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Research Article

Potentially Toxic Elements and Health Risk Assessment in Farmland Systems around High-Concentrated Arsenic Coal Mining in Xingren, China

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The health risk of potentially toxic elements (PTEs) via contamination of the food chain has attracted widespread concern. The aim of this study is to evaluate the effects of PTEs in environment and human body (fingernail, hair, and blood) of people living in agricultural soil near arsenic coal mining areas in Xingren County (Guizhou, southwest China). 89 crop samples which included vegetables, rice, maize, and coix seed and their corresponding soils and 17 local surface water and biological tissue samples (41×3) in near arsenic coal mining areas were collected, and the concentrations of potentially toxic elements (As, Cd, Cu, Cr, and Pb) in all the samples were determined. The health risk assessment methods developed by the United States Environmental Protection Agency were employed to explore the potential health hazards of PTEs in soils growing crops. Results showed that 4 toxic elements, Cd, Cu, As, and Cr, were found to have different degrees of contamination in soils in the studied area. The total concentration of toxic elements (As, Cr, Cu, and Pb) in fingernail, hair, and blood samples were 90.50, 69.31, and 6.90 $mg \cdot kg^{-1}$, respectively. Fingernail samples from females were more likely to show exposure to trace metals compared to males. As the age of the subject increased, the concentration of As also increased in all three biological samples. The risk assessment for the mean hazard index value from the consumption of local food crops was 14.81, indicating that consumers may experience adverse, noncarcinogenic health effects. The estimated mean total cancer risk value of was 5.3×10^{-3}, which was approximately 10 to 1000 times higher than the acceptable range of 10^{-6}–10^{-4}, indicating serious carcinogenic risks for local people consuming crops from the area. This study provides evidence that local residents in this study area may be at a high risk of disease caused from toxic element exposure.

1. Introduction

Although coal mining creates economic benefits, it can also result in significant contamination to the environment [1]. With the exploitation of coal, a variety of underlying toxic elements can be released into the environment, which is found in the soil and water in the mining area, resulting in damage to plants and disease in humans and animals [2]. Most heavy metals accumulate in the food chain through the ingestion of food crop, which can endanger human health. Heavy metals at high concentrations in food and crops are of great concern due to their toxicity to humans and animals [3]. In addition, potentially toxic elements (PTEs) can be identified in many parts of the body (e.g., bone, nails, blood, and hair) and then excreted through faeces [4].

Potentially toxic elements present an environmental hazard within the vicinity of coal mining. The metals' uptake by vegetation is dependent on the soil characteristics, including chemical and physical characteristics, as well the species of vegetation grown [5]. The ingestion of harmful elements, such as As, Cd, Cr, Cu, and Pb, can seriously cause the depletion of certain essential nutrients in humans, which in turn causes deficiencies in the immune system, psychosocial dysfunction, malnutrition resulting from imbalanced diets, and an increase in the incidence of upper gastrointestinal cancer [6]. Moreover, the incidence of cancer in general has been linked with an excessive intake of heavy metals (Cd, Cu, and Pb).

Several methods have been established to evaluate the potential health risks of pollutants, which are divided into carcinogenic and noncarcinogenic effects [7]. Khan took the methods of potential health risks to assess the metal uptake by food crops and the potential health risks associated with human consumption of food crops contaminated with heavy metals [8]. To ensure food safety, it is important to understand the level of contamination of PTEs found in vegetables and grains grown in the mining area [9]. In addition, to ameliorate the soil environment, it is necessary to identify the contamination characteristics of trace metals in soils and to understand the risk of exposure to these trace metals. Identifying their sources is needed for the prevention and control of soil pollution in mining areas [10]. Blood, fingernail, and scalp hair samples are used as biomarkers of polluting PTEs due to their accessibility and ease of transport for laboratory analysis [11–13].

Our study focuses on assessing the potential health risks of PTEs exposure to multiple targets in the environment (local surface water, soil, and crops) and examining biological indicators in humans for assessing multiple exposures to metals in the local population of Xingren, Guizhou. Particular emphasis is placed on the determination of heavy metals in blood, fingernail, and scalp hair samples and the comparison and assessment of the potential health risks of heavy metal exposure across multiple sites in the mining area. This data could be used to control the environmental hazards to human health in the mining area [14]. The primary objectives of this research were to (1) understand the content of PTE in nearby agricultural soils and corresponding vegetable, grain, and water samples around coal mining in the Xingren County, which is the primary food source for the local people; (2) explore the exposure levels of trace elements found in the blood, fingernails, and scalp hair of local residents; (3) evaluate the level of PTEs in the fingernail, hair, and blood samples with respect to age and gender; and (4) analyze the potential health risks to humans and their impact on the health of the local inhabitants.

2. Materials and Methods

2.1. Study Area. This study was carried out in Xingren (104°54′33″E-105°33′46″E, 25°15′49″N-25°46′58″N), a typical county located in Qianxi Prefecture in central Guizhou Province (China). In the 1980s and 1990s, a large number of coal mining activities were carried out in this area. The coal reserves exceeded 45 million tonnes, and the coal mining activities in Xingren contaminated the soil. A large number of abandoned mines, mine and coal gangue reactors, leaching from rain, and the discharge of acidic wastewater have caused harmful substances to be deposited in the surrounding environment. The soils in this area are primarily loess and dark brown soils. The food crops cultivated in the area are primarily rice, maize, coix seed, and vegetables.

2.2. Sampling and Analysis. A total of 89 soil samples and corresponding crop samples (edible parts only), including 22 rice (*Oryza sativa*), 21 maize (*Zea mays*), 24 Coix Seed (*Semen Coicis*), 22 vegetables samples (*Viciafaba, Brassica oleracea, Alliumfistulosum, Brassica oleracea and Lactuca sativa*), and 17 surface water samples, were collected in October 2015 from Xingren, Guizhou [15]. Water samples were collected from a stream or spring near the village in polyethylene bottles. Samples were acidified to a pH of 2 using HNO_3 transported to the laboratory.

