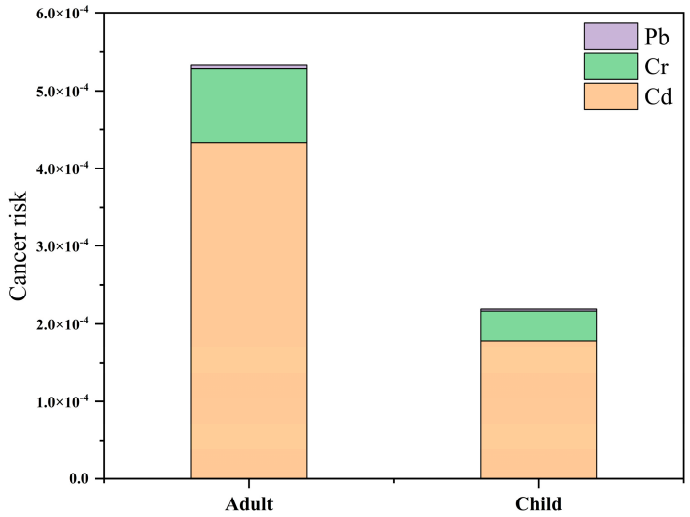



**Figure 8.** Carcinogenic risk of heavy metals in vegetables to adults and children.

The TCR levels of the eight vegetables studied for adults were as follows (Figure 9): spinach ($8.75 \times 10^{-4}$) > taro ($8.39 \times 10^{-4}$) > water spinach ($7.48 \times 10^{-4}$) > pakchoi ($5.63 \times 10^{-4}$) > eggplant ($5.26 \times 10^{-4}$) > lettuce ($3.82 \times 10^{-4}$) > tomato ($2.38 \times 10^{-4}$) > pumpkin ($2.99 \times 10^{-5}$). This result indicates that spinach had the highest cancer risk to adults in the sampling area. In addition, except pumpkin, the $TCR_{Cd}$ of all vegetables to adults was greater than $1 \times 10^{-4}$. Additionally, Cd in taro had the greatest risk of carcinogenicity to adults ($TCR_{Cd} = 8.23 \times 10^{-4}$). It can be seen that most vegetables in this region cause carcinogenic risk to adults through Cd. In addition, according to the analysis of carcinogenic risk of various vegetables to children, except tomato and pumpkin, the carcinogenic risk of other vegetables to children was within the tolerable range. It is worth noting that water spinach can not only cause carcinogenic risk through Cd, but also is the only vegetable that can cause carcinogenic risk through Cr.

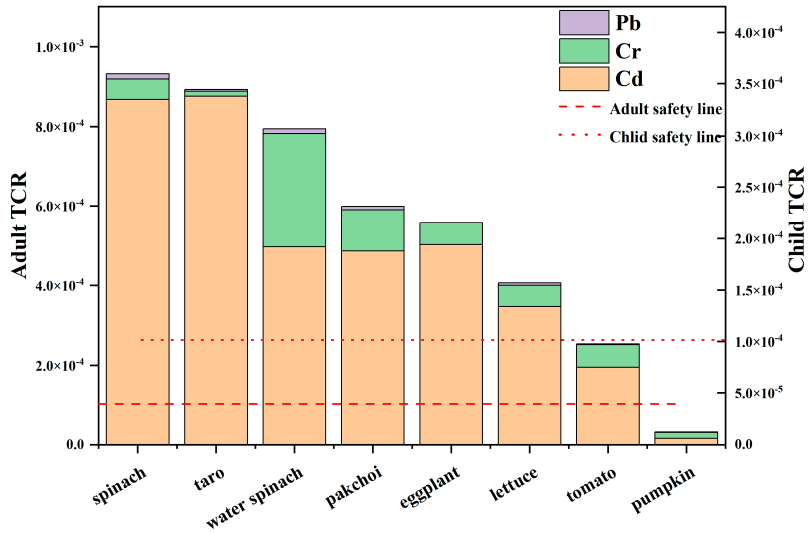



**Figure 9.** Carcinogenic risk assessment results of various vegetables.

As shown in Table 10, among the four carcinogenic risks caused by ingestion, respiratory inhalation, dermal contact, and vegetable intake, CRveg had the highest index and was shown to cause the greatest harm to the human body. However, the carcinogenic risk to the human body caused by ingestion, respiratory inhalation, and dermal contact is far less than $1 \times 10^{-4}$, which is almost negligible. Overall, the TCR in the study area was $5.40 \times 10^{-4}$, therefore causing greater risk of cancer to local residents. In the future,

we should focus on the prevention and control of heavy metal pollution in vegetables in the Jinhua area, reduce the potential carcinogenic risk and take reasonable measures to alleviate the health risks faced by local residents.

