Distribution and Health Risk Assessment of Dissolved Metal in Surface and overlying water at the Xiangjiang River in Southern China

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Abstract
Background: Metal pollution in rivers has been a serious environmental problem in aquatic ecosystems. The Xiangjiang River is an important drinking water resource for the Hunan province of China. It is crucial to ascertain the pollution status and health risk of metal in this river. In this study, both surface and overlying water samples were collected from the Xiangjiang River and 12 dissolved metals (Mg, V, Cr, Mn, Fe, Co, Ni, Zn, As, Cd, Sb, and Ba) were investigated.

Results: Average concentrations fell in the order of dissolved metal Mg > Mn > Ba > Fe > Zn > As > Sb > Ni > Cd > V > Cr > Co, all of which were lower than the threshold values for drinking water guidelines of China. There was no significant difference in metal concentrations between surface and overlying water. Health risk assessment shows carcinogenic risk (CR) values of As and Cd were higher than the critical value, and children are more susceptible to the health risk of dissolved metals caused by drinking ingestion.

Conclusion: The water quality in this area was good overall. Metals pollution appeared more serious in the midstream and on the southern side of the investigated area. Anthropogenic activities are the main source of heavy metals in the river. Dissolved metals have health risk to local children with hazard index (HI) > 1. While more attention should be paid to As and Cd, which had a potential carcinogenic risk to human. The results provide guidance for controlling metal pollution and protecting drinking water sources in the Xiangjiang River.

Background
The health of surface water is closely related to human society, because surface water is not only an important source of drinking water for human beings, but also a living environment for aquatic plants and animals, and can also be used as irrigation water for crops [1, 2]. Surface water is an important part of urban ecosystem, mainly rivers and lakes, which play an irreplaceable role in urban development and human life. Urban rivers are an important sink of contaminants, a large number of contaminants, including trace metals, organic and inorganic compounds, etc., have been released into rivers and contaminated water because of the development of industrialization and population growth [3, 4].
Among these contaminants found in rivers, metal contaminants are a significant global concern because of their persistence, environmental toxicity, bioaccumulation, etc [5–8]. Human beings can be threatened by metals in water bodies directly by drinking water, or indirectly, by food chain [9]. There are many sources of metal in water, mainly including nature sources, such as geological erosion, weathering, and precipitation; anthropogenic activities sources, such as mining; metal processing; industrial wastewater; and the application of pesticides and fertilizers [10–12]. Many studies have shown that some toxic trace metals have triple effects (carcinogenesis, teratogenesis and mutagenesis). Among the many metal elements, some elements are necessary for human metabolism, such as Cu, Zn, Fe, and Mn, but above a certain level has toxic effects. Some elements have no physiological activity, such as As, Cd, Hg, and Pb, which can damage the human's endocrine system and are listed as environmental endocrine disruptors by the U.S. environmental protection agency (EPA) [13–15]. Therefore, it is of great practical significance to investigate and assess the distribution and human health risk of metals in water bodies.

The effect of human beings threatened by metals in water bodies is particularly significant in some developing countries including China. The Xiangjiang River has become one of the most seriously and heavily polluted rivers in China over the past few decades due to the metallurgical industries and wastewater discharge from mining [16]. The Xiangjiang River is the second tributary of the Yangtze River and an important drinking water source in south China. It flows through the Hunan province and supports the major cities, providing service to industry agriculture and population [14, 17]. There are many researchers have studied the distribution and risk assessment of heavy metals in surface water or sediment of the Xiangjiang River [18, 19]. Prevalently, Cd, Cr, Zn, Cu, Ni, As and Pb, were previously studied in the Xiangjiang River, while some unheeded metals such as Mg, Co, V, Mn, Fe, Ba and Sb have been overlooked [20]. Moreover, riverine sediments, as a reservoir of contaminants, accumulates a large amount of metals. In the case of external environmental disturbance, the metals in the sediments will be desorbed and released into the overlying water and then resuspend into the surface water [21, 22]. Thus, there is a lack of research on the vertical distribution of metals in the water and a systematic study is necessary to associate the surface and overlying water bodies with
the distribution, characteristics, health risk assessment, and possible sources of metals.

In this work, we collected 60 surface and overlying water samples from the Zhuzhou and Xiangtan Reaches of the Xiangjiang River as a typical area in order to (1) characterize the vertical distributions of 12 metals (Mg, V, Cr, Mn, Fe, Co, Ni, Zn, As, Cd, Sb, and Ba) in the water bodies, (3) identify possible sources of metals pollution from principle component analysis (PCA) and Pearson's correlation analysis, and (3) assess the potential human health risk posed by the target metals in the river water. The results are expected to provide basic data and scientific evidence for the prevention and control of metal pollution in drinking water sources and help in the development of appropriate water quality management strategies in nearby areas and similar riverine systems.

