Assessment of heavy metal contaminated agricultural soils affected by mining in Ganzhou China

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ABSTRACT

Soil heavy metal contamination caused by mining is a significant issue in China. The site of this study is located in Ganzhou of Jiangxi province in China. 102 soil samples were collected along the Yangmeijiang River. ICP-MS was used to obtain heavy metal concentrations in the soils. Significant contamination was found in the agriculture soils adjacent to the river and near mining industries. The heavy metal concentrations were high at depths of 20 cm and 40 cm. According to geo-accumulation index $I_{geo}$, the soils were extremely polluted with Cd ($I_{geo} = 4–7$), heavily polluted with As ($I_{geo} = 2–4$), moderately to heavily polluted with Pb, Zn and Cu ($I_{geo} = 0–4$) and virtually unpolluted with Ni, Cr and Hg ($I_{geo} = -3–1$). These results may be a result of large amounts of As, Cd, Pb, Cu and Zn being produced by nearby copper heap leach facilities. Based on USEPA method for health risk assessment, with ingestion being the major pathway for health risks, heavy metals pose a non-carcinogenic risk to adults ($HQ_{max} = 2.87$, $CR_{max} = 4.25 \times 10^{-4}$), but pose both non-carcinogenic and carcinogenic risk to children ($HQ_{max} = 20$, $CR_{max} = 1.15 \times 10^{-3}$). Overall, As, Pb and Cr pose the primary health risks for the soils in the study area.

Keywords: geo-accumulation, health risk assessment, heavy metals, soil contamination

1 INTRODUCTION

Owing to rapid and increasing development of human activities, especially mining and smelting, heavy metals in agricultural soils have become a great concern in China (Lian et al. 2019). Heavy metal pollution has the characteristics of long incubation period, high toxicity and enrichment in food chain, which is harmful to human health. Hence, assessing heavy metal contamination caused by mining is necessary.

Wang et al (2016) studied heavy metal pollution in the farmland surrounding a coal mine in Huainan. They found that Cd, Pb, Cu and Zn were significantly higher than the background values, which were at a mild to moderate risk level. Heavy metal pollution resulting from Cd, As, Cu, Zn and Cr in agricultural soil also has been found near the Xiaojiang River of Jiangxi Province. (Lin et al. 2014).

Fig. 1. Sampling sites location and main mine factories distribution along the Yangmeijiang River.
Due to the influence of mining, pollution in agricultural soils along the Yangmeijiang River, located in Chongyi county, Jiangxi Province is a significant, historical problem. The towns of Changlong, Yangmei and Longgou in the Yangmeijiang River watershed are impacted areas of polluted farmland in Chongyi county.

This study conducted a survey of heavy metal contamination in the agricultural soils along the Yangmeijiang River. The characteristics of soil heavy metal pollution were systematically analyzed. The human health risks of heavy metals were also assessed to provide the scientific basis for prevention of soil heavy metal contamination, ecological environmental protection and healthy living.

2 MATERIALS AND METHODS

2.1 Study area

As shown in Fig. 1, the Yangmeijiang River watershed (25°36′N-25°44′N, 114°18′E-114°38′E) is located in the east of Chongyi County, Ganzhou City, Jiangxi Province, China. There are three towns including Changlong Town, Yangmei Town and Longgou Town along the river. The Yangmeijiang River flows from west to east with a length of 57 km. The total area of the control watershed is about 281 km$^2$. The Yangmeijiang River watershed is rich in mineral resources, but the historical large-scale mining has brought serious environmental pollution and ecological destruction. Currently, there are still five mining plants in Changlong Town.

Based on the field investigation and the distribution of mine factories, 45 sampling points were chosen along the mainstreams of the river. The farmland soil samples were collected within 50 m of the river banks with sampling depths 20, 40 and 60 cm. According to the direction of the river, sampling sections 1-2, 3-7, 8-29, 30-38 and 39-45 are divided into source section, upstream, middle stream, downstream, and tributaries, respectively.

