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Evaluation of heavy metal contamination of soil and the health risks in four potato-producing areas

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Areas polluted by heavy metals in soil may pose a major risk to human health and ecological environment safety. In this study, 89 soil samples were collected from four potato producing areas (Libo, Chishui, Panxian and Weining) in Guizhou Province, China, and the concentrations of 9 soil heavy metals were analyzed and measured. The aims of this study was to evaluate the human health risk and pollution index of heavy metals in the soil of some potato-producing areas in Guizhou Province by using the geoaccumulation index method, pollution load index method and health risk assessment method. The results revealed that Igeo<0 in Libo and Chishui, Igeo>0 in Panxian except Pb, The Igeo of As and Sb were less than 0 in Weining, and other elements were polluted to varying degrees. The pollution load index is Panxian (1.47) > Weining (1.39) > Libo (0.67), Chishui (0.67), Libo and Chishui were generally no polluted, soils in Panxian and Weining were polluted. The health risks of potatoes through food ingestion are less than 1. In terms of carcinogenesis, the risk of human in each study area through the ingestion was Cr > As > Cd. Cr and As would be produced certain carcinogenic risk to human through the dermal contact. Cr had a strong carcinogenic risk to adults through the inhalation. In terms of non-carcinogenesis, children in each study area had a strong risk under the each pathways. The risk of carcinogenesis in adults through inhalation pathway is greater than that in children, and the risk of carcinogenesis and non-carcinogenesis in children through Ingestion and dermal contact pathway is greater than adults. The results of this study suggest that attention should be paid to the remediation of heavy metals in contaminated soil to protect human health.

KEYWORDS

soil, heavy metals, potato, pollution evaluation, health risk evaluation

1 Introduction

Soil is the most important natural resource that ensures the safety, quantity and quality of human food and is also an important object of ecological and environmental protection (Ministry of Environmental Protection 2014). The continued acceleration of industrialization in China indicates that the problem of soil environmental pollution has gradually become a major factor that affects the quality of agricultural products and threatens human health (Mohmand et al., 2015). The common heavy metals in soil include Hg, As, Cd, Cr, Cu, Zn, Ni, and Pb, which have strong toxicity (SUN et al., 2008). Human activities will cause the content of heavy metals in soil to be significantly higher than its natural background value, and cause ecological damage and environmental quality deterioration (Jiang 2008).

In recent years, with the intensification of urbanization and the changes in land use, some heavy metal elements caused by the geological background have also been activated, causing the soil's heavy metals to migrate and become enriched (TUCL et al., 2013). Heavy metals in the soil not only affect and change the ecological function of soil but also directly or indirectly endanger human health through ingestion, dermal contact, and inhalation. When the human body is overloaded with heavy metals, it can damage the function of the nervous system, disrupt the endocrine system, and affect IQ (intelligence quotient) and behavior (US EPA 1994). Heavy metals in soil can combine with proteins, polypeptides, enzymes, and other macromolecular substances in agricultural objects to enrich edible parts, such as potato tubers and carrot roots, and enter the human body through the food chain (Wang et al., 2006). This process poses potential health risks and can have serious carcinogenic and non-carcinogenic hazards. Therefore, the evaluation of the contamination status of soil by heavy metals is a matter of food safety and human health (Yang et al., 2014). For example, the heavy metal Cd will lead to renal dysfunction, lung adenocarcinoma, and prostate hyperplasia, as well as lead to skin cancer, neuropathy, and cardiovascular and cerebrovascular diseases. Excessive intake of Pb will damage human brain cells and cause damage to kidneys, digestion, and the immune system. The toxicity levels of Cu and Ni are relatively small, but excessive intake will also cause damage to human organs (Patlolla et al., 2012; Pascaud et al., 2014; Zhao et al., 2018).

Therefore, it is important to highlight the human health risks brought by heavy metals in the soil so that focus can be given to the study of heavy metal pollution in soil and agricultural areas and the assessment of the harm caused by these heavy metals. The geoaccumulation index, pollution load index, and health risk evaluation methods are usually utilized by researchers to evaluate the heavy metals contamination of soil. The results of such evaluations can accurately reflect the degree of contamination status in a study area. Many studies have focused on this field (Fakhri et al., 2018; Kamani et al., 2018; Rezaei et al., 2018; Yousefi et al., 2018). However, there is no investigation and evaluation of soil heavy metal pollution in many potato-producing areas, and some evaluation methods are too simple. Therefore, the aims of this study were to determine the distribution of soil heavy metal content, pollution situation, and human health risk pollution in some potato-producing areas of Guizhou Province, China.

2 Materials and methods

2.1 Study area description

Guizhou Province in China is between 103° 36′—109° 35′E and 24° 37′—29° 13′N, with an east-west length of approximately 595 km and a north-south distance of approximately 509 km. The total area of the province is 176,167 km^2, accounting for 1.8% of the total area of the country. The geomorphology of the province can be divided into four basic types: plateau, mountain, hill, and basin. The altitude difference is large, with an average altitude of approximately 1100 m. The climate is warm and humid, belonging to the subtropical humid monsoon climate. The annual average temperature is 15–18°C, and the annual average precipitation is 800–1500 mm. The annual average sunshine duration is 1,200–1600 h. There is no excessive heat in summer, the spring is warm, and the autumn is cool. The unique climate and geographical location give rise to diverse ecological types. The soil in Guizhou Province is generally slightly acidic, and the main soil types include yellow soil, lime soil, red soil, yellow-brown soil, purple soil, and paddy soil, which respectively account for 46.51%, 17.55%, 7.22%, 6.21%, 5.59%, and 9.77% of the total soil area in Guizhou Province. Libo and Chishui are both World Natural Heritage Sites, which are protected to a certain extent. Panxian and Weining have been engaged in industrial and mining activities for nearly 60 years; the generated waste residue, smoke and dust pollutes the environment to a certain extent. In addition, local residents apply pesticides and fertilizers to the soil, and the domestic waste is disposed disorderly, resulting in serious heavy metal pollution accumulation. The location of the study area is shown in Figure 1.