Materials And Methods

Study area
The Xiangjiang River is one of the main tributaries of the Yangtze River and a key drinking water source in south China. This basin covers 94,721 km² (44.6%) and supports > 30 million residents of the Hunan Province [23]. It flows from south to north en route 6 major cities in Hunan, i.e., Yongzhou, Hengyang, Zhuzhou, Xiangtan, Changsha, and Yueyang, and finally joins the Yangtze River via the Dongting Lake. The Hunan Province is known as the “Nonferrous Metal Village” because of its abundant mineral resources (e.g., Cd, Zn, Pb, Cu, etc.) [24]. However, the mining and smelting of nonferrous metals over the past years has caused severe metal pollution to the Xiangjiang River, especially in the Zhuzhou and Xiangtan sections [25]. These two cities at the east of the Hunan Province is at the lower reaches of the Xiangjiang River with typical subtropical monsoon climate. The average annual temperature is 16–18 °C. The average annual rainfall is approximately 1,400 mm [18, 26].

Sample collection and analysis
To investigate the metal contamination status and health risk assessment of the drinking water source, 10 sampling sites (S1 – S10) were selected from upstream to downstream regions of the investigated area (Fig. 1). Specifically, the 10 sampling sites covered 2 cities: S1-S8 from Zhuzhou; S9 and S10 from Xiangtan, and the S10 located at the intake of the water works, which supplies the urban residents. Detailed information about these sampling sites is presented in Table S1. Surface,
and overlying water samples (2 L) were collected in the north, middle and south sides of the Xiangjiang River in August, 2011 using a hydrophore at each sampling site. Among them, the samples collected at 0-15cm on the surface of river water were defined as surface water. Samples collected about 10 cm above the river-bottom sediment junction were identified as overlying water. Each sample consists of a mixture of three samples from one sampling site. All samples were filtered through 0.45 µm micropore membranes and then transported immediately to the laboratory for storage at −4 °C until further analysis.

Water samples analysis were conducted at the National Engineering Laboratory for Lake Pollution Control and Ecological Restoration of the Chinese Academy of Environmental Sciences. The concentrations of 12 dissolved metals ((i.e., Mg, V, Cr, Mn, Fe, Co, Ni, Zn, As, Cd, Sb, and Ba) were analyzed using inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7500 series, USA). The recovery rates of standard reference metals were 90–110%. All reagents and solvents used in the water samples analysis were of analytical grade. The results were within the acceptable level of uncertainty given by certified values.

Human health risk assessment

Human health risk assessment is an effective method widely used in aquatic environmental pollution assessment. It works by establishing a qualitative and quantitative relationship between water pollutants and human health. Its purpose is to assess the potential risks of water pollutants to human health by determining the intensity of pollutants exposure and their tendency, conducting a pollutant exposure assessment, and a dose–response relationship of pollutants and the human health. We employed the health risk assessment methods proposed by the US EPA. Human beings can be exposed by metals in river water could occur through three pathways including direct ingestion, inhalation through the mouth and nose, and dermal absorption. However, direct ingestion and dermal absorption are the main pathways [27, 28]. Thus, the average daily dose (ADD) into human bodies by the two pathways was computed according to Eqs. (1) and (2), which is recommended by the U.S. Environmental Protection Agency:
where, \( \text{ADD}_{\text{ingestion}} \) and \( \text{ADD}_{\text{dermal}} \) indicate the average daily dose via ingestion and dermal adsorption (mg/kg/day), respectively; \( CW \) is the average concentration of the metals in water (µg/L); \( IR \) is the daily ingestion rate (L/day); \( EF \) is the exposure frequency (day/year); \( ED \) is the exposure duration (year); \( BW \) is the average body weight (kg); \( AT \) is the average time of exposure (days); \( K_p \) is the dermal permeability coefficient in water (cm/h); and \( SA \) is the exposed skin area (cm\(^2\)); \( ET \) is the exposure time (h/day). These parameters are listed in Supplementary Table S2 and S3, referenced from [27, 29] and the US EPA (2009).