2.2 Sampling and analysis

After the soil samples were obtained, they were crushed, grounded with a mortar, and passed through a 100-mesh nylon sieve. About 0.25–0.5 g of air-dried and screened samples (accuracy 0.0001 g) were then placed into the digestion tank and moistened with a small amount of ultrapure water. In an acid-proof ventilation location, 5mL HNO$_3$ and 5mL HF were added successively to digest the soil sample. After microwave assisted acid digestion, the concentrations of water samples were determined by inductively coupled plasma-mass spectrometry (ICP-MS). The same samples were determined by inductively coupled acid digestion, the concentrations of water samples were determined by inductively coupled plasma-mass spectrometry (ICP-MS). The same samples were determined by inductively coupled acid digestion, the concentrations of water samples were determined by inductively coupled plasma-mass spectrometry (ICP-MS). The same samples were determined by inductively coupled acid digestion, the concentrations of water samples were determined by inductively coupled plasma-mass spectrometry (ICP-MS). The same samples were determined by inductively coupled acid digestion, the concentrations of water samples were determined by inductively coupled plasma-mass spectrometry (ICP-MS). The same samples were determined by inductively coupled acid digestion, the concentrations of water samples were determined by inductively coupled plasma-mass spectrometry (ICP-MS). The same samples were determined by inductively coupled acid digestion, the concentrations of water samples were determined by inductively coupled plasma-mass spectrometry (ICP-MS).

2.3 Geocaccumulation index ($I_{geo}$)

The Geocaccumulation Index, $I_{geo}$, commonly known as Muller Index (Muller 1969), has been applied to the assessment of soil heavy metal pollution, and is defined as follows:

$$I_{geo} = \log_2 \frac{C_n}{1.5 \times B_n}$$

where $C_n$ is the measured value of element $n$ in the sample, and $B_n$ is the geochemical background value of the same element in soil. Sometimes the content of the element in local uncontaminated areas is used as the background value. The constant term 1.5 is used for possible lithological variations in the background value (Fan 2011). The background values for Cu, Pb, Zn, Cd, Ni, Cr, Hg, and As in Jiangxi Province are 20.8, 32.1, 69.0, 0.1, 19.0, 48.0, 0.08 and 10.4 mg/kg respectively (He et al. 2006).

The $I_{geo}$ values of each heavy metal can be separated into seven classifications (Martínez and Polojo 2014): class 0, $I_{geo}$ ≤ 0, uncontaminated; class I, 0 < $I_{geo}$ ≤ 1, weakly contaminated; class II, 1 < $I_{geo}$ ≤ 2, moderately contaminated; class III, 2 < $I_{geo}$ ≤ 3, moderately to heavily contaminated; class IV, 3 < $I_{geo}$ ≤ 4, heavily contaminated; class V, 4 < $I_{geo}$ ≤ 5, heavily to extremely contaminated; class VI, and $I_{geo}$ > 5, extremely contaminated.

2.4 Health risk assessment

Based on the U.S. Environmental Protection Agency (USEPA) method for health risk assessment, the assessments of exposure calculation and risk characterization were included. The calculations of exposure and risk characterization were as follows (Bao et al. 2020):

$$ADD_{ingest} = C_{soil} \times \frac{IE \times EF \times ED \times AT}{BW \times PT} \times 10^6$$

$$ADD_{inhal} = C_{soil} \times \frac{IE \times EF \times ED \times AT}{BW \times PEF}$$

$$ADD_{dermal} = C_{soil} \times \frac{IE \times EF \times ED \times AT}{BW \times PEF} \times 10^{-6}$$

where $ADD_{ingest}$, $ADD_{inhal}$ and $ADD_{dermal}$ are the daily exposure dose to heavy metals (mg/kg/d) via ingestion, inhalation, and dermal contact, respectively, and $C_{soil}$ (mg/kg) is heavy metal concentration in soil. Other parameters are listed in Table 1 (USEPA 2011; HJ 25.3-2014). The calculation of the average daily exposure to carcinogenic heavy metals in children requires a weighted average of the exposure of individual children and adults.

Carcinogenic and non-carcinogenic risk characterization can be obtained from the following equations (Bao et al. 2020):
\[ HQ = \frac{\sum_{i=1}^{n} ADD_{inhale} + ADD_{inhalation} + ADD_{dermal}}{RfD} \]  
(5)

\[ CR = \frac{\sum_{i=1}^{n} ADD_{inhale} + ADD_{inhalation} + ADD_{dermal} \times SF}{i} \]  
(6)

where \( HQ \) is the non-carcinogenic health risk index of element \( i \), \( HQ \) is the sum of \( HQ_i \), \( CR \) is the carcinogenic health risk index of element \( i \), \( CR \) is the sum of \( CR_i \), \( RfD \) is the chronic reference dose of the toxicant and \( SF \) is the oncogenic slope factor. The values of \( RfD \) and \( SF \) are shown in Table 2 (USEPA 2009; USEPA 2013; HJ 25.3-2014). An \( HQ \) greater than 1 indicates that non-carcinogenic risk may occur. Some scholars believe that \( 10^{-6} - 10^{-4} \) is an acceptable range for \( CR \) or \( CR_i \) (Yin et al. 2018).