2.2 Sampling area distribution and sample collection

The distribution of points in each sampling area is shown in Figure 1. The major counties in Guizhou Province that produce potatoes include Libo (Figure 1A), Chishui (Figure 1B), Panxian (Figure 1C), and Weining (Figure 1D). These counties were selected to serve as the source of 89 soil samples from the upper layer of soil (0–20 cm), including 12 from Libo, 11 from Chishui, 29 from Panxian, and 37 from Weining. The "five-point method" was used to randomly sample five batches of inter-root soil and mix them to generate one soil sample (Brewer R et al., 2017). A total of 1 kg of samples were brought back to the laboratory for processing. A GPS locator was used to precisely position and record the latitude, longitude, elevation, sampling location, and soil type of each sample during the collection process. First, plant residues, gravel, and other debris were removed from the soil samples. These samples were then sieved through 100 mesh after natural air-drying to determine the soil's physical and chemical properties and the contents of heavy metals.

2.3 Sample determination

The soil pH was determined using the $CaCl_2$ leaching method with a pH meter (water:soil = 2.5:1 [v/v]) (Bao 2000). The concentrations of As and Pb were determined by atomic fluorescence spectrometry using the Chinese standard (GB/T 22105.2-2008), (GB/T 22105.3-2008). The concentrations of Mn, Zn, Cu, Ni, and Cr were determined using flame atomic absorption spectrophotometry (HJ 491–2019). The concentration of Cd was determined using graphite furnace atomic absorption spectrophotometry (GB/T 17141-1997). Sb was determined using inductively coupled mass spectrometry (ICP-MS) with microwave digestion, as described by Wang et al. (2022). A blank was used throughout the determination, and the national reference material GB W07428 (GSS-14) was used for quality control (Long and TanJ, 2013). The spiked recoveries of each metal element were in the range of 90%–110%.

2.4 Evaluation methodology

2.4.1 Geoaccumulation index method

The geoaccumulation index method was proposed by the German scientist Muller in 1979 (MÜLLER 1969). The effect of

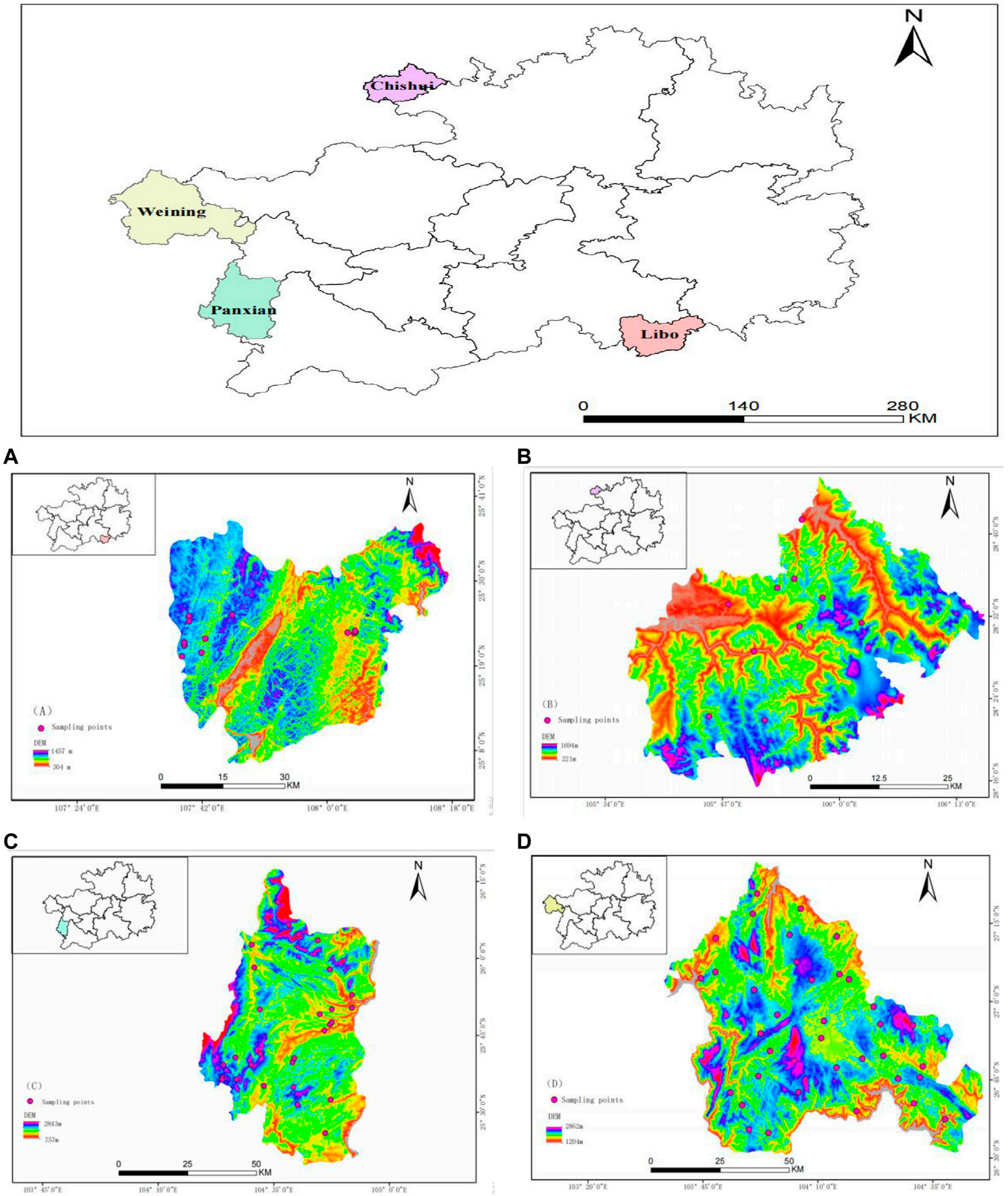

FIGURE 1
Distribution map of sampling points in the study area. Note: **(A–D)** represent Libo, Chishui, Panxian, and Weining in Guizhou Province, China.