Non-carcinogenic and carcinogenic risks were used for expressing the health risk for metals in this paper. The noncarcinogenic risk, characterized by hazard quotient (HQ), was reckoned by dividing the average daily dose of contaminants from each exposure pathways (ingestion, dermal) with corresponding reference dose (RfD) using Eqs. (3) and (4). Additionally, the comprehensive non-carcinogenic risks posed by metal through the two exposureways were measured by the hazard index (HI) (Eq. (5)). An HQ > 1 or HI > 1 indicated that hazards may be caused by metals to human health [30].

\[
\text{HQ} = \frac{\text{ADD}}{\text{RfD}} \quad (3)
\]

\[
\text{RfD}_{\text{dermal}} = \text{RfD} \times \text{ABS}_{\text{GI}} \quad (4)
\]

\[
\text{HI} = \sum_{i=1}^{n} \text{HQ}_i \quad (5)
\]

where RfD originates from a risk-based concentration table. The carcinogenic risks (CR) were characterized by Eq. (6), as described by [28]. The calculated value represents the probability of
catching cancer during lifetime because of carcinogenic exposure. The acceptable or tolerable range of CR values ranges from $10^{-6}$ to $10^{-4}$ were adopted by the U.S. EPA (2009).

$$CR = ADD \times CSF \ (6)$$

Where CSF is cancer slope factor $(\mu g/kg/day)^{-1}$. In this study, we only computed the CR values for As, Cr and Cd, because these metals were the carcinogenic elements among the examined metals [28]. All the listed parameters for the computation process are shown in Table S2.

**Statistical analysis**

To explore mutual correlations among water quality parameters and metals in water samples, correlation analysis characterized by Pearson’s correlation matrix was conducted using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). Principal component analysis (PCA) was performed to identify the source of the metals. PCA was performed using Canoco 5.0 (Biometris, Netherlands). Data analyses and statistical tests were performed using Origin 9 and Microsoft Excel 2010.

**Results And Discussion**

**Distribution characteristics of metals**

Table 1 summarize the mean concentrations (ug/L) of the 12 dissolved metals in the surface and overlying water samples from the Xiangjiang River. All 12 heavy metals were detected in all water samples. In general, in surface water samples, the concentrations of Mg, V, Cr, Mn, Fe, Co, Ni, Zn, As, Cd, Sb, and Ba ranged in 4469.25 – 5889.31, 0.21 – 1.19, 0.02 – 0.98, 0.39 – 286.70, 0.64 – 432.30, 0.04 – 1.96, 0.88 – 13.27, 2.78 – 57.87, 3.95 – 8.86, 0.22 – 2.43, 1.79 – 2.8, and 29.10 – 38.17 ug/L, respectively (Fig. 2). And the mean concentrations in surface water ranked in the order of Mg (4833.21 ug/L) > Mn (32.60 ug/L) > Ba (31.27 ug/L) > Fe (17.52 ug/L) > Zn (16.76 ug/L) > As (5.55 ug/L) > Sb (1.93 ug/L) > Ni (1.86 ug/L) > Cd (1.05 ug/L) > V (0.58 ug/L) > Cr (0.27 ug/L) > Co (0.19 ug/L). The average concentrations of 12 metals in the surface water were similar with in the overlying water, while Fe had relatively low concentration in overlying water, with concentrations ranged in 0.24 – 53.16 ug/L, showed significant difference ($p<0.05$).

Compared with the permissible limits of drinking water quality standards (Table 1), the means concentrations of metals in the study area were all lower than the criteria limit set by China (2007), US EPA(2012) and WHO (2011) in both surface and overlying water. It is worth mentioning that there
is still one surface water sample in which the concentration of Fe exceeds the permissible limit of drinking water quality standards of China and WHO. In addition, two surface and overlying water samples respectively exceeded the permissible limits of China, but were lower than the WHO’s permissible limits. Thus, the above results indicating the water quality of the Xiangjiang River was good overall.

Table 1 also summarizes the concentrations of the examined metals in other other rivers in southern China [5, 31–33]. Compared with other rivers, the distribution of metals concentrations is clearly different among different rivers. Co, Zn, As and Cd concentrations were higher than Yangtze River and Pearl River; the Mn and Ni concentrations were higher than Upper Han River. The metals V and Sb concentrations were particularly higher than others. The distinct distribution differences of metals in different rivers may be associated with temporally specific and metal-specific [33]. Overall, the Xiangjiang River is clearly slightly polluted by metals than other rivers in southern China.