### 3 RESULTS AND DISCUSSION

#### 3.1 Profile of heavy metal contamination in soil

The results in terms of the pH and heavy metals for the farmland soil in the study area are shown in Table 3. The mean pH of the soil at depths of 20, 40 and 60 cm are 6.49, 6.48 and 6.51, respectively and represent a weakly acidic soil. In addition, the pH variation coefficients of the three depths are all within 10%. Therefore, the soil pH varies over a small range. The average pH values measured in the Le’an River watershed in the northeast

| Symbol | Definition | Unit | Adult value | Children value |
|--------|------------|------|-------------|----------------|
| IngR   | Ingestion rate of soil | mg/d | 100 | 200 |
| EF     | Exposure frequency | day/a | 350 | 350 |
| ED     | Exposure duration | a | 25 | 6 |
| BW     | Body weight of the exposed individual | kg | 56.8 | 15.9 |
| AT     | Average time | d | 26280(carcinogenic) | 2190(non-carcinogetic) |
| InhR   | Inhalation rate of soil | m³/d | 14.5 | 7.5 |
| PEF    | Particle emission factor | m³/kg | 1.36 × 10⁹ | 1.36 × 10⁹ |
| SA     | Exposed skin surface area | cm²/d | 2415 | 1295 |
| SL     | Adherence factor | mg/cm² | 0.2 | 0.2 |
| ABS    | Dermal absorption factor | 0.001 | 0.001 |

| Heavy metal | Ingestation | Inhalation | Dermal contact | Ingestation | Inhalation | Dermal contact |
|-------------|-------------|------------|----------------|-------------|------------|----------------|
| Cu | 4.0 × 10⁻² | - | 4.0 × 10⁻² | - | - | - |
| Pb | 3.5 × 10⁻³ | 3.5 × 10⁻³ | 5.3 × 10⁻⁴ | - | - | - |
| Zn | 3.0 × 10⁻¹ | - | 3.0 × 10⁻¹ | - | - | - |
| Cd | 1.0 × 10⁻³ | 1.0 × 10⁻⁵ | 2.5 × 10⁻⁵ | 6.1 | 6.3 | 6.1 |
| Ni | 2.0 × 10⁻² | 2.3 × 10⁻⁵ | 8.0 × 10⁻⁴ | - | - | - |
| Cr | 3.0 × 10⁻³ | 2.55 × 10⁻⁵ | 7.5 × 10⁻⁵ | - | 42 | - |
| Hg | 3.0 × 10⁻⁴ | 3.0 × 10⁻⁴ | 2.1 × 10⁻⁵ | - | - | - |
| As | 3.0 × 10⁻⁴ | 1.5 × 10⁻⁵ | 3.0 × 10⁻⁴ | 1.5 | 4.3 × 10⁻³ | 1.5 |

Table 2. Exposure parameters for heavy metals (USEPA 2011; HJ 25.3-2014).

Table 3. Profile of heavy metals in the study area (mg/kg).
of Jiangxi Province were 6.63-6.68 (Ji et al. 2018), which are close to those in this study.

The average concentration (mg/kg) of the eight heavy metals in Table 3 at the three depths are generally higher than the environmental background values of heavy metals in the soil of Jiangxi Province. This result indicates that the study area may be polluted. The mean value concentrations of the eight heavy metals vary with respect depth in the order 40 cm > 20 cm > 60 cm, and the coefficients of variation (CV) are the largest at a depth of 40 cm. Therefore, this study focuses on soil pollution at a depth of 40 cm. Liu et al. (2016) noted that the CV reflects the influence of human activities on heavy metal distribution, i.e., an increase in CV reflects an increase interference by human activities. Hence, the soil at 40 cm is most susceptible to the influence of surrounding environment and human activities in Yangmeijiang River watershed. Subsequent assessments were based on data at a depth of 40 cm.

3.2 Results of Geaccumulation Index Assessment

As shown in Fig. 2, ignoring the individual extreme data, the soils were extremely polluted with Cd ($I_{geo} = 4–7$), heavily polluted with As ($I_{geo} = 2–4$), moderately to heavily polluted with Pb, Zn and Cu with ($I_{geo} = 0–4$), virtually unpolluted with Ni, Cr and Hg ($I_{geo} = -3–1$). In addition, heavy metal contamination increases dramatically at sampling sites 10–12 and 16–20. Serious contamination was found in the agriculture soils adjacent to the river near the mining industries.