diagenesis on the background values of soils is considered and commonly used to quantitatively evaluate the degree of heavy metals contamination in sediments and soils in the aquatic environment and their classification (Ma et al., 2020). The formula is as follows:

$$I_{geo} = \log_2\left(\frac{C_i}{1.5 \times B_i}\right) \tag{1}$$

Where I_{geo} is the geoaccumulation index; C_i is the measured content of element i in the soil sample; B_i is the soil background value for element i, and 1.5 is the constant term. B_i used the background values of soil elements from Guizhou Province in this study (China General Environmental Monitoring Station 1990), and the evaluation grading criteria are shown in Supplementary Table S1 (Xu et al., 2013; NEYESTANI et al., 2016).

2.4.2 Pollution load index method

The background soil values of heavy metals in Guizhou Province were used as a reference (Yang, 2019), and the pollution load index method proposed by Tomlinson was used to evaluate the heavy metal pollution in soil in the study area. This index can visually reflect the degree of contribution of individual heavy metals to pollution and reflect the trend of heavy metals in time and space (DU et al., 2021). The formula is as follows:

$$\mathrm{CF_i} = \mathrm{C_i}/\mathrm{C_{0i}} \tag{2}$$

$$\mathrm{I_{PL}} = \sqrt[n]{\mathrm{CF_1} \times \mathrm{CF_2} \times \cdots \times \mathrm{CF_n}} \tag{3}$$

$$\mathrm{I_{PLzone}} = \sqrt[m]{\mathrm{I_{PL1}} \times \mathrm{I_{PL2}} \times \cdots \times \mathrm{I_{PLm}}} \tag{4}$$

Where CF_i is the pollution index of heavy metal i; C_i is the measured value of I; C_{0i} is the background value of i; I_{PL} is the pollution load index of a sampling point; n is the number of sampling points; I_{PLzone} is the pollution load index of a sampling area, and m is the number of species of polluting heavy metal i. The evaluation criteria for the pollution load index method are shown in Supplementary Table S1.

2.4.3 Human health risk assessment

Heavy metals in soil enter the human body through exposure routes, such as ingestion, dermal contact, and inhalation, thus affecting human health, as well as posing carcinogenic and non-carcinogenic risks that are generated in this process (LÜ et al., 2017). The health risk evaluation method recommended by the US Environmental Protection Agency (EPA) was used and calculated using the following formulas (US EPA 2001; US EPA 2011):

$$\mathrm{ADD_{Soil-ingestion}} = (\mathrm{C_s} \times \mathrm{IR_1} \times \mathrm{CF} \times \mathrm{EF} \times \mathrm{ED})\big/(\mathrm{BW} \times \mathrm{AT}) \tag{5}$$

$$\mathrm{ADD_{Soil-dermal\ contact}} = (\mathrm{C_s} \times \mathrm{CF} \times \mathrm{EF} \times \mathrm{SA} \times \mathrm{AF} \times \mathrm{ABS} \times \mathrm{ED}) \times/(\mathrm{BW} \times \mathrm{AT}) \tag{6}$$

$$\mathrm{ADD_{Soil-inhalation}} = (\mathrm{C_s} \times \mathrm{IR_2} \times \mathrm{EF} \times \mathrm{ED})/(\mathrm{BW} \times \mathrm{PEF} \times \mathrm{AT}) \tag{7}$$

$$\mathrm{ADD_{vegetable}} = (\mathrm{C_v} \times \mathrm{IR_v} \times \mathrm{EF} \times \mathrm{ED})\big/(\mathrm{BW} \times \mathrm{AT}) \tag{8}$$

$$\mathrm{HQ_i} = \mathrm{ADD_i}/\mathrm{RfD} \tag{9}$$

$$\mathrm{R} = \mathrm{ADD_i} \times \mathrm{SF_i} \tag{10}$$

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

Where ADD_i is the long-term average daily exposure dose ($mg.kg^{-1}.d^{-1}$) of heavy metal i; HQ_i is the non-carcinogenic risk entropy of each heavy metal; RfD is the reference dose ($mg.kg^{-1}.d^{-1}$) of heavy metals following different exposure pathways (Ferreira-Baptista and De Miguel, 2005); R is the heavy metal carcinogenic risk index; SF_i is the slope of carcinogenic risk of heavy metal i (US EPA 2002); HI is the non-carcinogenic risk index, and C_S is the content of soil heavy metals ($mg.kg^{-1}$). The US EPA recommended standard parameters that indicate that the non-carcinogenic risk is negligible when the $HQ < 1$, and there is a non-carcinogenic risk when the $HQ > 1$. The carcinogenic risk is insignificant when $R < 10^{-6}$. An R of 10^{-6} to 10^{-4} indicates that there is some carcinogenic risk to humans, and when $R > 10^{-4}$, there is a strong carcinogenic risk. The values and significance of the specific parameters are shown in Supplementary Tables S2, S3.