**Table 10.** Carcinogenic risk assessment results.

| | Adult | | | | Child | | | |
|---|---|---|---|---|---|---|---|---|
| | **Cd** | **Cr** | **Pb** | **TCR** | **Cd** | **Cr** | **Pb** | **TCR** |
| $CR_{ingest\text{-}soil}$ | $9.21 \times 10^{-7}$ | $6.10 \times 10^{-6}$ | $9.44 \times 10^{-8}$ | $7.12 \times 10^{-6}$ | $4.96 \times 10^{-7}$ | $3.28 \times 10^{-6}$ | $5.08 \times 10^{-8}$ | $3.83 \times 10^{-6}$ |
| $CR_{dermal\text{-}soil}$ | $2.18 \times 10^{-9}$ | $1.44 \times 10^{-8}$ | $2.23 \times 10^{-10}$ | $1.68 \times 10^{-8}$ | $1.17 \times 10^{-9}$ | $7.77 \times 10^{-9}$ | $1.20 \times 10^{-10}$ | $9.07 \times 10^{-9}$ |
| $CR_{inhala\text{-}soil}$ | $2.17 \times 10^{-10}$ | $1.44 \times 10^{-9}$ | $2.22 \times 10^{-11}$ | $1.67 \times 10^{-9}$ | $1.17 \times 10^{-10}$ | $7.73 \times 10^{-10}$ | $1.20 \times 10^{-11}$ | $9.02 \times 10^{-10}$ |
| $CR_{veg}$ | $4.34 \times 10^{-4}$ | $9.35 \times 10^{-5}$ | $5.78 \times 10^{-6}$ | $5.33 \times 10^{-4}$ | $1.78 \times 10^{-4}$ | $3.84 \times 10^{-5}$ | $2.37 \times 10^{-6}$ | $2.19 \times 10^{-4}$ |
| CR | $4.35 \times 10^{-4}$ | $9.96 \times 10^{-5}$ | $5.88 \times 10^{-6}$ | $5.40 \times 10^{-4}$ | $1.79 \times 10^{-4}$ | $4.17 \times 10^{-5}$ | $2.42 \times 10^{-6}$ | $2.23 \times 10^{-4}$ |

## 4. Discussion

On the whole, the concentration of Cd was 1.5 times that of China's Risk Control Standard for Soil Contamination of Agricultural Land (GB 15618-2018), while the concentrations of Cr and Pb were much lower than this standard. This result indicates that the Cd pollution in the sampling area of Jinhua City is serious. Compared with the soil background value of Jinqu Basin reported in 2007, the increase rate of soil Cd concentration in Jinhua City was 60.5%. Jin et al. [42] investigated heavy metal pollution in the farmland soil of Jinhua City and found that there were many characteristic industries such as electronics industries, electromechanical industries and auto parts industries in the JD industrial zone. Simultaneous to industrial development is the inevitable discharge of a lot of waste water, waste gas and so on. Therefore, the Cd pollution of farmland in Jinhua City may be influenced by local industry. Industrial wastes enter the soil through irrigation, infiltration and atmospheric deposition, resulting in heavy metal pollution of the soil. In response to the continuous accumulation of heavy metal pollution, reasonable improvement measures can be made in combination with the geographical structure, production and life of the sampling area. For example, we should improve the recovery rate of heavy metals from industrial waste residues; actively transform our current methods to green agriculture, circular agriculture, and organic agriculture; reduce the harm of heavy metals in soil; and ensure the safety of the people's "vegetable basket".