Each fresh soil sample was approximately 1 kg in dry weight and was a composite of 3 subsamples from nearby sites, taken at a depth of 0 to 20 cm in and around paddy fields, maize, coix seed, and vegetable cultivation areas. After sampling, the crop and soil samples were sealed in polyethylene bags and transported to the laboratory. The soil samples were dried, ground, passed through a100 mesh sieve [16], and digested in a mixture of HNO_3, $HClO_4$, and HF to measure the total content of Cd, Cu, Cr, and Pb and digested with 50% aqua regia ($HNO_3 : HCl = 1 : 3$) to determine the total concentration of As [17].

The crop samples were first washed with tap water and then with distilled water, cut into small pieces with a plastic knife, dried in an oven at 50°C, and finally powdered in a grinder to be conserved in polyethylene bags [15]. Crop, dried hair, and fingernail samples (0.5 g) were placed in Teflon tubes. Six mL of HNO_3 and then 2 mL hydrogen peroxide (H_2O_2) were added and left to digest overnight. One mL blood samples were placed in Teflon tubes, and 8 mL of HNO_3 was added. The following day, all samples were digested in a microwave-assisted reaction system (CEM MARs 6, NC, USA) [16].

A questionnaire based on analysis was collected about gender, age, and living habits for local residents during the sampling period. We had collected and analyzed biological tissue samples (41×3) from local residents. The blood, fingernail, and hair samples of the residents of the coal mining areas were assessed to determine the current status of PTE exposure. The ages and gender of each resident were recorded during sampling. The young generation was out to work early, resulting in little research on children or young people. The concentrations of trace elements in the blood, fingernail, and hair samples taken from residents in the mining areas were divided into 3 age groups, 15–30, 31–50, and ≥50 years (Table 1). Hair and fingernail were taken by using stainless scissors and kept in zip-lock polyethylene bags. Venous blood sample was taken from each subject, mixed in anticoagulant tube, stored at 4°C for transportation and frozen preservation.

Soil pH was measured in using a 1 : 2.5 soil-to-water ratio with a pH meter (PHS-3C, Shanghai INESA Scientific Instrument Co., China). Levels of heavy metals (Cd, Cr, Cu, and Pb) in the soil, crops, water, fingernail, blood, and hair samples were measured using atomic absorption spectrometry (ZEEnit700P, Analytikjena, Germany) and As was determined using atomic fluorescence spectrometry (AFS-933, Beijing Titan, China).

2.3. Quality Control Analysis. The reagents used in these studies were of guaranteed or analytical grade, and experimental

Table 1: The numbers of males and females in each age group.

Ages (years)	Females	Males
15–30	$n = 2$	$n = 2$
31–50	$n = 10$	$n = 11$
≥50	$n = 10$	$n = 6$

water was ultrapure water (18.2 MΩ·cm). The laboratory analysis process used the national standard reference materials (GBW-07456 (soil), GBW-07409 (soil), GBW07603 (plant)), a reagent blank, and 20% duplicate samples, to control quality. Precision, which was ascertained by replicate analysis, was less than 5% relative standard deviation (RSD). In addition, accuracy expressed as recovery of the reference material was 96.31–105.27% for all metals, and the determination of results of all samples were in the range of the accepted error [18]. The method detection limits in soil samples were 0.01, 0.003, 0.001, 0.002, and 0.004 $mg\cdot kg^{-1}$, respectively, for, As, Cd, Cr, Cu, and Pb; the method detection limits in plant, fingernail, blood and hair samples were 0.004, 0.001, 0.0003, 0.001, 0.002 $mg\cdot kg^{-1}$ for As, Cd, Cr, Cu, and Pb; the method detection limits in water samples were 0.039, 0.013, 0.003, 0.006, and 0.018 $mg\cdot L^{-1}$.

2.4. Health Risk Assessment

2.4.1. Noncarcinogenic Effects. The target hazard quotient (THQ) and hazard index (HI) were used to determine the noncarcinogenic health risks caused by the consumption of vegetables by local people. The measure was provided by USEPA (2005) [19]. THQ is expressed as the ratio of the defined dose of a contaminant to a reference dose. The THQ can be calculated using the following equation:

$$\mathrm{THQ} = \frac{C_{\mathrm{crop}} \times D_{\mathrm{food\ intake}} \times \mathrm{EF} \times \mathrm{ED}}{B_{\mathrm{W}} \times \mathrm{AT} \times \mathrm{RfD}}, \tag{1}$$

where C_{crop} is the heavy metal concentration in crops ($mg\cdot kg^{-1}$); EF is the exposure frequency (365 days/year); ED is the average exposure duration (70 years); AT is the average time (365 × ED days); and RfD is the daily intake of metals and oral reference dose (mg/kg/day). The oral reference doses are 0.0010, 1.5000, 0.0400, 0.0003, and 0.0035 $mg\cdot kg^{-1}$/day for Cd, Cr, Cu, As, and Pb (USEPA, 2005) [19]. BW is the average body weight (70 kg); $D_{\mathrm{food\ intake}}$ is the crop average daily intake rate for rural inhabitants: 0.25 kg of rice, 0.34 kg of vegetables, 0.15 kg of maize, and 0.20 kg of coix seed per day per person [8].

$$\begin{aligned} \mathrm{TTHQ}(\mathrm{crop}) &= \sum \mathrm{THQ}_{\mathrm{M}} \\ &= \mathrm{THQ}_{\mathrm{M1}} + \mathrm{THQ}_{\mathrm{M2}} + \cdots + \mathrm{THQ}_{\mathrm{M}n}, \\ \mathrm{HI} &= \sum \mathrm{TTHQ}. \end{aligned} \tag{2}$$

TTHQ indicates the total of crop THQ for an individual crop of selected elements using the equation above. For assessing the overall potential of noncarcinogenic risks across more than one crop, a hazard index (HI) was calculated based on the Guidelines for Health Risk assessment of Chemical Mixtures of USEPA [19]. When the HI value was smaller than 1, it is assumed the exposed population is considered to be not at risk, and levels of contaminants are acceptable. When the HI value is greater than 1, it indicates that the risk of noncarcinogenic disease may occur and measures should be taken.