2.5 Data analysis

SPSS 20.0 (IBM, Inc., Armonk, NY, United States) was used for descriptive statistical analyses of heavy metal content in soil, Microsoft Excel 2016 (Redmond, WA, United States) was used for data processing, and Origin 9.2 (OriginLab, Northampton, MA, United States) for graph plotting. ArcGIS 10.2 (ESRI, Redlands, CA, United States) was used to map sample points.

3 Results and analysis

3.1 Characteristics of heavy metal content in soil in the study area

The concentrations of heavy metals in the soils of each sampling area are shown in Table 1. Comparing the average value of heavy metals in the soil with the background value of the soil in Guizhou Province, it can be seen that the Cu element in Panxian is 5.84 times the background value, and there is some pollution; In Weining, Cu and Cd exceeded the standard by 3.87 times and 3.74 times of the background value, respectively. There were significant differences in heavy metal.

Concentrations in soil for different zones in the study area (Figure 2). As a whole, the content of heavy metals in soil in Panxian and Weining was higher than that in Libo and Chishui.

The coefficient of variation can reflect the average variation of each sampling point in the overall sample, and it is influenced by the environment and degree of spatial variation. The coefficient of variation indicates medium variation when it is in the range of 15%–36%, and high variation when it is >36%; a value >50% indicates that there is a possibility of local contamination of the soil (Wilding, 1985). In Libo, the coefficients of variation for Cd, Mn, and Sb were >50%. In Chishui, the coefficients of variation for Cd and As were >50%. Ni in Panxian had medium variability. Other heavy metals were highly variable with the coefficients of variation for Cd, As, Sb, and Cr being >50%. Their sources were complex and subject to human interference. Ni in Weining was <50%, and the coefficients of variation of the remaining eight heavy metal elements were >50%. All were highly variable, indicating that they are primarily influenced by local pollution sources. The coefficient of variation of Ni in Weining was <50%, and the coefficients of variation of the other eight heavy metals were >50%, indicating that they are primarily influenced by local pollution sources and could be attributed to the influence of anthropogenic activities, such as industry, agriculture, and transportation (Pan et al., 2016).

The degree of kurtosis and skewness are primarily used to measure the distribution status of the data (Zhang. 2021). Each heavy metal in Libo and Chishui had a low kurtosis, which belongs to the low peak state, indicating that there were more points with low concentrations. The skewness of nine heavy metals in the soil in Panxian and Weining was >0, which indicates positive skewness. This means that the distribution of heavy metal concentrations in soiul was subject to different degrees of external interference.

3.2 Evaluation of heavy metal pollution in the soil

3.2.1 Evaluation using the geoaccumulation index

The evaluation results of the geoaccumulation index for each heavy metal in the soil in each study area are shown in Figure 3. The

TABLE 1 Descriptive statistics of heavy metal content in the soil (Zeng Q Q et al., 2021; China General Environmental Monitoring Station 1990).

Region	Project	Heavy metals in soil (mg.kg^{-1})								
		Cr	Mn	Ni	Cu	Zn	As	Cd	Sb	Pb
Libo	Min	53.55	102.10	13.35	14.63	53.69	5.39	0.12	0.58	23.24
	Max	168.20	856.00	39.69	50.82	161.40	12.68	2.81	3.71	39.00
	Median	104.95	400.75	20.13	25.74	88.15	8.61	0.52	1.50	31.64
	Mean	96.93	451.52	21.48	28.37	96.59	8.76	0.69	1.53	31.32
	Standard deviation (SD)	34.81	268.11	6.76	10.05	29.84	2.52	0.71	0.81	5.05
	Coefficient of variation (CV)/%	36.02	59.38	31.49	35.43	30.89	28.78	103.02	52.53	16.13
	Skewness	0.38	0.25	1.50	1.25	0.84	0.15	2.46	1.61	−0.02
	Kurtosis	−0.49	−1.57	3.59	1.20	0.13	−1.54	6.67	3.56	−1.21
Chishui	Min	58.55	162.10	11.60	21.01	48.28	3.94	0.14	0.53	23.23
	Max	95.82	862.80	45.03	42.93	158.00	23.28	1.65	1.79	52.32
	Median	65.52	683.80	30.19	26.10	106.00	8.43	0.35	0.74	31.72
	Mean	71.37	630.74	31.57	27.61	106.47	9.75	0.48	0.90	34.32
	Standard deviation (SD)	12.77	246.69	8.86	6.20	27.98	4.90	0.42	0.36	8.22
	Coefficient of variation (CV)/%	17.89	39.11	28.08	22.46	26.28	50.23	86.63	40.67	23.96
	Skewness	1.07	−1.06	−0.74	1.54	−0.20	1.93	2.18	1.42	0.85
	Kurtosis	−0.34	−0.17	0.95	2.32	0.79	5.15	5.55	1.88	0.52
Panxian	Min	58.08	135.10	10.49	21.17	43.52	3.18	0.24	0.27	8.72
	Max	490.50	3639.60	166.80	425.60	487.50	253.80	11.29	24.66	71.54
	Median	129.90	1,478.90	79.02	175.80	190.90	12.43	0.59	1.76	24.05
	Mean	159.21	1,416.05	81.62	186.73	216.70	38.56	1.32	4.28	28.71
	Standard deviation (SD)	87.96	685.09	29.13	92.04	103.49	59.00	2.11	5.83	13.87
	Coefficient of variation (CV)/%	55.25	48.38	35.69	49.29	47.76	153.02	159.01	136.33	48.32
	Skewness	2.09	0.86	0.32	0.71	1.06	2.49	3.96	2.32	1.38
	Kurtosis	5.75	2.44	1.92	0.55	0.78	6.11	17.56	5.07	2.04
Weining	Min	32.32	113.00	15.63	5.32	93.69	0.28	0.20	0.28	10.02
	Max	400.70	4368.00	129.60	400.80	1,291.40	50.60	20.58	9.35	575.90
	Median	135.50	1,145.90	67.83	80.61	182.10	17.06	1.08	1.56	47.82
	Mean	150.04	1,319.14	70.74	123.70	270.40	18.92	2.47	2.17	83.71
	Standard deviation (SD)	82.89	829.71	24.92	97.66	228.83	14.00	3.65	1.98	109.97
	Coefficient of variation (CV)/%	55.25	62.90	35.23	78.95	84.63	74.03	147.53	91.55	131.36
	Skewness	1.39	1.50	0.34	1.32	2.85	0.54	3.60	1.93	3.05
	Kurtosis	2.13	3.61	0.33	0.98	10.12	−0.59	16.06	4.20	10.52
	Soil background values in Guizhou Province	95.90	794.00	39.10	32.00	99.50	20.00	0.66	2.24	35.20