In addition, the degree of soil Cd pollution in the three sampling areas was in the order of WC > KF > JD. This was the opposite trend to the enrichment concentration of vegetable Cd in each region (JD > KF > WC). It can be seen that there is no direct relationship between Cd pollution of vegetables and soil Cd concentration. However, in this experiment, the trends in the concentrations of Cd, Cr and Pb in the vegetables from each region were completely consistent with the trends of the corresponding availability of heavy metals in each region. Additionally, according to the correlation analysis, we found that the concentrations of Cd, Cr and Pb in the vegetables were significantly positively correlated with the corresponding availability of heavy metals in soil. This shows that the heavy metals in the vegetables mainly came from the availability of heavy metals in the soil. This result is consistent with former research; the higher the availability of heavy metals in the soil, the higher the accumulation of heavy metals in vegetables [43]. In addition, the Cd content in the vegetables was significantly correlated not only with the availability of Cd, but also with the total amount of Cd in the soil. Liu et al. [44] found that, compared with other elements, Cd had a lower partition coefficient in soil colloids and was more inclined to enter the soil solution. Therefore, Cd has higher migration ability and is more easily absorbed and enriched in vegetables.

According to the correlation analysis, there was a very significant positive correlation between SOM and the total concentrations of Cd, Cr and Pb in soil. SOM did not contain heavy metals, and the increase in SOM content did not increase the presence of heavy metals in the soil. However, SOM can affect the cation exchange capacity of soil and further increase the adsorption of heavy metals in soil; it affects the migration and transfor-

mation process of heavy metals, and then affects the accumulation of heavy metals [45]. He et al. [46] found that the adsorption capacity of Cd in soils with high organic matter content was 1.13–1.42 times that of the control group, which is consistent with the results of this study. In addition, SOM can adsorb heavy metal ions through its own functional groups (carboxyl, hydroxyl, carbonyl, etc.), changing the availability of heavy metals in soil. Li et al. [47] concluded that SOM affects the availability of heavy metals through electrostatic adsorption and chelation; there was a very significant positive correlation between SOM and soil available Cd, Zn, Pb and Cu. However, there was no significant correlation between SOM and the availability of Cd, Cr and Pb in soil in this study; perhaps this is due to the higher cation exchange capacity of soil organic matter.

BCF can reflect the enrichment ability of heavy metals in vegetables. Studying the BCFs of different vegetables for different heavy metals could effectively guide the rational utilization of heavy-metal-contaminated soils and prevent heavy metals entering the human body through the food chain. In this experiment, the enrichment capacity of all kinds of vegetables was Cd > Cr > Pb, which may be related to the slight acidity of the soil in the Jinhua area. The slight acidity of soil is favorable for the dissociation of Cd and uptake in plants [48]. Similar findings have been reported by Alexander et al. [49]. In this study, the BCFs of three types of vegetables to Cd, Cr and Pb were as follows: leafy vegetables > rootstalk vegetables > solanaceous vegetables. The reason was that the larger leaf area of the edible part of leafy vegetables provided a greater possibility for particulate matter loaded with heavy metals in the atmosphere to enter the plant; therefore, the health risk of fresh leafy vegetables was greater [50]. According to statistics, 75–90% of heavy metals are adsorbed by inhalable particulate matter and enriched in leafy vegetables through dry and wet sedimentation [51]. In addition, leafy vegetable leaves and other organs have a large amount of evaporation, which is prone to the accumulation of heavy metals. Combined with the results of human health assessment, leafy vegetables caused higher non-carcinogenic factors to the human body than other vegetables, and eating water spinach may cause non-carcinogenic risks in children. Therefore, it is necessary to reduce the probability of heavy metals entering the human body.