2.4.2. Cancer Risk Assessment. Carcinogenic risks to humans associated with crop consumption can be assessed as a cancer risk (CR). CR was determined using following equation:

$$\begin{aligned} \mathrm{CR} &= \frac{C_{\mathrm{crop}} \times D_{\mathrm{food\ intake}} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{SF}}{B_{\mathrm{W}} \times \mathrm{AT}}, \\ \mathrm{TCR} &= \mathrm{CR}_{\mathrm{M1}} + \mathrm{CR}_{\mathrm{M2}} + \cdots + \mathrm{CR}_{\mathrm{M}n}, \\ \mathrm{TTCR} &= \sum \mathrm{TCR}. \end{aligned} \tag{3}$$

where cancer risk represents the probability of a person's risk from carcinogens over their lifetime. C_{crop} is the heavy metal concentration in crops, and SF is the cancer slope factor of hazardous substances (mg/day/kg), and the cancer slope factors are 0.3800, 1.5000, and 0.0085 mg/kg/day for Cd, As, and Pb, respectively (USEPA, 2010) [20]. The regulation acceptable risk threshold is within the range of 10^{-6}–10^{-4} [21]; $\mathrm{CR} < 1 \times 10^{-6}$ is assumed to be negligible risk, while $\mathrm{CR} > 1 \times 10^{-4}$ is not acceptable cancer risk (USEPA, 2005; FAO/WHO, 2001) [19, 22]. TTCR indicates the total of crop TCR for individual crops of selected elements using the equation. For assessing the overall carcinogenic risk from more than one crop, TTCR has been calculated based on the sum of individual crop TCRs.

2.5. Data Analysis. The data were processed, analyzed, and plotted using Excel (2013), SPSS (19.0), and Origin 8.5, respectively.

3. Results and Discussion

3.1. Concentration of PTEs in Soils. The pH range of soil samples is 3.95–6.37 which may be related to the acidification of the surface soil of the mine surrounding the acid mine drainage produced by the mining process. The range of TOC is 13.47–52.36 $g\cdot kg^{-1}$, and the average value is 26.33 $g\cdot kg^{-1}$. There is a lot of focus on PTE levels in farmland soil. Statistics on soil samples containing 5 kinds of PTEs are illustrated in Figure 1. The mean concentration of As, Cd, Cr, Cu, and Pb in soil-cultivating vegetables was lower than paddy soil, maize soils, and coix seed soils. The mean concentrations of the heavy metal elements (As, Cd, Cr, Cu, and Pb) in paddy soils were 0.78, 147.40, 119.03, 183.11, and 188.73 $mg\cdot kg^{-1}$, respectively. The average values of Pb and Cr were not more than the maximum acceptable concentrations (MAC, level II) as outlined by the Environmental Quality Standard for Soils in China (GB15618-2008) [23]. Average values for As, Cd, Cr and Cu were more than twice the accepted national level in maize soil and coix seed soils. Mean concentrations of heavy metal elements (Cd, Cu, As, Pb, and Cr) in vegetable soils were 0.05, 99.57, 84.00, 19.90, and 20.05 $mg\cdot kg^{-1}$, respectively. Pb, Cr, and Cd did not exceed the standard accepted levels.

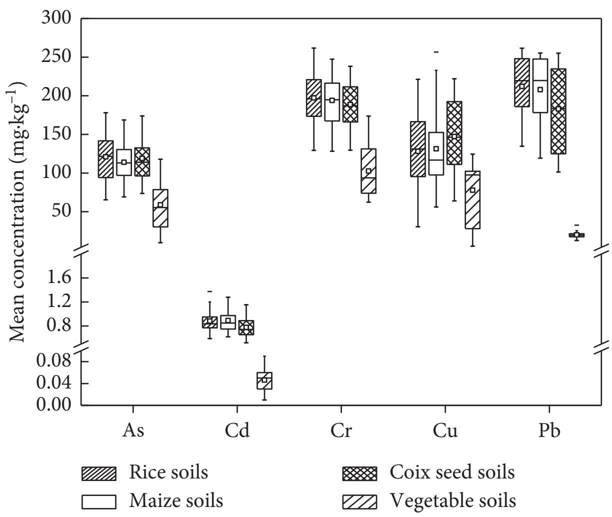


Figure 1: Box-plots of concentrations of As, Cd, Cr, Cu, and Pb ($mg \cdot kg^{-1}$) in soil samples from the Xingren district.

In addition to Pb, 4 other toxic elements, Cd, Cu, As, and Cr, were found to have different degrees of contamination in the 4 soils in the studied area. Cadmium is considered as an agronomic element and primarily exists in soils through the use of chemical fertilizers, livestock manure, and ground water [24, 25]. Moreover, atmospheric deposition is also considered as one of the major sources of heavy metal contamination, as more and more studies have confirmed that atmospheric dry and wet deposition represent principal pathways of anthropogenic inputs of heavy metals into the topsoil environment [26].