average geoaccumulation index of heavy metal elements in Libo and Chishui was less than 0, indicating a clean state. The average Igeo value of heavy metals in Panxian was Cu (1.96) > Zn (0.54) > Ni (0.48) > Cd (0.42) > As (0.36) > Sb (0.35) > Mn (0.25) > Cr (0.15). The average Igeo value of heavy metals in Weining was Cu (1.37) > Cd (1.32) > Zn (0.86) > Pb (0.66) > Ni (0.27) > Mn (0.15) > Cr (0.06). It could be seen that the Cu in Panxian indicates significant contamination, and the Cu, Cd, Zn, and Pb in Weining also indicate significant contamination. Nazeeram et al. (2021) used the geoaccumulation index method to evaluate the status of heavy metals as pollutants in rural soils in Urümqi, China, and found that the average degree of pollution by heavy metals was in the order of Hg > Cd > Pb > Zn >

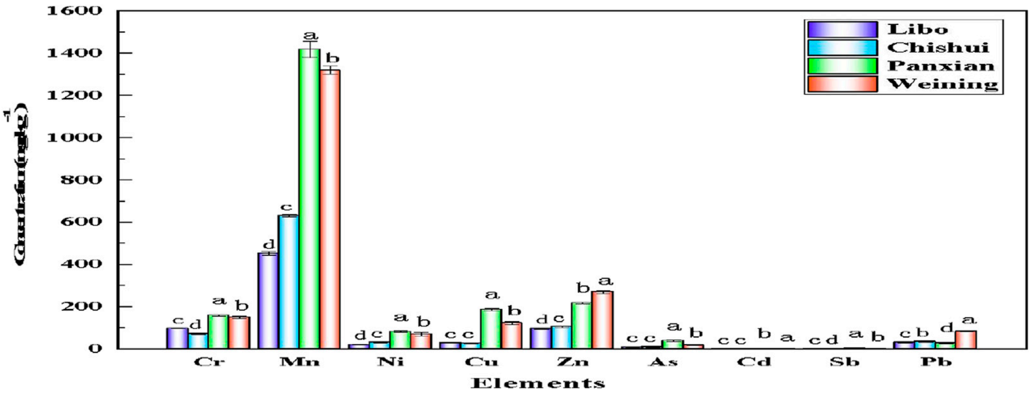

FIGURE 2
The concentrations of heavy metals in soil in different study areas (different letters indicate significant differences at $p < 0.05$)