In the process of eating vegetables, adults and children face different levels of health risks. In general, children are more likely to suffer from non-carcinogenic risks; in contrast, adults are more susceptible to cancer risk, and these results are consistent with former studies [52]. In our study, leafy vegetables were more likely to cause non-carcinogenic risks to the human body, and these risks were mainly derived from Cd and Cr. The accumulation of heavy metals in water spinach could pose a non-carcinogenic risk to children, to which Cr contributed the most ($HQ_{Cr}$ = 0.74). Studies have shown that Cr pollution not only destroys the composition of the ecosystem, but also damages human skin, the respiratory tract and the gastrointestinal tract [53]. In addition, the non-carcinogenic risk of pumpkin consumption to local residents was relatively low due to the low bioactive factors of heavy metals in pumpkin. Therefore, it is suggested that local children can moderately reduce the intake of water spinach and adjust the proportion of each vegetable in their diet. Moreover, vegetables in the sampling area could cause carcinogenic risks to children and adults, and Cd was the main factor causing carcinogenic risks. The Cd in taro could cause carcinogenic risk to adults as high as $8.23 \times 10^{-4}$, which is far higher than the tolerable carcinogenic risk of the human body. Previous studies have clarified that Cd could induce reactive oxygen species in cells, reduce the activity of antioxidant enzymes and inhibit the repair function of DNA, thereby inducing the incidence of human cancer [54]. Therefore, in view of the correlation between the concentration of heavy metals in vegetables and the availability of heavy metals in soil in this study, the local government should rationally use passivating agents to reduce the availability of Cd in soil so as to reduce the carcinogenic risk of vegetables. In addition to diet, heavy metals in soil can enter the body through other routes, such as ingestion, inhalation and dermal contact by people working in the field. However, the contribution of these three pathways to health risk in this study was small; that being said, their long-term impact on human health cannot be ignored. Heavy metals

in soil migrate into groundwater reserves through rainfall and irrigation, thereby indirectly affecting human health [55]. Therefore, the health risks posed by heavy metal pollution may be more serious than our estimates. Due to competing economic and environmental interests, more research and policies on land-use security should be undertaken to achieve sustainable development.

## 5. Conclusions

(1) The soil in Jinhua sampling area was weakly acidic; the single-factor pollution index shows that the soil pollution in the sampling area was Cd > Pb > Cr. The evaluation results of the Nemerow integrated pollution index show that the soil in the study area was slightly polluted by Cd;

(2) The enrichment ability of heavy metals in vegetables was as follows: leafy vegetables > rootstalk vegetables > solanaceous vegetables. Through the human health risk assessment, it was found that the sampled vegetables could cause different degrees of non-carcinogenic and carcinogenic risks to the human body, and water spinach and spinach contributed the most to health risks. Children are more likely to suffer from non-carcinogenic risks; in contrast, adults are more susceptible to carcinogenic risks. Cd and Cr were the main elements causing non-carcinogenic risk in vegetables, and Cd was the main element causing carcinogenic risk in vegetables;

(3) There was a correlation among Cd, Cr and Pb in the soil, and the sources of the three heavy metals might be similar. The concentrations of Cd, Cr and Pb in the vegetables were correlated with the availability of heavy metals in the corresponding soil, indicating that the heavy metals in vegetables mainly come from the availability of heavy metals in the soil. Appropriate soil remediation should be adopted to reduce the concentration of heavy metals in vegetables.

**Author Contributions:** Conceptualization, Y.M.; data curation, M.W., H.W. and C.Z.; funding acquisition, F.W.; investigation, M.W. and N.G.; software, Y.M.; writing—original draft, Y.M.; writing—review and editing, F.W. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was supported by the Jinhua Science and Technology Project (No. 2020-2-035) and Zhejiang Provincial Natural Science Foundation of China (No. LQ20D010009).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data are contained within the article.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. He, M.; Shen, H.; Li, Z.; Wang, L.; Wang, F.; Zhao, K.; Liu, X.; Wendroth, O.; Xu, J. Ten-year regional monitoring of soil-rice grain contamination by heavy metals with implications for target remediation and food safety. *Environ. Pollut.* **2019**, *244*, 431–439. [CrossRef]
2. Yu, S.; Chen, Z.; Zhao, K.; Ye, Z.; Zhang, L.; Dong, J.; Shao, Y.; Zhang, C.; Fu, W. Spatial Patterns of Potentially Hazardous Metals in Soils of Lin'an City, Southeastern China. *Int. J. Environ. Res. Public. Health* **2019**, *16*, 246. [CrossRef] [PubMed]
3. Huang, Y.; Wang, L.; Wang, W.; Li, T.; He, Z.; Yang, X. Current status of agricultural soil pollution by heavy metals in China: A meta-analysis. *Sci. Total Environ.* **2019**, *651*, 3034–3042. [CrossRef] [PubMed]
4. Yang, Q.; Li, Z.; Lu, X.; Duan, Q.; Huang, L.; Bi, J. A review of soil heavy metal pollution from industrial and agricultural regions in China: Pollution and risk assessment. *Sci. Total Environ.* **2018**, *642*, 690–700. [CrossRef] [PubMed]
5. Jianjun, Z.; Ju, Z.; Renguo, F. Status of China's Heavy Metal Contamination in Soil and Its Remediation Strategy. *Bull. Chin. Acad. Sci.* **2014**, *29*, 315–320+350+272.
6. Luo, C.; Liu, C.; Wang, Y.; Liu, X.; Li, F.; Zhang, G.; Li, X. Heavy metal contamination in soils and vegetables near an e-waste processing site, south China. *J. Hazard. Mater.* **2011**, *186*, 481–490. [CrossRef]
7. Liu, X.; Gu, S.; Yang, S.; Deng, J.; Xu, J. Heavy metals in soil-vegetable system around E-waste site and the health risk assessment. *Sci. Total Environ.* **2021**, *779*, 146438. [CrossRef] [PubMed]