Table 1
Concentration of dissolved metals (µg/L) in the Xiangjiang River and of other rivers in southern China, and comparison with drinking water quality criteria.

| Ref. | Surfac. this study | Overlying | Yangtze River [31] | Pearl River [32] | Upper Han River [5] | Southeastern hilly area rivers [33] | Water quality criteria for drinking water |
|------|--------------------|-----------|-------------------|-----------------|------------------|-------------------------------------|-----------------------------------------|
|      | Mg                 | V         | Cr                | Mn              | Fe               | Co                   | Ni                     | Zn                      | As                     | Cd                      | Sb                      | Ba                      |
|      | 4833.6             | 0.58      | 0.27              | 32.60           | 17.52            | 0.19                 | 1.86                   | 16.76                  | 5.55                   | 1.05                   | 1.93                   | 31.27                  |
|      | 4862.0             | 0.55      | 0.25              | 28.80           | 8.67             | 0.17                 | 1.77                   | 16.34                  | 5.50                   | 1.03                   | 1.94                   | 31.42                  |
|      | 4.54               | 0.07      | 1.35              | 9.53            | 3.05             | 0.09                 | 1.19                   |                       |                       |                       |                       |                       |
|      | 1.70               | 1.06      | 1.89              | 3.61            | 0.04             |                       |                       |                       |                       |                       |                       |                       |
|      | 69.71              | 8.11      | 30.50             | 30.65           | 2.23             | 1.71                 | 14.16                  | 2.30                   | 41.27                  | 87.79                  |                       |                       |
|      | 1.10               | 2.05      | 45.59             | 0.11            | 2.19             | 32.45                | 2.02                   | 0.30                   | 1.22                   |                       |                       |                       |

Water quality criteria for drinking water

| Chinaa | US EPA b | WHOC |
|--------|----------|------|
| Mg     | 50       |      |
| V      | 50       |      |
| Cr     | 100      |      |
| Mn     | 300      |      |
| Fe     | 20       | 1000 |
| Co     | 1000     | 10   |
| Ni     | 5        | 5    |
| Zn     | 700      |      |
| As     | 700      |      |
| Cd     | 5000     | 10   |
| Sb     | 5000     | 5    |
| Ba     | 20000    | 6    |

| Mg     | 50       |      |
| V      | 500      |      |
| Cr     | 300      |      |
| Mn     | 40       | 70   |
| Fe     | 5000     | 10   |
| Co     | 5000     | 5    |
| Ni     | 20000    | 6    |
| Zn     | 700      |      |
| As     | 700      |      |
| Cd     | 5000     | 10   |
| Sb     | 5000     | 5    |
| Ba     | 20000    | 6    |

Figure 2 and Fig. 3 illustrate the spatial distribution of metals concentration in surface and overlying water. There variation of metal concentrations were small, but most metals showed similar trends,
except for Cr and As. The concentrations gradually increases as the water flows and peaks at midstream sites (S3-S6), then gradually decreases at the downstream sites (S7 – S10). There may be point source pollution near the midstream of study area. Several studies have been conducted on the local mining activities and development of agriculture were the primary sources of metal pollution in the Xiangjiang River [19, 23]. Besides, most metals have significantly higher concentration in the south side than the middle and north side (Fig. 4). In particular, the concentrations of Mn and Fe in the south is nearly twice as much as in the middle and the north. The asymmetrical concentration can be associated with the nonferrous metal mining and smelting plants in the south of Xiangjiang River that produce Mn, Fe, and alloys and discharge wastewater into river.

Identification of the sources of heavy metals

Pearson's correlation analysis and principal components analysis (PCA) were used to analyze the probable source of the metals. The correlation analysis among metals is shown in Table 2. Significant positive correlation was observed among Mg, Mn, Co, Zn, Sb and Ba with a p < 0.01, indicating that they have homology and compound contamination to a great extent [34]. There are significant positive correlations among V, Cd, Fe, and As with coefficients ranged in 0.39–0.96 (p < 0.01 or p < 0.05), indicating that they might have similar sources. And Ni is not related to all metals except for Mg, indicating that the source of Ni might different from other metals.