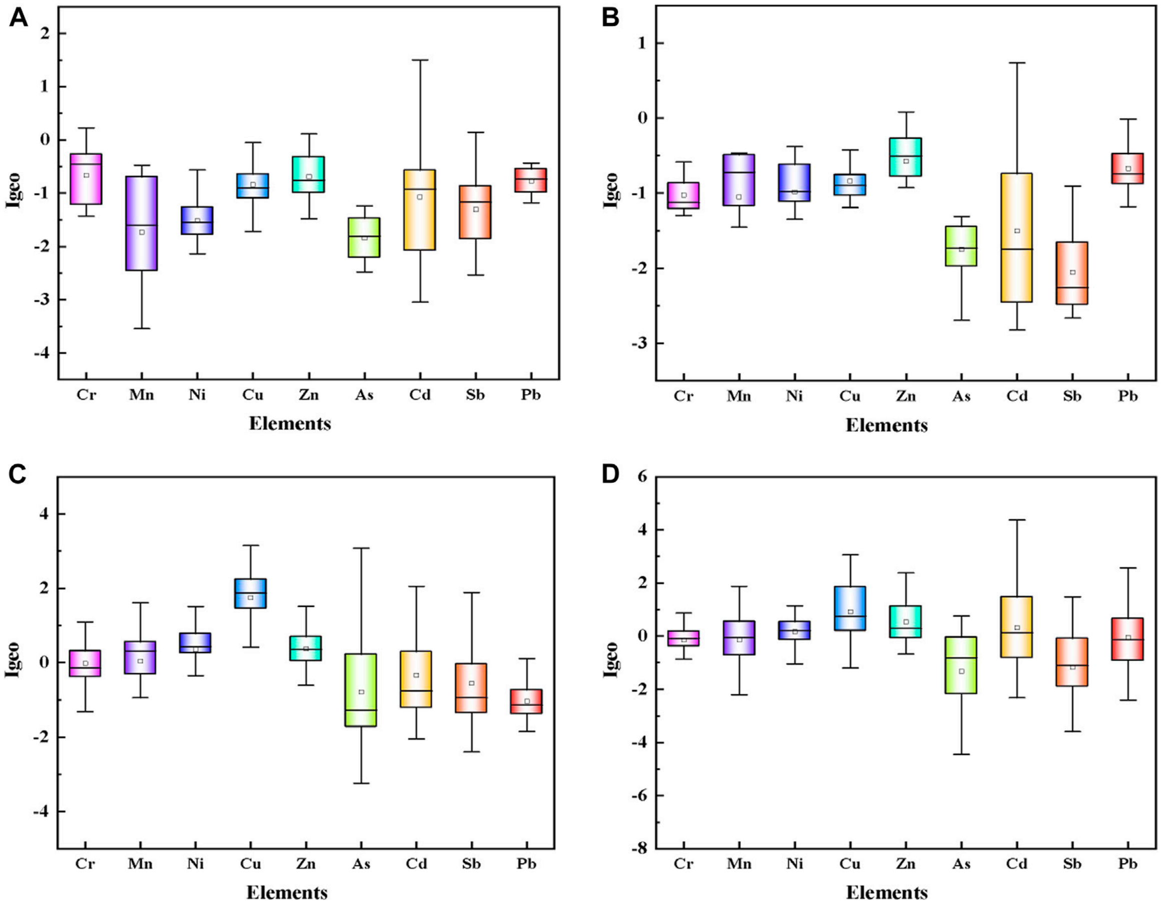

FIGURE 3
Evaluation results of the geoaccumulation index
Note: **(A–D)** represent Libo, Chishui, Panxian, and Weining in Guizhou Province, China.

Cu > Ni > As > Cr. The average I_{geo} values of Hg, Cd, and Pb was >0, and Hg and Cd had different degrees of pollution. Zhang et al. (2015) evaluated the amount of heavy metal contamination in the soil in the potato production area of Panxian and found that the soil was free of contamination from Cu and As, while there was slight contamination from Cd. A comparison of their findings with those of this study indicates that the levels of Cu, As, and Cd are increasing over time. Morteza et al. (2019) evaluated the amount of heavy metal contamination in soil in the Persian Gulf (southern Iran), and the EF and I_{geo} values indicated that the sediments were contaminated

TABLE 2 Results of evaluation by the pollution load index.

Region	Cr	Mn	Ni	Cu	Zn	As	Cd	Sb	Pb	
	I_{PL}									I_{PLzone}
Libo	0.94	0.45	0.53	0.84	0.93	0.42	0.71	0.61	0.88	0.67
Chishui	0.73	0.70	0.77	0.84	1.03	0.44	0.55	0.37	0.95	0.67
Panxian	1.47	1.53	1.91	5.03	1.94	0.87	1.18	1.03	0.73	1.47
Weining	1.35	1.35	1.68	2.83	2.17	0.60	1.86	0.66	1.44	1.39

with Cd and Pb. Contamination with Pb was more serious in this area compared with the findings of this study, which found that the contamination with Pb was relatively light and contamination with Cd was more serious.

3.2.2 Evaluation of the pollution load index

The results of an evaluation of the soil in each study area using the heavy metal pollution load index are shown in Table 2. The soil in Libo was slightly polluted with Cr, Cu, Zn, Cd, and Pb. In Chishui, the soil was lightly polluted with Zn and slightly polluted with Cr, Ni, Cu, and Pb. In Pan County, the soil was extremely polluted with Cu, lightly polluted with Cr, Mn, Ni, Zn, Cd, and Sb, and slightly polluted with As. In Weining, the soil was moderately polluted with Cu and Zn and slightly polluted with Cr, Mn, Ni, Cd, and Pb. The regional pollution degree was as follows: Panxian (1.47)>Weining (1.39)>Libo (0.67), and Chishui (0.67).

A comparison with the evaluation results of the geoaccumulation index method indicates that the pollution load index was more stringent at evaluating the degree of pollution of each heavy metal. In addition, the division was more detailed, which enabled the evaluation of each pollution point in the region. This method is suitable to compare the evaluation of regional pollution in several areas and can also reflect the contribution of each heavy metal to the region. The results of different heavy metals in soil under the various evaluation methods differed slightly, primarily owing to the different emphasis of varying evaluation methods. Alternatively, the geoaccumulation index method includes the influence of natural geological effects and anthropogenic activities on heavy metals in soil, and its results are more intuitive. Hadi et al. (2022) evaluated the degree of heavy metal contamination in the soil of the site around Moghan'stannery, Ardabil, Iran, by examining the levels of As, Cd, Cr, Cu, Ni, Pb, and Zn. The average levels of all the heavy metals in the soil, except for Pb, were below the maximum allowable levels. Among them, the levels of Cd and Zn were the lowest and highest, respectively, which showed that contamination with Zn was more serious at this site, while Cd caused less contamination. This differs from the results of this study, which identified higher levels of contamination with Cd, probably owing to differences in the areas studied. Pan et al. (2022) used the pollution load index and health risk evaluation methods to analyze the characteristics of heavy metals in surface sediments of autumnal mangrove wetlands of different origins in eastern Fujian, China, and assess their health risks. They found that the regional pollution load index of heavy metals in the surface sediments of natural mangrove forests was lower than that of artificial mangrove forests. The corresponding pollution levels were all one, which indicates moderate pollution. The non-carcinogenic risk of heavy metals in the surface sediments of autumnal mangrove wetlands was very low for adults, and Cd posed a serious non-carcinogenic risk for children. Pb posed a non-carcinogenic risk to children, and Cd posed a serious carcinogenic risk to adults and children. Ghazaryan et al. (2018) determined and assessed the impact of mining on soil contamination by utilizing various contamination indices. Soil was selected for sampling from 13 points, eleven elements were determined, and the levels of soil contamination were determined using a pollution load index, contamination level (Cd), and a geoaccumulation index. The Cd-based assessment showed that 33.3% of the soil samples had very high levels of contamination.