8. Hu, J.; Wu, F.; Wu, S.; Cao, Z.; Lin, X.; Wong, M.H. Bioaccessibility, dietary exposure and human risk assessment of heavy metals from market vegetables in Hong Kong revealed with an in vitro gastrointestinal model. *Chemosphere* **2013**, *91*, 455–461. [CrossRef]
9. Pan, X.; Wu, P.; Jiang, X. Levels and potential health risk of heavy metals in marketed vegetables in Zhejiang, China. *Sci. Rep.* **2016**, *6*, 20317. [CrossRef]
10. Gupta, N.; Khan, D.K.; Santra, S.C. An assessment of heavy metal contamination in vegetables grown in wastewater-irrigated areas of Titagarh, West Bengal, India. *Bull. Environ. Contam. Toxicol.* **2008**, *80*, 115–118. [CrossRef]
11. Hoaghia, M.-A.; Cadar, O.; Moisa, C.; Roman, C.; Kovacs, E. Heavy metals and health risk assessment in vegetables grown in the vicinity of a former non-metallic facility located in Romania. *Environ. Sci. Pollut. Res.* **2022**, *29*, 40079–40093. [CrossRef]
12. Hu, Y.; Wang, C.; Song, Z.; Chen, M.; Ding, L.; Liang, X.; Bi, X.; Li, Z.; Li, P.; Zheng, W. Heavy Metal in Rice and Vegetable and Human Exposure near a Large Pb/Zn Smelter in Central China. *Int. J. Environ. Res. Public. Health* **2021**, *18*, 12631. [CrossRef]
13. Ye, X.; Xiao, W.; Zhang, Y.; Zhao, S.; Wang, G.; Zhang, Q.; Wang, Q. Assessment of heavy metal pollution in vegetables and relationships with soil heavy metal distribution in Zhejiang province, China. *Environ. Monit. Assess.* **2015**, *187*, 378. [CrossRef] [PubMed]
14. Kim, S.O.; Moon, S.H.; Kim, K.W. Removal of Heavy Metals from Soils using Enhanced Electrokinetic Soil Processing. *Water Air Soil Pollut.* **2001**, *125*, 259–272. [CrossRef]
15. Zhang, Y.; Man, R.L.; Ni, W.D.; Wang, H. Selective leaching of base metals from copper smelter slag. *Hydrometallurgy* **2010**, *103*, 25–29. [CrossRef]
16. Liu, G.; Meng, J.; Huang, Y.; Dai, Z.; Tang, C.; Xu, J. Effects of carbide slag, lodestone and biochar on the immobilization, plant uptake and translocation of As and Cd in a contaminated paddy soil. *Environ. Pollut.* **2020**, *266*, 115194. [CrossRef]
17. Deng, Y.; Wang, L.; Luo, K.; Peng, D.; Jiang, H.; Jin, C.; Zhou, X.; Bai, L. Screening and Identifying a Cadmium-resistant Fungus and Characterizing its Cadmium Adsorption. *Pol. J. Environ. Stud.* **2017**, *26*, 1011–1021. [CrossRef]
18. Lin, X.; Mou, R.; Cao, Z.; Xu, P.; Wu, X.; Zhu, Z.; Chen, M. Characterization of cadmium-resistant bacteria and their potential for reducing accumulation of cadmium in rice grains. *Sci. Total Environ.* **2016**, *569*, 97–104. [CrossRef]
19. Singh, N.; Marwa, N.; Mishra, S.K.; Mishra, J.; Verma, P.C.; Rathaur, S.; Singh, N. *Brevundimonas diminuta* mediated alleviation of arsenic toxicity and plant growth promotion in *Oryza sativa* L. *Ecotoxicol. Environ. Saf.* **2016**, *125*, 25–34. [CrossRef]
20. Bartholomew, C.J.; Li, N.; Li, Y.; Dai, W.; Nibagwire, D.; Guo, T. Characteristics and health risk assessment of heavy metals in street dust for children in Jinhua, China. *Environ. Sci. Pollut. Res.* **2020**, *27*, 5042–5055. [CrossRef]