3.2. PTEs Accumulation in Crops. The concentrations of As and other heavy metals in the edible parts of different plant samples were found to be significantly different (Figure 2). In this study, the concentration of Cu was the greatest of the heavy metals in all crops, with the grains having the highest Cu concentrations, coix seed > maize > rice. In the vegetable crops, the Cu mean concentration was lettuce > horsebean > cauliflower > scallion > cabbage, with mean values of 22.2, 11.9, 9.7, 7.8, and 3.38 $mg \cdot kg^{-1}$ (based on dry weight), respectively. The concentration of Cr in grains was smaller than that in vegetables, and the content of horsebean among vegetables was much lower than in the study results [27]. The Cd concentration was generally lower in the three grains. The highest concentration of Cd was found in lettuce, with a mean value of 1.8 $mg \cdot kg^{-1}$, and lowest in horsebeans which was greater than the acceptable limit set by WHO (0.05 $mg \cdot kg^{-1}$) (FAO/WHO, 2001) [22]. The content of Pb and Cd in grains was significant. The highest mean concentration of Pb was observed in cauliflower (1.16 $mg \cdot kg^{-1}$) and the lowest mean concentration was found in maize with a mean value of 0.1 $mg \cdot kg^{-1}$. The vegetables with the highest concentrations of As were lettuce > scallion > cabbage > horsebean > cauliflower, while in grains rice > coix seed > maize. The lowest mean concentration of As was found in cauliflower and the highest was found in lettuce. The difference in the heavy metal content in different crops is influenced by a number of factors, such as soil composition, water, nutrient balance, and metal permissibility [28] and varied greatly across plant species and among genotypes within the same species [29].

3.3. The Levels of PTEs in Water Samples. The mean values of the chemical and biological characteristics of pH, K^+, Na^+, Ca^{2+}, and Mg^{2+} in the water samples were 7.13, 1.64, 5.22, 62.51, and 18.27 $mg \cdot L^{-1}$, respectively. Primary descriptive statistics of parameters in water samples are presented in Table 2. The mean values of Pb, As, Cu, Cd, and Cr were 0.61, 0.77, 12.50, 0.18, and 1.57 $\mu g \cdot L^{-1}$, respectively (Table 2). In water samples, the mean values of PTEs in decreasing content order were As > Pb > Cu > Cr > Cd. The data showed that the average concentration of PTE in the water samples did not exceed the provisional guideline values introduced by the standard of drinking water quality (GB 5749-2006), with the exceptions of Pb and As. This could be the reason for the high PTEs concentrations found in this study that are greater than the reported indices, especially for the total content of Cu, Cd, and Cr [15]. The concentration of As was the highest in water samples, which was higher than the standard of drinking water quality and also higher than that reported for other regions in Northern Greece [15]. In addition, the value for Pb in water samples was 60 times greater the provisional guideline value introduced by the standard of drinking water quality and higher than that reported other regions in Algeria (0.087 $\mu g \cdot mL^{-1}$) [20].

3.4. Concentrations of PTEs in Human Hair, Fingernails, and Blood Samples. In Figure 3, the average content of As was 2.39 $mg \cdot kg^{-1}$, which is greater than the value of As recommended by the Ministry of Health of China (0.6 $mg \cdot kg^{-1}$) [30], and exceeding the As poisoning standard (1.0 $mg \cdot kg^{-1}$) [31]. Mean concentration of Pb in local residents was 16.143 $mg \cdot kg^{-1}$, 2.26 times greater than the mean value for hair Pb content for residents in China in general (7.14 $mg \cdot kg^{-1}$) [32]. The average content of Cu in hair was 24.90 $mg \cdot kg^{-1}$. The mean content of Cr in hair was equivalent to Cu (25.88 $mg \cdot kg^{-1}$). Analysis of the nail samples for the 4 elements revealed the following: Cr > Pb > Cu > As. Mean concentration of As was 0.78 $mg \cdot kg^{-1}$, which is lower than that reported in Cambodia [33] whose nail As concentration is 1.90 $mg \cdot kg^{-1}$. The average content of Pb in human nail samples suggested similar concentration to Cu: 17.020 and 16.451 $mg \cdot kg^{-1}$, respectively. In this study, the content of Pb in nail samples was greater than that reported in Egypt (1.8~9.7 $mg \cdot kg^{-1}$) [34]. In human blood samples, the 4 elements showed the following: Cr > Cu > Pb > As. On comparison, concentrations of Cu and As in hair samples were greater than those in fingernail and blood samples (hair > nails > blood) and the concentration of Pb was higher in nail samples compared to hair samples, which is in agreement with the findings of Samanta and Batool [35, 36].

Table 3 reveals the Pearson correlation coefficients between trace elements (As, Pb, Cr, and Cu) in nail, hair, and blood samples. Fingernail samples of residents As-Pb,