There may be several reasons for result. A large amount of As, Cd, Pb, Cu and Zn were produced by the copper heap leach facilities, which are located close to the mine factories, downstream of the mine. The pollution also may be a result of sewage discharged from these facilities. Yu et al. (2020) revealed that heavy metal pollution near the Le'an River in Jiangxi Province was the highest near the mining area during the dry period, and the highest in the downstream during the normal and wet periods. Also, these locations are near the convex banks of the Yangmeijiang River where the river flow velocity decreases rapidly, such that heavy metals can be easily deposited and migrate through the farmland soil along the river via groundwater and irrigation. Chen (2007) also found a surge in heavy metals along the convex banks of rivers in the Suzhouhe River of Shanghai.

3.3 Results of Health Risk Assessment

As shown in Table 4, based on the USEPA non-carcinogenic health risk assessment, the non-carcinogenic risk of adults and children for different exposure pathways are all shown as $HQ_{ingest} > HQ_{inhale} > HQ_{dermal}$ for the same element. This relative trend indicates that accidental ingestion of soil particles is the main exposure pathway for non-carcinogenic risk. The non-carcinogenic risk of eight heavy metals are in the order: As > Cr > Pb > Cd > Cu > Ni > Zn > Hg.

As for adults, the average values of both $HQ$ and total $HQ$ for each heavy metal are less than unity. The maximum value of $HQ$ for As is 2.20 and the maximum of total $HQ$ is 2.87. These results show that all of the heavy metals except As have yet to reach the non-carcinogenic risk for adults. But the risk prevention of As should be taken seriously. In general, children have a higher risk than adults and are more likely to be exposed to non-carcinogenic health risk. In addition, the mean and maximum values of the children's $HQ$ for As are both significantly greater than unity (4.46 and 15.7, respectively). The mean and maximum values of the children's total $HQ$ were 5.46 and 20, respectively. These results indicate that the soil in the Yangmeijiang River watershed poses non-carcinogenic risks to children, and greater efforts should be made to prevent and abate As, Pb and Cr pollution. Fan (2011) noted that As is usually associated with non-ferrous metals, so in the smelting of non-ferrous ores, a large amount of arsenide is discharged into the soil, water and atmosphere. The mining and smelting of nonferrous metals are the primary source of As pollution.

As shown in Table 5, based on the carcinogenic health risk assessment of the USEPA, the carcinogenic risk of adults and children for different exposure pathways are in the order: $CR_{ingest} > CR_{dermal} > CR_{inhale}$. The accidental ingestion of soil particles is also the primary exposure pathway of non-carcinogenic risk. The non-carcinogenic risk of heavy metal elements decreases in the order: As > Cr > Cd.

As for adults, the individual and total $CR$ are both in the range $10^{-6}$–$10^{-4}$, and the carcinogenic risk is acceptable, but it is still higher than the soil treatment limit value of $10^{-4}$ proposed by USEPA. As for children, the mean and maximum values of $CR$ for a single element are in the range $10^{-6}$–$10^{-4}$. Nonetheless, the maximum of total $CR$ is $1.15 \times 10^{-3}$, which is beyond the acceptable range and represents a carcinogenic risk. Moreover, this risk is primarily due to oral ingestion of As. Therefore, preventing the carcinogenic risk of As is urgent. Zhou (2016) also found that As was the primary element that caused local residents to be exposed to non-carcinogenic risk in farmland soil around a tailings pond in Hunan Province.
Fig. 2. Spatial distribution of $I_{\text{geo}}$ of Cd, As, Pb, Cu, Zn, Cr, Ni and Hg along the Yangmeijiang River.