|        | Mg  | V   | Cr  | Mn  | Fe  | Co  | Ni  | Zn  | As  | Cd  | Sb  | Ba  |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Mg     | 1.00| 0.05| -0.12| 0.61**| 0.08| 0.69**| 0.38* | 0.61**| -0.09| 0.32| 0.83**| 0.69**|
| V      |     | 1.00| 0.76**| 0.36| 0.96**| 0.34| 0.06 | 0.50**| 0.61**| 0.77**| -0.14| 0.47**|
| Cr     |     |     | 1.00| 0.18| 0.74**| 0.16| -0.08| 0.35 | 0.70**| 0.70**| -0.29| 0.26  |
| Mn     |     |     |     | 1.00| 0.49**| 0.97**| 0.18 | 0.83**| -0.17| 0.67**| 0.69**| 0.85**|
| Fe     |     |     |     |     | 1.00| 0.47**| 0.02 | 0.57**| 0.50**| 0.77**| -0.08| 0.48**|
| Co     |     |     |     |     |     | 1.00| 0.22 | 0.85**| -0.17| 0.64**| 0.75**| 0.85**|
| Ni     |     |     |     |     |     |     | 1.00| 0.14 | -0.05| 0.08 | 0.35 | 0.37* |
| Zn     |     |     |     |     |     |     |     | 1.00| 0.06 | 0.82**| 0.55**| 0.82**|
| As     |     |     |     |     |     |     |     |     | 1.00| 0.39 | -0.33| 0.03  |
| Cd     |     |     |     |     |     |     |     |     |     | 1.00| 0.18 | 0.73**|
| Sb     |     |     |     |     |     |     |     |     |     |     | 1.00| 0.67**|
| Ba     |     |     |     |     |     |     |     |     |     |     |     | 1.00 |

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

PCA was performed to further identifying the possible sources of metals based on the determined
concentrations of metals with varimax rotation (Table 3). The KMO test gives $> 0.7$ and Bartlett test gives $p < 0.001$, indicating that PCA can be used to reduce the dimensionality of variables [35]. In this regard, three principal components (factor 1, factor 2 and factor 3) with eigenvalues $> 1$ were extracted, explained 86.77% of the entire variance (43.07% of the variance was explained by factor 1, 33.34% by factor 2, and 10.36% by factor 3). According to the absolute loading values of $> 0.75$, 0.75 − 0.50 and 0.50 − 0.30, factor loading was divided into "strong", "moderate", and "weak", respectively [36]. Factor 1 had strong positive loading on metals Mg, Mn, Co, Zn, Sb, and Ba; moderate positive loading on Cd, and weak positive loading on Fe. Factor 2 had high positive loading on V, Cr, Fe, Cd, and As, and weak positive loading on Zn and Ba. Finally, the metals Ni had relatively higher loadings, and Mg, Sb had weak positive loading for factor 3. Principal component 1 and 2 were from the anthropogenic activities sources, including mining; metal processing; industrial or agricultural wastewater. The co-occurrence of Mg, Mn, Zn, Sb, Co and Ba resulted from a large amount of wastewater from many industrial enterprises along the Xiangjiang River [23, 37]. In detail, Zn, Mn and Sb probable originated from mining processes due to the rapid development of the mining industry in Hunan province. Cr, Fe were affected by industrial wastewater is mainly affected by the discharge of wastewater from various industrial processes, such as electroplating and alloys [26]. Principal component 3 explained few (10.36%) of the total variance and was dominated by Ni. Natural activities mainly contributed to the metal pollution in factor 3. Previous studies of the Zijiang (southern Chian) have also found Ni to be a natural source[38].

|                | factor 1 | factor 2 | factor 3 |
|----------------|----------|----------|----------|
| Mg             | 0.75     | -0.11    | 0.44     |
| V              | 0.22     | 0.92     | 0.00     |
| Cr             | 0.02     | 0.91     | -0.09    |
| Mn             | 0.95     | 0.16     | -0.04    |
| Fe             | 0.33     | 0.87     | -0.10    |
| Co             | 0.97     | 0.14     | 0.02     |
| Ni             | 0.17     | 0.00     | 0.91     |
| Zn             | 0.86     | 0.37     | -0.02    |
| As             | -0.28    | 0.80     | 0.18     |
| Cd             | 0.59     | 0.73     | -0.05    |
| Sb             | 0.81     | -0.34    | 0.32     |
| Ba             | 0.86     | 0.30     | 0.26     |
| Total          | 5.17     | 4.00     | 1.24     |
| % of variance  | 43.07    | 33.34    | 10.36    |
| Cumulative%    | 43.07    | 76.41    | 86.77    |
Health risk assessment analysis
The quality of drinking water sources is closely related to people, and the assessment of health risks of metals in drinking water sources has received extensive attention[39-41]. The HQ value of each metal and the HI value both in surface and overlying water were calculated and shown in Fig. 5, and the calculated HQ values for each metals via drinking ingestion and dermal absorption for adults and children are displayed in Table. S4, S5. For non-carcinogenic risks, HI ranged from 0.67 to 0.90 for adults, and from 1.55 to 2.21 for children. All metal HQ values and the HI values were less than 1 for adults (Fig. 5a), indicating no non-carcinogenic risk to adults from exposure to metals in the Xiangjiang River. But for children, As had high HQ value (1) in 90% surface water samples and 80% overlying water samples, which was dominant in the HI value, resulting in HI value higher than 1 in all water bodies (Fig. 5b). The results suggested that As exposure poses a potential noncarcinogenic risk to local children, which were consistent with other studies on several rivers in southern China and the Three Gorges Reservoir [33, 42]. There are significant differences in the health risks associated with metals through drinking ingestion and dermal absorption. The average HI value through drinking ingestion pathway was 1-3 orders of magnitude greater than dermal absorption (Table S4, S5), indicating that drinking ingestion was the primary exposure route to the health of human beings [43]. As also can be seen from Fig. 5 and Table S4, S5, the mean total health risk (HI) of children is about 2.2 times than that of adults, indicating that children are more susceptible to metals than adults, which is due to differences of physiological characteristics and behavioral characteristics between children and adults (EPA, 2008). Children are more sensitive to external environment during their growth and development stage [44]. In addition, the non-carcinogenic risk of surface water is slightly higher than that of overlying water, possibly because the overlying water is less disturbed by the external environment.