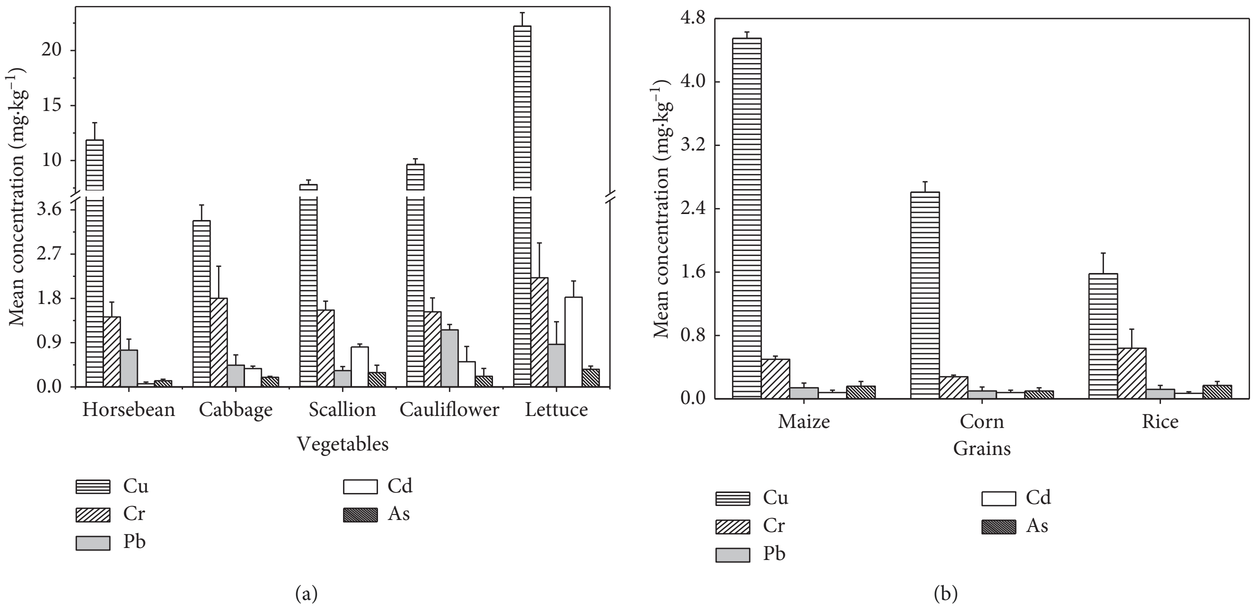


Figure 2: The concentration of As, Cd, Cr, Cu, and Pb in grains and vegetables.

Table 2: Statistical parameters for trace element concentrations in water samples.

Parameters	Minimum	Maximum	Mean	SD	Cv (%)	Skewness	Kurtosis	GB5749-2006
Pb ($\mu g \cdot L^{-1}$)	49	1328	611	0.462	75.68	−0.10	−1.59	10
As ($\mu g \cdot L^{-1}$)	16	1583	766	0.527	68.85	−0.20	−1.21	10
Cu ($\mu g \cdot L^{-1}$)	6.619	23.200	12.499	6.115	48.92	0.82	−0.83	1000
Cd ($\mu g \cdot L^{-1}$)	0.001	0.579	0.184	0.221	120.11	0.77	−1.14	5
Cr ($\mu g \cdot L^{-1}$)	0.130	3.843	1.568	1.350	86.07	0.76	−1.18	50

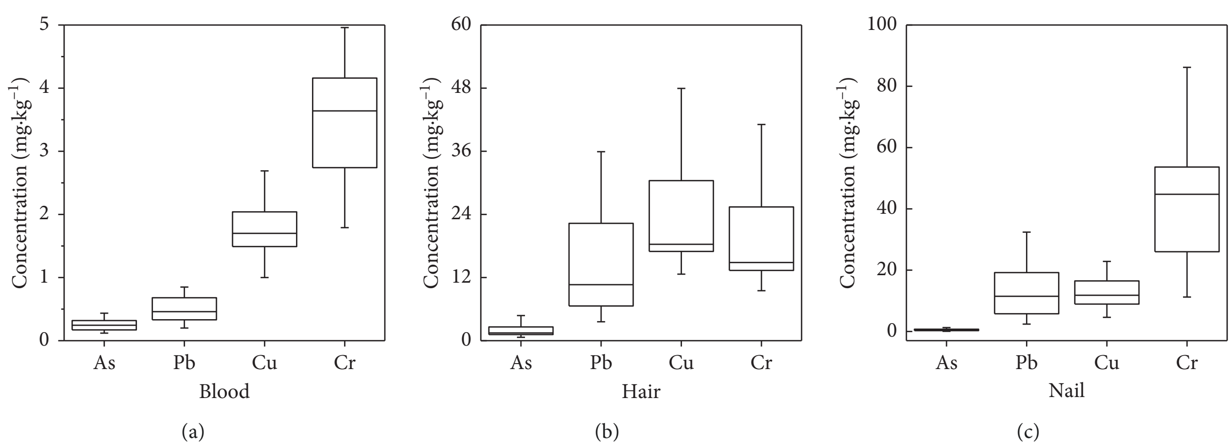


Figure 3: Levels of PTEs in nail, hair, and blood samples of inhabitants in Xingren, Guizhou, China ($mg \cdot kg^{-1}$).

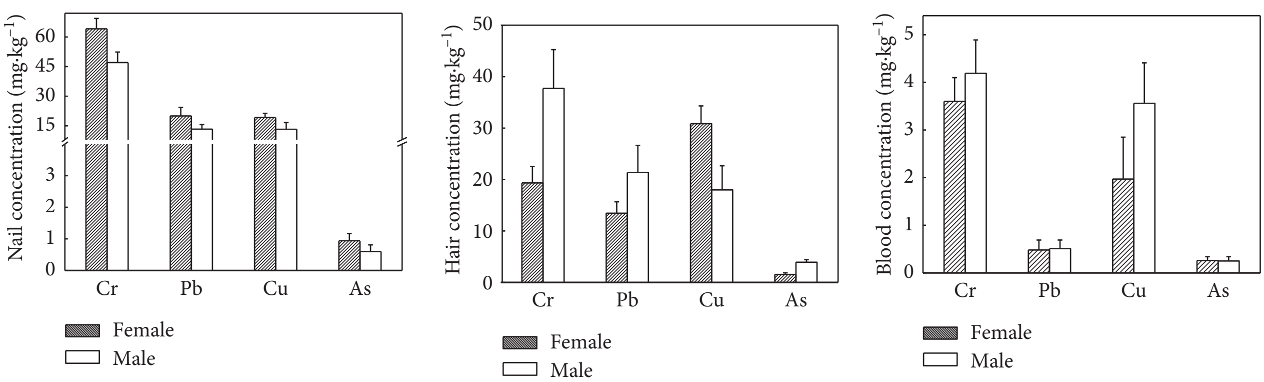
As-Cu, and As-Cr had a significant positive correlation ($P < 0.01$), with correlation coefficients being 0.83, 0.63, and 0.76, respectively. This suggests that the resident nail samples As and Pb, Cr, and Cu may come from the same source. In the human nail samples, Pb-Cu, Pb-Cr, and Cu-Cr also have good correlations. Significant positive correlation ($P < 0.01$) shows Pb and Cu, Cr, Cu, and Cr may have come from the same source. In hair samples, As-Pb, As-Cr, and Cr-Pb have a significant positive correlation ($P < 0.01$) which suggests As and Cr, Pb, Cr, and Pb may have come from the same source. In blood samples, Pb-Cu, Pb-Cr, and Cu-Cr showed significance ($P < 0.01$) indicating Pb and Cu, Cr, Cu, and Cr may have come from the same source.