Table 4. Non-carcinogenic health risk index of heavy metals in soil.

| Heavy metal | $HQ_{\text{ingest}}$ Adults | $HQ_{\text{ingest}}$ Children | $HQ_{\text{inhal}}$ Adults | $HQ_{\text{inhal}}$ Children | $HQ_{\text{derma}}$ Adults | $HQ_{\text{derma}}$ Children | Adults | Children |
|-------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|--------|----------|
| Cu          | Maximum                     | 2.96×10^{-2}               | 2.12×10^{-1}               | -                           | 1.43×10^{-4}               | 2.74×10^{-4}               | 2.98×10^{-2} | 2.12×10^{-2} |
|             | Mean                        | 6.93×10^{-3}               | 4.95×10^{-2}               | -                           | 3.35×10^{-5}               | 6.41×10^{-5}               | 6.97×10^{-3} | 4.96×10^{-2} |
| Pb          | Maximum                     | 1.94×10^{-1}               | 1.38                       | 2.06×10^{-5}               | 3.81×10^{-5}               | 6.17×10^{-3}               | 1.18×10^{-2} | 2.00×10^{-1} |
|             | Mean                        | 4.34×10^{-2}               | 3.10×10^{-1}               | 4.63×10^{-6}               | 8.55×10^{-6}               | 1.38×10^{-3}               | 2.65×10^{-3} | 4.48×10^{-3} |
| Zn          | Maximum                     | 7.32×10^{-3}               | 5.23×10^{-2}               | -                           | 3.54×10^{-5}               | 6.78×10^{-5}               | 7.36×10^{-3} | 5.24×10^{-3} |
|             | Mean                        | 1.73×10^{-3}               | 1.23×10^{-2}               | -                           | 8.33×10^{-5}               | 1.60×10^{-5}               | 1.73×10^{-3} | 1.23×10^{-2} |
| Cd          | Maximum                     | 3.78×10^{-2}               | 2.70×10^{-1}               | 1.61×10^{-4}               | 2.98×10^{-4}               | 1.83×10^{-2}               | 3.50×10^{-2} | 5.62×10^{-2} |
|             | Mean                        | 8.80×10^{-3}               | 6.28×10^{-2}               | 3.75×10^{-5}               | 6.93×10^{-5}               | 4.25×10^{-3}               | 8.14×10^{-3} | 1.31×10^{-2} |
| Ni          | Maximum                     | 1.11×10^{-2}               | 7.92×10^{-2}               | 1.03×10^{-3}               | 1.90×10^{-3}               | 1.34×10^{-3}               | 2.56×10^{-3} | 3.34×10^{-2} |
|             | Mean                        | 3.29×10^{-3}               | 2.35×10^{-2}               | 3.05×10^{-4}               | 5.63×10^{-4}               | 3.97×10^{-4}               | 7.60×10^{-4} | 3.99×10^{-3} |
| Cr          | Maximum                     | 2.98×10^{-1}               | 2.13                       | 3.74×10^{-3}               | 6.91×10^{-3}               | 5.76×10^{-3}               | 1.10×10^{-2} | 3.60×10^{-1} |
|             | Mean                        | 5.63×10^{-2}               | 4.02×10^{-1}               | 7.06×10^{-4}               | 1.30×10^{-3}               | 1.09×10^{-2}               | 2.08×10^{-2} | 6.78×10^{-2} |
| Hg          | Maximum                     | 3.91×10^{-3}               | 2.79×10^{-1}               | 4.17×10^{-7}               | 7.70×10^{-7}               | 2.70×10^{-6}               | 5.17×10^{-6} | 4.18×10^{-6} |
|             | Mean                        | 4.64×10^{-4}               | 3.31×10^{-2}               | 4.94×10^{-8}               | 9.13×10^{-8}               | 3.20×10^{-5}               | 6.13×10^{-5} | 4.96×10^{-5} |
| As          | Maximum                     | 2.19                       | 1.56×10^{-1}               | 4.66×10^{-3}               | 8.62×10^{-3}               | 1.06×10^{-2}               | 2.02×10^{-2} | 2.20×10^{-2} |
|             | Mean                        | 6.37×10^{-1}               | 4.55                       | 1.36×10^{-3}               | 2.51×10^{-3}               | 3.08×10^{-3}               | 5.90×10^{-3} | 6.42×10^{-3} |
| $HQ$        | Maximum                     | 2.77                       | 1.98×10^{-1}               | 9.61×10^{-3}               | 1.78×10^{-2}               | 9.44×10^{-2}               | 1.81×10^{-1} | 2.87×10^{-1} |
|             | Mean                        | 7.58×10^{-1}               | 5.42                       | 2.41×10^{-3}               | 4.46×10^{-3}               | 2.01×10^{-2}               | 3.84×10^{-2} | 7.81×10^{-1} |

|$HQ_{\text{ingest}}$ is the health risk index of ingestion, $HQ_{\text{inhal}}$ is the health risk index of inhalation, and $HQ_{\text{derma}}$ is the health risk index of dermal contact. The values are calculated based on the maximum and mean concentrations of each heavy metal in the soil. The $HQ$ values are calculated considering all three exposure routes. The health risk index is categorized as follows: not contaminated, slightly contaminated, moderately contaminated, heavily contaminated, and extremely contaminated.
Table 5. Carcinogenic health risk index of heavy metals (As, Cd, Cr) in soil.