Among the investigated metals, As, Cr, and Cd are present the carcinogenic risks (CR); thus, we calculated the CR values of As, Cr, and Cd and the results are shown in Fig. 6. The CR values of As, Cr, and Cd for adults ranged in $1.06 \times 10^{-4} - 1.60 \times 10^{-4}$, $2.12 \times 10^{-5} - 4.77 \times 10^{-5}$ and $4.40 \times 10^{-4} - 1.16 \times 10^{-3}$, respectively (Fig. 6a). The CR values of Cd and As for adults were above the safe limit
(10^{-4}) in all samples, indicating a probable risk of carcinogenicity exposure. For children, only Cd had a CR value above 10^{-4}, but As was also near to the safety value (Fig. 6b). The results of carcinogenic indicated that Cd and As were the major carcinogenic risk in the Xiangjiang River. Previous studies have also found cancer risks from exposure to arsenic and cadmium in surface water [45, 46]. The presence of As in drinking water can cause significant health risks, including liver cancer, lung cancer, hypertension and neuropathy, and Cd can cause damage to lungs and DNA [27, 47]. Therefore, the Cr and Cd in the drinking water source of the Xiangjiang River should pay more attention to, appropriate and effective measures to control and manage metal pollution are needed to ensure human health and the healthy development of aquatic ecosystem.

Conclusions
This study investigated 12 metals in the Xiangjiang River in southeastern China, focusing on the pollution characteristics, source apportionment and health risk assessment. Average concentrations fell in the order of dissolved metal Mg > Mn > Ba > Fe > Zn > As > Sb > Ni > Cd > V > Cr > Co, none of which exceeded the water quality standard of drinking water, indicating that the water quality in this area was good overall. There was no significant difference in metal concentration between surface and overlying water. But metals pollution appeared more serious in the midstream and on the southern side of the Xiangjiang River, possibly due to point source pollution nearby. PCA results showed that anthropogenic activities (mineral exploitation and industrial wastewater) are the major source of dissolved metals in water, whereas Ni might be attributed to natural sources. Children are more susceptible to the health risk of dissolved metals caused by drinking ingestion. There are no health risks from dissolved metals to adults, but there are potential health risks from As exposure to local children. Cd and As may pose a potential cancer risk to residents and should be taken seriously.

Abbreviations
PCA principle component analysis
ADD average daily dose
HQ hazard quotient
HI hazard index
CR carcinogenic risks
EPA environmental protection agency

Declarations

Acknowledgements

None applicable.

Authors’ contributions

ZH and XZ were involved in the experiments and manuscript writing. ZH were responsible for the data analysis. CL and XQ collected samples. ZH and BZ designed the study. XZ and BZ contributed to correction of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets obtained and analyzed in the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

![Figure 1](image)

Map of the Xiangjiang River Basin and the sampling sites. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 2

Spatial distribution of metals concentration in surface water
Figure 3

Spatial distribution of metals concentration in overlying water
Metal concentrations in water samples collected at the south side, the north side, and in the middle of the river.

HQ and HI values for metals in surface and overlying water (a) adults, (b) children.
Figure 6

CR values of metals in the Xiangjiang River (a) adults, (b) children.

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