The total concentration of individual elements (As, Cr, Pb, and Cu) in human nail, hair, and blood for males and females living in the mining area is shown in Figure 4. For fingernail samples (Figure 4(a)), the average content for both females and males living in the mining areas was as follows:

Table 3: Pearson's correlation of PTEs contents in human nail, hair, and blood samples.

	1 Nail As	2 Nail Pb	3 Nail Cu	4 Nail Cr	5 Hair As	6 Hair Pb	7 Hair Cu	8 Hair Cr	9 Blood As	10 Blood Pb	11 Blood Cu	12 Blood Cr
1	1	0.834**	0.627**	0.759**	0.067	0.23	-0.074	0.015	-0.09	-0.187	-0.016	-0.196
2		1	0.722**	0.942**	−0.034	0.239	−0.027	−0.036	0.029	−0.177	0.071	−0.091
3			1	0.783**	0.030	0.196	−0.062	−0.055	−0.100	−0.201	0.124	−0.041
4				1	0.042	0.230	−0.005	0.056	0.086	−0.231	0.059	−0.145
5					1	0.644**	−0.010	0.567**	0.115	−0.181	−0.038	−0.145
6						1	−0.006	0.401**	−0.049	0.147	0.107	0.016
7							1	0.104	0.021	−0.219	−0.057	−0.073
8								1	0.092	−0.011	0.058	0.012
9									1	−0.159	0.191	0.149
10										1	0.319**	0.363**
11											1	0.793**
12												1

**Correlation is significant at the 0.01 level (2 tailed); * correlation is significant at the 0.05 level (2 tailed).



(a) (b) (c)

Figure 4: Concentration of Cr, Pb, Cu, As (mg·kg^{-1}) for the nail (a), hair (b), and blood (c) samples for females and males in local residents from mining areas.

Cr > Pb > Cu > As, and the concentrations of these 4 elements were greater in females than males. In hair samples (Figure 4(b)), concentrations of these 4 elements were higher for males than females, particularly Cr, Pb, and As, which are in agreement with the findings of Baker et al. [37]. Only Cu concentrations were higher in females compared to males. In blood samples (Figure 4(c)), Cr, Pb, and Cu concentrations in males were higher than in females, and the concentration of As was similar in males and females (Figure 4(c)).

Figure 5 shows 4 elements, Cr, Pb, Cu, and As, for the nail, hair, and blood samples in relation to the age (15–30, 31–35, >50 years) of local residents. As age increased, the concentration of As increased in nail (a), hair (b), and blood (c) samples. The results indicate that the greater a residents' age, ergo exposure time, the higher the degree of accumulation of heavy metals in their body. In human hair samples (Figure 5(a)), the concentration of Cr increased as age increased, and the concentration of Cu was slightly increased in the age group 31–50 years compared to other age groups, whereas, Pb concentration was found to decline with age in hair samples. Pb levels in hair are influenced by blood pressure, weight, and lifestyle factors, leading to a negative correlation with age [38]. In human blood samples (Figure 5(b)), Pb, Cu, and Cr were found to be slightly elevated in the age group 15–30 years in three age groups. In hair samples (Figure 5(c)), the content of As increased with age.

3.5. Health Risk for Local Inhabitants. As the staple food (rice, coix seed, and maize) and vegetables of the local people are grown in the area, their consumption contributes a large part of their daily intake of PTEs. The above results indicate that toxic metals are found in high concentrations in local crops, indicating a health risk assessment is essential. Assessment of potential health effects of human contamination of toxic metals through the consumption of food includes carcinogenic and noncarcinogenic risks.

The noncarcinogenic risk from the consumption of vegetables, rice, coix seed, and maize by local people were calculated based on the EDI and the THQ values. The THQ is a ratio of a defined dose of a pollutant to a reference dose level, which is calculated using EDIs to indicate the pollution level due to contaminant exposure. If the ratio is greater than 1, the exposed population is likely to experience health effects; otherwise, the exposed population is considered to be not at risk, and levels of contaminants are acceptable (USEPA, 2005; FAD/WHO, 2001) [19, 22]. THQ indicates