| Heavy metal | CR<sub>ingest</sub> | CR<sub>inhale</sub> | CR<sub>dermal</sub> | CR<sub>Adults</sub> | CR<sub>Children</sub> | CR<sub>Adults</sub> | CR<sub>Children</sub> |
|-------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Cd          | Max: 8.01×10<sup>-5</sup> | 2.17×10<sup>-4</sup> | 8.82×10<sup>-9</sup> | 1.27×10<sup>-8</sup> | 3.87×10<sup>-7</sup> | 5.63×10<sup>-7</sup> | 8.05×10<sup>-5</sup> |
|             | Mean: 1.86×10<sup>-5</sup> | 5.06×10<sup>-6</sup> | 2.05×10<sup>-9</sup> | 2.96×10<sup>-8</sup> | 9.00×10<sup>-8</sup> | 1.31×10<sup>-7</sup> | 1.87×10<sup>-5</sup> |
| Cr          | Max: 3.92×10<sup>-4</sup> | 9.28×10<sup>-4</sup> | 1.04×10<sup>-6</sup> | 1.51×10<sup>-6</sup> | 1.65×10<sup>-6</sup> | 2.41×10<sup>-6</sup> | 3.43×10<sup>-4</sup> |
|             | Mean: 9.96×10<sup>-5</sup> | 2.70×10<sup>-4</sup> | 3.04×10<sup>-11</sup> | 4.39×10<sup>-11</sup> | 4.81×10<sup>-7</sup> | 7.02×10<sup>-7</sup> | 1.00×10<sup>-4</sup> |
| As          | Max: 4.22×10<sup>-4</sup> | 1.15×10<sup>-3</sup> | 1.40×10<sup>-6</sup> | 2.02×10<sup>-6</sup> | 2.04×10<sup>-6</sup> | 2.97×10<sup>-6</sup> | 4.25×10<sup>-4</sup> |
|             | Mean: 1.18×10<sup>-4</sup> | 3.21×10<sup>-4</sup> | 2.64×10<sup>-7</sup> | 3.82×10<sup>-7</sup> | 5.71×10<sup>-7</sup> | 8.34×10<sup>-7</sup> | 1.19×10<sup>-4</sup> |

4 CONCLUSIONS

A total of 102 soil samples were collected and analyzed along the Yangmeijiang River. The Geoaccumulation Index and health risk assessment were used to provide the scientific basis for soil heavy metal contamination prevention and ecological environmental protection.

The concentration of Cu, Pb, Zn, Cd, Ni, Cr and Hg in the agricultural soil along the Yangmeijiang River are all generally higher than the environmental background values in Jiangxi Province. The vertical distribution in the mean concentration of the eight heavy metals varied with depth in the order: 40 cm > 20 cm > 60 cm. The coefficients of variation for the heavy metals concentrations were the greatest at 40 cm, which is likely due to the influence of human activities.

The results of the Geoaccumulation Index indicated that the soils were extremely polluted with Cd ($I_{geo} = 4–7$), heavily polluted with Pb, Zn and Cu ($I_{geo} = 2–4$) and moderately to heavily polluted with Pb, Zn and Cu ($I_{geo} = 0–4$), and virtually unpolluted with Ni, Cr and Hg ($I_{geo} = -3–1$). Significant contamination was found in the agriculture soils adjacent to windings of the river near the mining industries. This may be due to a sharp increase in heavy metal deposition as the velocity of flow slows in the convex bank of downstream from the mine. The heavy metals may be derived subsequently from groundwater and irrigation.

Based on health risk assessment, compared to adults, children are more susceptible to the heavy metal contamination along the Yangmeijiang River. Ingestion is the major pathway for both carcinogenic and non-carcinogenic risks. Heavy metals pose primarily a non-carcinogenic risk to adults with $HQ_{max} = 2.87$ and $CR_{max} = 4.25×10^{-4}$ but pose both non-carcinogenic and carcinogenic risks to children with $HQ_{max} = 20$ and $CR_{max} = 1.15×10^{-3}$. Overall, soil pollution by As, Pb and Cr represents the primary risk in the study area, and the high-risk hazards of As to children need to be addressed.

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