21. Hu, K.; Jia, J.; Hu, Z.; Yang, L.; Fan, Y.; Zhang, X. New insight into the temperature dependence of pedogenic magnetic susceptibility in humid climate region. *Quat. Sci.* **2022**, *42*, 461–471.
22. Massas, I.; Kalivas, D.; Ehaliotis, C.; Gasparatos, D. Total and available heavy metal concentrations in soils of the Thriassio plain (Greece) and assessment of soil pollution indexes. *Environ. Monit. Assess.* **2013**, *185*, 6751–6766. [CrossRef]
23. Suleiman, J.S.; Hu, B.; Huang, C.; Zhang, N. Determination of Cd, Co, Ni and Pb in biological samples by microcolumn packed with black stone (Pierre noire) online coupled with ICP-OES. *J. Hazard. Mater.* **2008**, *157*, 410–417. [CrossRef]
24. Islam, M.S.; Ahmed, M.K.; Raknuzzaman, M.; Habibullah-Al-Mamun, M.; Kundu, G.K. Heavy metals in the industrial sludge and their ecological risk: A case study for a developing country. *J. Geochem. Explor.* **2017**, *172*, 41–49. [CrossRef]
25. Ripin, S.; Hasan, S.; Kamal, M.L.; Hashim, N.M. Analysis and pollution assessment of heavy metal in soil, Perlis. *Malays. J. Anal. Sci.* **2014**, *18*, 155–161.
26. Zheng, N.; Liu, J.; Wang, Q.; Liang, Z. Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. *Sci. Total Environ.* **2010**, *408*, 726–733. [CrossRef]
27. Solomon, K.R.; Giesy, J.P.; LaPoint, T.W.; Giddings, J.M.; Richards, R.P. Ecological risk assessment of atrazine in North American surface waters. *Environ. Toxicol. Chem.* **2013**, *32*, 10–11. [CrossRef] [PubMed]
28. Zhao, B.; Xu, X.; Liu, W.; Zhang, R.; Cui, M.; Liu, J.; Zhang, W. The evaluation of immobilization behavior and potential ecological risk of heavy metals in bio-char with different alkaline activation. *Environ. Sci. Pollut. Res.* **2021**, *28*, 21396–21410. [CrossRef] [PubMed]
29. Parven, S.; De, A.; Gupta, A. Cu and Pb accumulation and removal from aqueous medium by *Enydra fluctuans* Lour. (Asteraceae)—A medicinal plant with potential for phytoremediation. *Environ. Sci. Pollut. Res.* **2022**, *29*, 66902–66912. [CrossRef]
30. Moya, J.; Phillips, L. Overview of the use of the U.S. EPA exposure factors handbook. *Int. J. Hyg. Environ. Health* **2002**, *205*, 155–159. [CrossRef]
31. Liu, X.; Song, Q.; Tang, Y.; Li, W.; Xu, J.; Wu, J.; Wang, F.; Brookes, P.C. Human health risk assessment of heavy metals in soil-vegetable system: A multi-medium analysis. *Sci. Total Environ.* **2013**, *463*, 530–540. [CrossRef] [PubMed]
32. Li, Z.; Ma, Z.; van der Kuijp, T.J.; Yuan, Z.; Huang, L. A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. *Sci. Total Environ.* **2014**, *468*, 843–853. [CrossRef] [PubMed]
33. Fakhri, Y.; Bjorklund, G.; Bandpei, A.M.; Chirumbolo, S.; Keramati, H.; Pouya, R.H.; Asadi, A.; Arnanidaz, N.; Sarafraz, M.; Sheikhmohammad, A.; et al. Concentrations of arsenic and lead in rice (*Oryza sativa* L.) in Iran: A systematic review and carcinogenic risk assessment. *Food Chem. Toxicol.* **2018**, *113*, 267–277. [CrossRef]
34. Fan, W.; Zhou, J.; Zhou, Y.; Wang, S.; Du, J.; Chen, Y.; Zeng, Y.; Wei, X. Heavy metal pollution and health risk assessment of agricultural land in the Southern Margin of Tarim Basin in Xinjiang, China. *Int. J. Environ. Health Res.* **2021**, *31*, 835–847. [CrossRef] [PubMed]