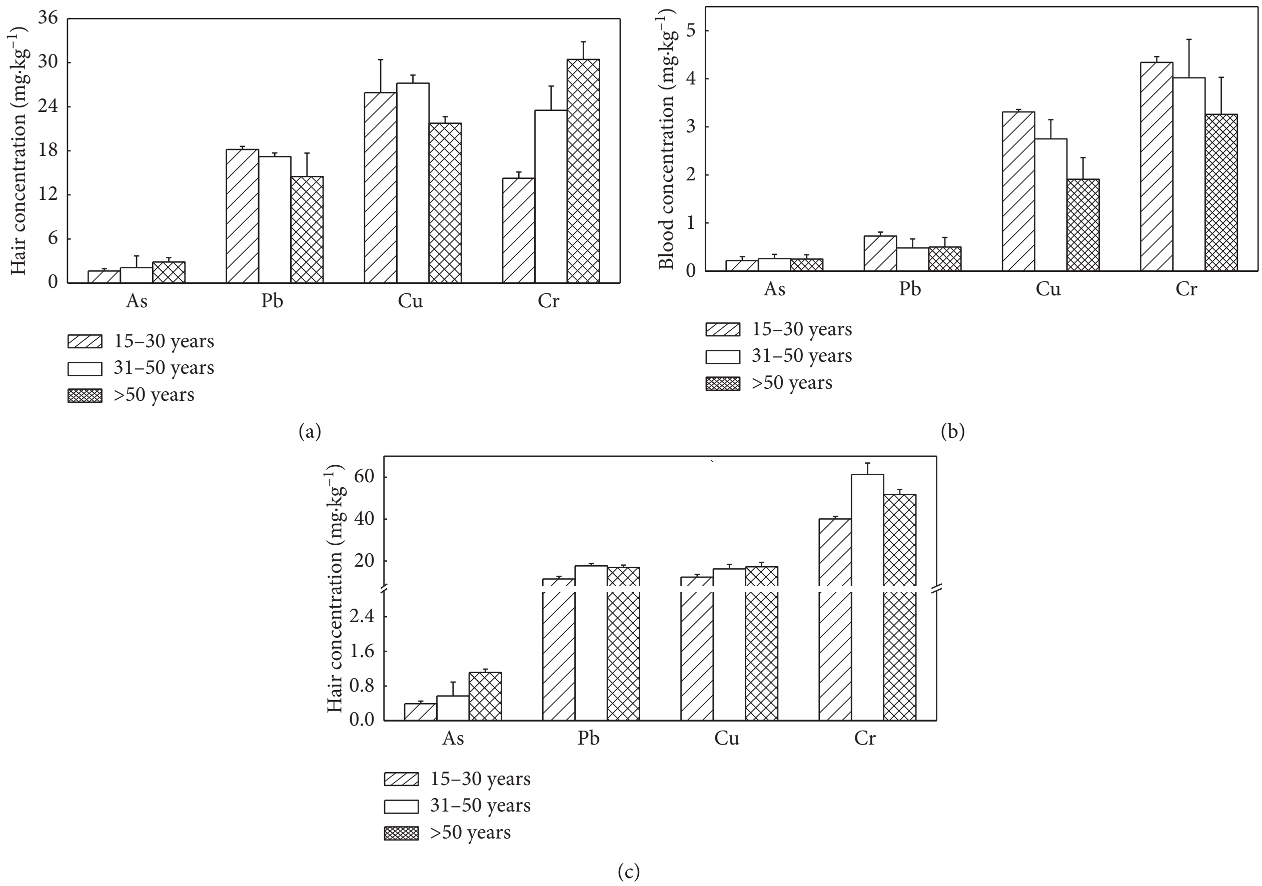


Figure 5: Concentrations of Cr, Pb, Cu, and As (mg·kg^{-1}) for the nail (a), hair (b), and blood (c) samples across different age groups (15–30, 31–50, >50 years).

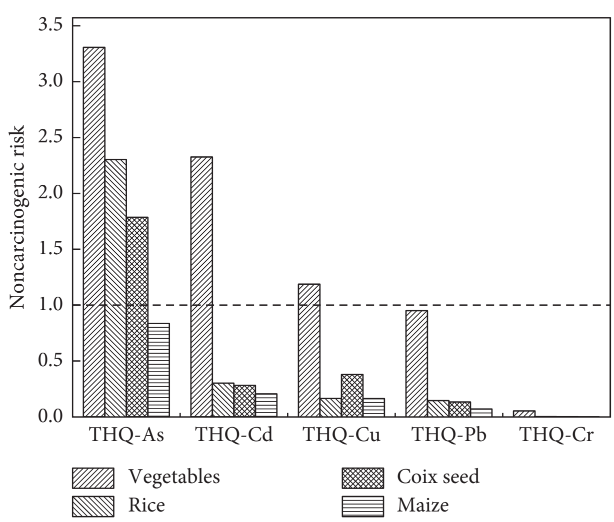


Figure 6: Noncarcinogenic risk assessment including THQ for As, Cd, Cu, Pb, and Cr through the consumption of vegetables, rice, coix seed, and maize grown in the mining affected areas.

target hazard quotient for an individual element in individual crop. TTHQ indicates THQ for an individual crop of selected elements. The THQ, TTHQ, and HI for local people in the mining affected area were calculated and shown in Figure 6 and Table 4. In villages close to the Xingren mining area, the mean TTHQ for vegetable, rice, coix seed, and maize consumption of local inhabitants were 7.78, 3.00, 2.70, and 1.33, respectively. The TTHQ was greater than 1, indicating significant potential health risks for individuals consuming vegetable, rice, coix seed, and maize grown in the area. The results also suggested serious risks of adverse health effects to the local people through the ingestion of contaminated vegetables because of relatively high TTHQ values. The THQs are ranked in the order of As > Cd > Cu > Pb > Cr, indicating that As, with the higher mean value of 3.31, 2.30, and 1.79 for vegetables, rice, and coix seed, respectively, contributed the greatest noncarcinogenic risk to local people. This high THQ was due to the smallest RfD value of As (1×10^{-4} mg/kg/day) and the high level of As in the vegetable and grains. The THQ-Cd (2.33) and THQ-Cu (1.19) exceeded 1, which indicated that chronic exposure to the population of the elevated levels of Cd and Cu from vegetables may cause serious health effects. The mean values of THQ-Pb in vegetables, rice, coix seed, and maize did not exceed 1, indicating these may not cause health effects. The HI expresses the combined noncarcinogenic effects of multiple metals (As, Cd, Cu, Pb, and Cr) and crops (vegetables and grains), as shown in Table 4. The mean HI value through the consumption of food crops was 14.81, indicating that consumers of the studied food

Table 4: Noncarcinogenic risk (TTHQ, HI) and carcinogenic risk (TCR, TTCR) of PTEs due to food crop consumption in the Xingren mine affected area.