3.2.3 Human health risk evaluation

3.2.3.1 Potato risk evaluation

The results of the potato health risk assessment are shown in Supplementary Table S4. In the four production areas of Libo, Chishui, Panxian, and Weining, the ADD of potatoes to adults and children was less than one, indicating that the potatoes would not cause risk to the human body after eating. Local residents do not have to worry about the risks posed by consuming potatoes. Although the soil of potato-producing areas was polluted with heavy metals to varying degrees, the potatoes planted showed no obvious harm to human health. The reason might be related to the absorption characteristics of potatoes to heavy metals, and to the fact that people peel potatoes before eating them, thus reducing the intake of heavy metals. Rattan et al. (2005) showed that in addition to oral intake of vegetables, the human body can also ingest heavy metals through other channels, so ADD is not solely responsible for all the health risks of heavy metals found in the human body.

The ADD in children is greater than in adults, indicating a greater potential for food risk in children; thus care is needed to ensure potato food safety to protect children's health. Therefore, measures should be taken to effectively prevent heavy metal pollution sources.

Selahvarzi and Ardakani (2020) evaluated the risk to human health from heavy metals found in the potatoes grown in the Lorestan Province, Iran, and found that the average levels of Cd, Cu, Pb, and Zn in the potato samples were 0.154, 0.148, 0.250, and 0.143 mg kg^{-1}, respectively, which were below the maximum allowable limits established by the World Health Organization, meaning that those potatoes exhibited no obvious potential health risks to human health. However, to ensure food security and reduce the health risks associated with food consumption, special attention should be paid to the content of Cd and Pb.

3.2.3.2 Carcinogenic risk evaluation

The carcinogenic evaluation indices of soil heavy metals for adults and children following different pathways of exposure in each study area are shown in Table 3. As shown in this table, in the study areas of

TABLE 3 Carcinogenic health risk index.

Region	Heavy metal	R ingestion		R dermal contact		R inhalation	
		Adult	Children	Adult	Children	Adult	Children
Libo	Cr	1.37×10^{-4}	3.19×10^{-4}	2.18×10^{-5}	3.57×10^{-5}	0.1	1.25×10^{-7}
	As	3.70×10^{-5}	8.64×10^{-5}	3.60×10^{-7}	5.90×10^{-7}	7.20×10^{-10}	3.21×10^{-10}
	Cd	1.19×10^{-5}	2.77×10^{-5}	4.73×10^{-8}	7.75×10^{-8}	—	—
Chishui	Cr	1.01×10^{-4}	2.35×10^{-4}	1.60×10^{-5}	2.63×10^{-5}	7.56×10^{-2}	9.24×10^{-8}
	As	4.12×10^{-5}	9.12×10^{-5}	4.01×10^{-7}	6.57×10^{-7}	5.01×10^{-10}	2.23×10^{-10}
	Cd	8.25×10^{-6}	1.93×10^{-5}	3.30×10^{-8}	5.39×10^{-8}	—	—
Panxian	Cr	2.24×10^{-4}	5.23×10^{-4}	3.58×10^{-5}	5.86×10^{-5}	0.17	2.06×10^{-7}
	As	1.63×10^{-4}	3.80×10^{-4}	1.59×10^{-6}	2.60×10^{-6}	1.38×10^{-9}	6.14×10^{-10}
	Cd	2.27×10^{-5}	5.29×10^{-5}	9.05×10^{-8}	1.48×10^{-7}	—	—
Weining	Cr	2.11×10^{-4}	4.94×10^{-4}	3.37×10^{-5}	5.52×10^{-5}	0.16	1.94×10^{-7}
	As	7.80×10^{-5}	1.87×10^{-4}	7.79×10^{-7}	1.27×10^{-6}	2.58×10^{-9}	1.15×10^{-9}
	Cd	4.25×10^{-5}	9.91×10^{-5}	1.69×10^{-7}	2.77×10^{-7}	—	—

Libo, Chishui, and Weining, the carcinogenic health risk of Cr to adults and children was greater than that of As and Cd under ingestion exposure. Cr had a very strong carcinogenic risk for adults through inhalation. In the four study areas, Cr had a weak carcinogenic risk to the human body under dermal contact. Cr had an extremely strong carcinogenic risk to adults, and the carcinogenic risk to children was not obvious, while As and Cd had no obvious carcinogenic risk to the human body under the inhalation pathway.

The human health evaluation focuses more on the health risk hazards caused by the intake of soil heavy metals into the human body through different pathways. The results of the carcinogenic risk evaluation in this study indicated that the three heavy metals Cr, As, and Cd that were found in the soil in the four study areas all had different degrees of carcinogenic risk for adults and children through ingestion, and the order of risk was Cr > As > Cd. The carcinogenic risk for humans was greater for children than adults, which is consistent with the results of Xu et al. (2021) and Wang et al. (2021). Exposure to Cd through dermal contact for both adults and children resulted in a carcinogenic risk of Cd that was not significant in the four study areas, while As had some carcinogenic risk for adults or children in some of the study areas. In contrast, Cr had some carcinogenic risk for both adults and children, and the carcinogenic risk for humans was greater for children than adults, which Yang C. C. et al. (2018) attributed to the tendency of children to suck their fingers and play with soil. Children are easily exposed to contaminated heavy metal particles. Only Cr presented a strong carcinogenic risk for adults through inhalation, and the carcinogenic risk for humans was greater for adults than for children. Cr in the soil was the main influencing factor of carcinogenic risk in each study area, and efforts to prevent and control the management of Cr pollution should be undertaken.