35. Yan, P.; Lin, K.; Wang, Y.; Zheng, Y.; Gao, X.; Tu, X.; Bai, C. Spatial interpolation of red bed soil moisture in Nanxiong basin, South China. *J. Contam. Hydrol.* **2021**, *242*, 103860. [CrossRef]
36. Chen, F.; Ma, J.; Khan, Z.I.; Ahmad, K.; Ahmad, T.; Malik, I.S.; Ashfaq, A.; Munir, M.; Nazar, S.; Munir, Z.; et al. Evaluation of transfer of lead in soil plant animal system: Assessment of consequences of its toxicity. *Environ. Sci. Pollut. Res.* **2021**, *28*, 38698–38705. [CrossRef]
37. Li, D.; Wang, J.; Xuan, B.; Cai, X.; Zhao, S. Heavy metals pollution and health risk evaluation of vegetables in southern suburbs of Guiyang, China. *Environ. Pollut. Control* **2019**, *41*, 1362–1367+1373. [CrossRef]
38. Mao, C.P.; Song, Y.X.; Chen, L.X.; Ji, J.F.; Li, J.Z.; Yuan, X.Y.; Yang, Z.F.; Ayoko, G.A.; Frost, R.L.; Theiss, F. Human health risks of heavy metals in paddy rice based on transfer characteristics of heavy metals from soil to rice. *Catena* **2019**, *175*, 339–348. [CrossRef]
39. Kong, X.; Liu, T.; Yu, Z.; Chen, Z.; Lei, D.; Wang, Z.; Zhang, H.; Li, Q.; Zhang, S. Heavy Metal Bioaccumulation in Rice from a High Geological Background Area in Guizhou Province, China. *Int. J. Environ. Res. Public. Health* **2018**, *15*, 2281. [CrossRef]
40. Loganathan, P.; Vigneswaran, S.; Kandasamy, J.; Naidu, R. Cadmium Sorption and Desorption in Soils: A Review. *Crit. Rev. Environ. Sci. Technol.* **2012**, *42*, 489–533. [CrossRef]
41. Guo, G.; Zhang, D.; Wang, Y. Probabilistic Human Health Risk Assessment of Heavy Metal Intake via Vegetable Consumption around Pb/Zn Smelters in Southwest China. *Int. J. Environ. Res. Public. Health* **2019**, *16*, 3267. [CrossRef]
42. Jin, G.; Fu, L.; Huang, Q.; Fang, W.; Xu, Y.; Xu, Y.; Ma, J.; Ma, R.; Ma, J.; Ye, Z.; et al. Analysis on the Occurrence Form and Pollution Assessment of Heavy Metals in Farmland Soil—A Case Study of Farmland in Zhejiang Province. *J. Green Sci. Technol.* **2019**, *24*, 74–78. [CrossRef]
43. Fairbrother, A.; Wenstel, R.; Sappington, K.; Wood, W. Framework for metals risk assessment. *Ecotoxicol. Environ. Saf.* **2007**, *68*, 145–227. [CrossRef] [PubMed]
44. Liu, Y.; Xiao, T.; Xiong, Y.; Ning, Z.; Shuang, Y.; Li, H.; Ma, L.; Chen, H. Accumulation of Heavy Metals in Agricultural Soils and Crops from an Area with a High Geochemical Background of Cadmium, Southwestern China. *Environ. Sci.* **2019**, *40*, 2877–2884. [CrossRef]
45. Nam, S.; Alday, J.G.; Kim, M.; Kim, H.; Kim, Y.; Park, T.; Lim, H.S.; Lee, B.Y.; Lee, Y.K.; Jung, J.Y. The relationships of present vegetation, bacteria, and soil properties with soil organic matter characteristics in moist acidic tundra in Alaska. *Sci. Total Environ.* **2021**, *772*, 145386. [CrossRef] [PubMed]