Health risk assessment		Crop types: Vegetable	Rice	Coix seed	Maize
Noncarcinogenic risk	TTHQ	7.78	3.00	2.7	1.33
	HI	14.81			
Carcinogenic risk	TCR	2.40×10^{-3}	1.16×10^{-3}	9.14×10^{-4}	4.57×10^{-4}
	TTCR	5.3×10^{-3}			

Note. TTHQ: sum of individual metal THQs (target hazard quotient); HI: sum of individual crop TTHQ; TCR: sum of individual metal CR; TTCR: sum of individual crop TCR.

crops may experience adverse health effects. Consequently, some effective measures are essential to reduce the level of heavy metal contamination in the soil and the integration of metal from soil to the edible parts of the crops. The implications for human health need to be identified in future studies.

The 3 metals, Cd, As, and Pb, are generally accepted as being carcinogenic. The CR, TCR, and TTCR for local people in the affected mine area were calculated and shown in Figure 7 and Table 4. The TCRs are ranked in the order As > Cd > Pb, indicating that As and Cd, with higher mean values, significantly contribute to the carcinogenic risk of the local people. Regarding carcinogenic risk of heavy metals, the mean CR values of As were greater than the USEPA threshold level or residual level for causing cancer (USEPA, 2010), indicating an elevated carcinogenic risk for local inhabitants. In cereals and vegetables, the CR of As was in the order of vegetables > paddy rice > coix seed > maize, while for Cd, it was vegetables > coix seed = paddy rice > maize. Moreover, the highest Pb concentration as found in coix seed was higher than the acceptable range (10^{-6}–10^{-4}), while the mean value in vegetables, paddy rice, and maize was lower than an acceptable range. The TTCR value expresses the combined carcinogenic effects of multiple metals and crops. As shown in Table 4, the mean TTCR value for the selected food consumption was 0.0053, which was about 10 to 1000 times greater than the acceptable range of 10^{-6}–10^{-4} (USEPA, 2010). The greatest uptake of heavy metals came from vegetables and rice, indicating serious carcinogenic risks for local people consuming crops in the areas. Overall, there is heavy metal pollution in the common food crops (vegetables, paddy rice, coix seed, and maize) cultivated in the soils in the vicinity of the Xingren mines.

A large daily intake of these crops by local people will cause high carcinogenic and noncarcinogenic risks. Moreover, it has also been reported that the exposure to 4 or more contaminants may result in additive or interactive effects, which increase the potential risk of adverse health effects for residents in this area.

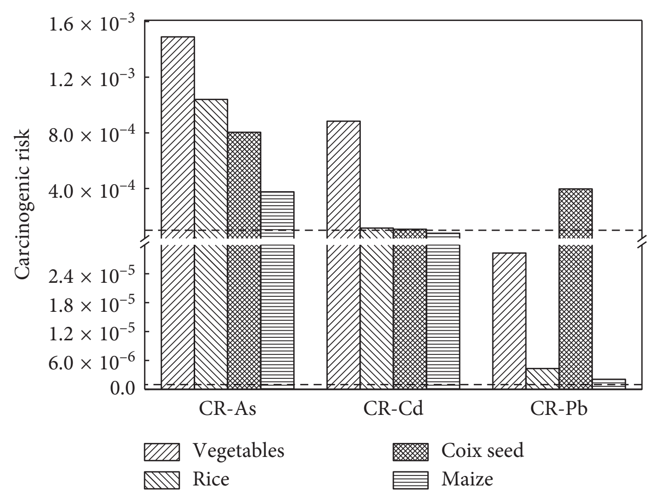


Figure 7: Carcinogenic risks including CR for As, Cd, and Pb through the consumption of vegetables, rice, coix seed, and maize in the mine affected areas.

4. Conclusions

The THQs in crops are ranked As > Cd > Cu > Pb > Cr. The mean HI value through food crop consumption was 14.81, indicating that consumers of the studied food crops may experience adverse health effects. Some effective measures are essential to reduce the PTE contamination levels in soil and metal migration from the soil to the edible parts of crops grown in the area. The TCRs are ranked in order As > Cd > Pb. The mean TTCR values for the consumption of selected food was 0.0053, which is about 10 to 1000 times greater than the acceptable range of 10^{-6}–10^{-4} (UA EPA, 2010). This suggests serious carcinogenic risks for local people consuming crops from the area. A large daily intake of these crops by the local people will cause carcinogenic and noncarcinogenic risks. Although various types of commonly consumed crops were collected from the study area, they are not representative of all vegetables and grains consumed by populations in other mining areas. The daily intake of other elements from other food sources needs to be evaluated to determine the actual exposure to As and other elements and to better evaluate the health risks of this section of the population. Total trace metals (As, Pb, Cu, and Cr) for fingernail, hair, and blood samples were 90.50 $mg \cdot kg^{-1}$, 69.31 $mg \cdot kg^{-1}$, and 6.90 $mg \cdot kg^{-1}$, respectively. Females were more likely to be exposed to trace metals (As, Pb, Cu, and Cr) in fingernail samples compared to males. This study included small sample sizes for soils and vegetables. Future studies should include larger sample sizes and additional food components. In addition, other elements need to be monitored regularly in the mining area.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the work described in this paper.

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