3.2.3.3 Non-carcinogenic risk evaluation

The non-carcinogenic evaluation indices of soil heavy metals for adults and children following different pathways of exposure in each study area are shown in Supplementary Table S5, and the total non-carcinogenic health risks (HI) for adults and children following the three pathways of exposure in each study area were 0.36 and 5.74 for Libo, respectively, 0.36 and 5.14 for Chishui, respectively, 1.33 and 16.60 for Panxian, respectively, and 0.74 and 10.95 for Weining, respectively. The non-carcinogenic risk only applied to adults in Panxian. The non-carcinogenic risk was stronger for children in all the study areas, and the non-carcinogenic risk for children was greater than that for adults.

In the study area of Libo, Chishui, and Weining, Cr and As had non-carcinogenic risks to the health of children but insignificant non-carcinogenic risks to the health of adults under ingestion exposure. In the study area of Panxian, the HQ of Cr in the soil to children under ingestion exposure was greater than one, indicating a non-carcinogenic risk to the health of children but an insignificant non-carcinogenic risk to the health of adults under ingestion exposure. As had a non-carcinogenic risk to the health of both adults and children. The non-carcinogenic risk to humans for each heavy metal following exposure through dermal contact and inhalation was not significant. In the four study areas, the non-carcinogenic risk to humans for each type of heavy metal following exposure through dermal contact and inhalation was insignificant.

The results of the evaluation of non-carcinogenic risks in this study indicated that following exposure by ingestion, both the heavy metals Cr and As found in the soils of the four study areas would pose non-carcinogenic risks to the health of children, and As in Panxian would pose non-carcinogenic risks to the health of adults. The non-carcinogenic risks to humans from the heavy metals found in the soils of the four study areas were not significant following exposure by either dermal contact or inhalation. The HQ of soil heavy metals for children was greater than those of the adult HQ following all three routes of exposure, indicating that the non-carcinogenic health risks from soil heavy metals were more likely to affect children. Sarva et al. (2015) examined the risk of heavy metals, including Pb, Cd, Cr, and As, to human health in urban soils in Seri Kembangan, Malaysia. The mean values of the heavy metal hazard index were found to follow the order of Pb (1.27) > Cr (0.11) > Cd (0.05) for non-cancerous patients. The total risk value for cancer from urban soil in Seri Kembangan owing to As (7.2×10^{-6}) was lower than the tolerable lifetime cancer risk for regulatory purposes (1×10^{-5}). Pb contamination was more serious in this area, while Cr and Cd posed health risks to humans as in this study. El-Alfy et al. (2017) evaluated drainage from the Nile Delta, in Egypt. The levels of Fe, Cd, Pb, Ni, Cr, and Co in the soil samples were determined. The HI calculations for HQ of the three different exposure pathways and metals from different locations were found to be >1, indicating the risk of non-carcinogenic effects. Only the CR of Co in the study area did not show a risk to humans. Azam K et al. (2020) evaluated heavy metals in agricultural soil irrigated with stable pond runoff in Birjand, Iran, using the human health risk index and found that the total hazard index values of heavy metals for adults and children through the three routes of exposure were 0.91 and 1.10, respectively, indicating a non-carcinogenic risk for children and less risk for adults, which is consistent with the results of this study. Many studies have shown that children have a higher health risk than adults (Rehman et al., 2017). These findings are also consistent with a study conducted by Karim and Qureshi, (2013). It has also been suggested that this is because children are at a developmental stage and have a higher sensitivity to health risks arising from heavy metals and are more vulnerable to hazards (Yang Q. Q. et al., 2018). This strongly suggests that greater effort should be conducted to protect the health of children from such risks.

4 Conclusion

Soils contaminated with heavy metals affect crop yields and quality and pose a potential threat to human health. In this study, the heavy metal pollution in the soil of some potato-producing areas of Guizhou Province was studied. We collected 89 soil samples from four potato-producing areas (Libo, Chishui, Panxian, and Weining), and the contents of nine heavy metals including Cr, Mn, Ni, Cu, Zn, As, Cd, Sb, and Pb were analyzed and determined. The heavy metal pollution in soil was evaluated by geoaccumulation index, pollution load index, and health risk assessment. The results revealed that Igeo<0 in Libo and Chishui, Igeo>0 in Panxian except for Pb. The Igeo of As and Sb were less than zero in Weining, and other elements had varying degrees of the index. The pollution load index in Panxian (1.47) > Weining (1.39) > Libo (0.67), Chishui (0.67). This showed that Libo and Chishui were not polluted in general, while some heavy metals in Panxian and Weining indicated the soils there were polluted. Human health risk assessment showed that potatoes in the four study areas will not harm the health of local residents through food ingestion. In terms of carcinogenesis, the risk of human carcinogenesis in all study areas under the ingestion pathway was Cr > As > Cd. Under the dermal contact pathway, Cr and As both have certain risks. In the inhalation pathway, Cr has a strong risk for adults. In terms of non-carcinogenic risk, children in the four study areas have a strong risk under each pathway. Heavy metals in the soil of the four study areas all pose health risks to the human body, so attention should be paid to the remediation of heavy metals in the contaminated areas to ensure human health. The data obtained in this study can be used by the public, including health assessors, educators, conservationists, and other stakeholders in Guizhou Province to assess health risks in the relevant areas and take series of measures in future work to minimize the health risks to local residents.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

Author contributions

The study conception and design were mainly performed by JZ and KL. Material preparation was mainly performed by MZ and QC. Data collection and analysis were mainly performed by XH and WL. The revision and editing of the revised manuscript were mainly performed by JZ.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer JZ declared a shared affiliation with the authors to the handling editor at the time of review.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1071353/full#supplementary-material

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