46. He, T.; Dong, L.; Liu, Y.; Shu, Y.; Luo, H.; Liu, F. Change of Physical-Chemical Properties and Heavy Mental Element in Soil from Different Parent Material/Rock. *J. Soil Water Conserv.* **2006**, *6*, 157–162. [CrossRef]
47. Li, Z.; Zhang, C.; Deng, C.; Gu, M.; Li, L.; Liu, M. Analysis on spatial distribution of soil available heavy metals and its influential factors in a lead-zinc mining area of Guangxi, China. *Ecol. Environ. Sci.* **2009**, *18*, 1772–1776. [CrossRef]
48. Huang, R.; Dong, M.; Mao, P.; Zhuang, P.; Paz-Ferreiro, J.; Li, Y.; Li, Y.; Hu, X.; Netherway, P.; Li, Z. Evaluation of phytoremediation potential of five Cd (hyper)accumulators in two Cd contaminated soils. *Sci. Total Environ.* **2020**, *721*, 137581. [CrossRef]
49. Alexander, P.D.; Alloway, B.J.; Dourado, A.M. Genotypic variations in the accumulation of Cd, Cu, Pb and Zn exhibited by six commonly grown vegetables. *Environ. Pollut.* **2006**, *144*, 736–745. [CrossRef] [PubMed]
50. Schreck, E.; Dappe, V.; Sarret, G.; Sobanska, S.; Nowak, D.; Nowak, J.; Stefaniak, E.A.; Magnin, V.; Ranieri, V.; Dumat, C. Foliar or root exposures to smelter particles: Consequences for lead compartmentalization and speciation in plant leaves. *Sci. Total Environ.* **2014**, *476*, 667–676. [CrossRef]
51. Kong, S.; Lu, B.; Ji, Y.; Zhao, X.; Bai, Z.; Xu, Y.; Liu, Y.; Jiang, H. Risk assessment of heavy metals in road and soil dusts within PM2.5, PM10 and PM100 fractions in Dongying city, Shandong Province, China. *J. Environ. Monit.* **2012**, *14*, 791–803. [CrossRef]
52. Li, X.Y.; Li, Z.G.; Lin, C.J.; Bi, X.Y.; Liu, J.L.; Feng, X.; Zhang, H.; Chen, J.; Wu, T.T. Health risks of heavy metal exposure through vegetable consumption near a large-scale Pb/Zn smelter in central China. *Ecotoxicol. Environ. Saf.* **2018**, *161*, 99–110. [CrossRef] [PubMed]
53. Shahid, M.; Shamshad, S.; Rafiq, M.; Khalid, S.; Bibi, I.; Niazi, N.K.; Dumat, C.; Rashid, M.I. Chromium speciation, bioavailability, uptake, toxicity and detoxification in soil-plant system: A review. *Chemosphere* **2017**, *178*, 513–533. [CrossRef] [PubMed]
54. Laboni, F.A.; Ahmed, M.W.; Kaium, A.; Alam, M.K.; Parven, A.; Jubayer, M.F.; Rahman, M.A.; Meftaul, I.M.; Khan, M.S.I. Heavy Metals in Widely Consumed Vegetables Grown in Industrial Areas of Bangladesh: A Potential Human Health Hazard. *Biol. Trace Elem. Res.* **2022**, *201*, 995–1005. [CrossRef] [PubMed]
55. Chen, G.; Zeng, G.; Du, C.; Huang, D.; Tang, L.; Wang, L.; Shen, G. Transfer of heavy metals from compost to red soil and groundwater under simulated rainfall conditions. *J. Hazard. Mater.* **2010**, *181*, 211–216. [CrossRef] [PubMed]


**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.