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EDITED BY
Miao Li,
Charles Sturt University, Australia

REVIEWED BY
Shaoda Liu,
Beijing Normal University, China
Jitao Lv,
Chinese Academy of Sciences (CAS),
China

*CORRESPONDENCE
Yujing Wang,
wangyujing@meescc.cn

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Environmental contamination characteristics of heavy metals from abandoned lead–zinc mine tailings in China

Wei Han[1], Ruifeng Zhao[1], Wanrong Liu[1], Yujing Wang[1]*, Shuai Zhang[2], Kang Zhao[1] and Jinglei Nie[1]

[1]Solid Waste and Chemicals Management Center, Ministry of Ecology and Environment, Beijing, China, [2]MOE Key Laboratory of Soft Soils and Geo-environmental Engineering, Zhejiang University, Hangzhou, China

China holds large-scale lead–zinc mineral resources; however, mining activities often cause severe contamination by heavy metals. This study systemically assessed contamination by eight heavy metals (Cu, Zn, Cd, Pb, Cr, Hg, Ni, and As) in mine tailings, soil, and groundwater from 27 contaminated sites across China. Regarding mine tailings, 1% of the mine tailing samples were hazardous waste and 20% were class II non-hazardous waste. Regarding soil, Zn and Pb showed the highest mean concentrations, at 5574.67 mg/kg and 2034.88 mg/kg, respectively. The indexes of geo-accumulation (I_{geo}) of eight heavy metals ranged from −3.62 to 7.67, while Zn, Pb, and Cd showed the highest environmental risk levels as the priority pollutants. The contamination levels of these heavy metals in groundwater were generally in the order of Zn>As>Pb>Ni>Cd>Cu>Hg>Cr. In this study, 20% of the soil and 10% of the groundwater samples exceeded the corresponding quality limits. The content of heavy metals in soil, groundwater, and mine tailing were positively correlated, demonstrating the main pollution source and transport paths. The pollution levels of heavy metals in soil and groundwater were listed in the foremost and moderate positions compared with similar sites from other countries, respectively. These results may help determine the pollution levels of lead–zinc mining regions and direct the remediation activities of target sites to support the environmental management of abandoned mining and tailing waste in China.

KEYWORDS

heavy metals, lead–zinc mine, mine tailing, soil and groundwater, contamination

1 Introduction

Soil and groundwater pollution has become a severe problem worldwide (Li et al., 2014; Yang et al., 2018). Heavy metal pollution has been serious in China with the rapid social and economic development in recent decades (Xiao et al., 2015; Zhu et al., 2021). The main contamination sources mainly include human activities in the industrial, mining, and farming sectors (Liu et al., 2020; Peng et al., 2022). Mining activities are among the most significant sources of heavy metal pollution (MEP of China, 2014), with mine tailings a critical contamination factor of heavy metals (Ganhurrel et al., 2020; Mezned et al., 2022). Heavy metals derived from mined areas may cause adverse effects on the ecological environment and the health of residents because they enter and accumulate in the soil and are then transported downward to diffuse into groundwater (Lee et al., 2005; Doya et al., 2020; Zhu et al., 2021; Tomiyama and Igarashi, 2022). China is one of the largest global producers and consumers of metals/metalloids such as antimony (Sb), iron (Fe), lead (Pb), manganese (Mn), and zinc (Zn) (Gunson and Jian, 2001). Mining alone has generated about 1,500,000 ha of wasteland in China. Moreover, the wasteland is increasing at a rate of 46,700 ha per year (Zhuang et al., 2009).

China is rich in lead–zinc mine resources (Zhao et al., 2007; Li et al., 2014). The resource reserves of lead and zinc in China are 20.41 million tons and 44.23 million tons (MNR of China, 2022), respectively, ranking third worldwide after the United States and Australia. China produced 7.36 million tons and 6.56 million tons of lead and zinc, respectively, in 2021, increases of 11.2% and 1.7%, which comprise 32.55% and 26.3% of the total global production (MIIT of China, 2022). Therefore, China plays a critical role in the lead–zinc industrial chains worldwide. Lead and zinc mining also threaten the environment by contaminating the surrounding soil and groundwater (Li et al., 2014). During the history of lead–zinc mining, many lead–zinc mine tailing ponds were abandoned in China. Moreover, the environmental risks increase continuously in abandoned mining areas despite the closure of the mining operation and the effects of natural attenuation (Rodríguez et al., 2022). Most early studies evaluated single or limited numbers of mining areas (Zhang et al., 2019; Zhou et al., 2022) and only one study reported on environmental media like soil (Li et al., 2014; Yang et al., 2018; Peng et al., 2022; Shi et al., 2022). Therefore, an overall evaluation of heavy metal pollution in lead–zinc mine areas including soil and groundwater on a national scale is severely lacking and urgently needed for environmental management.

The present study systematically investigated heavy metal pollution in 27 abandoned lead–zinc mine tailing sites in eight provinces in China. The analyzed targets included mine tailings, soil, and groundwater in the mine vicinity. The objectives of this study were to 1) determine the contamination levels of heavy metals in solid waste from abandoned lead–zinc mine tailings and environmental matrices around the sites, 2) determine the prior contaminants with greater environmental risks, and 3) propose policy recommendations for environmental management agencies.

2 Materials and methods

2.1 Database source

Information on the 27 abandoned zinc–lead mine sites and pollution data of the heavy metals in different environmental matrices including mine tailings, soils, and groundwater surrounding the mine tailing storage sites were collected from the China Knowledge Full-text Literature Database and survey reports provided by the environmental consulting companies and the government. The target samples were collected from southwest, northwest, and middle south regions of China, where rich lead–zinc mine resources are located. Solid waste was present in the mine tailings in the abandoned mining areas. The running and piling times of the mine tailings ranged from 10 to 60 years. The soils were sampled in the vicinity of the mine tailings to a depth of 0–20 cm from the soil surface. The groundwater samples were collected from wells located downstream of the studied mine tailing areas. A typical site field in the present study is shown in Figure 1.

2.2 Pollution assessment compared to the limit standards

For solid waste samples, leaching toxicity was applied to identify the environmental risk. The solid waste extraction procedure for leaching toxicity was performed using the sulfuric acid and nitric acid method (HJ/T299-2007). The identification standards (GB 5085.3-2007) for hazardous waste were used to compare the leaching toxicity to identify hazardous wastes. The horizontal vibration method (HJ-557 guideline, pure water as the extracting agent) was used during the extraction for leaching toxicity to identify class I or II non-hazardous industrial wastes.

For soil and groundwater sample treatment and analysis, the sampling strategies and processing methods used are widely accepted by the scientific community. The heavy metal content in the groundwater was compared with the standard for groundwater quality class III (GB/T 14848-2017). The heavy metal contents in the soil samples were compared to the risk screening and risk intervention values for soil contamination for the development of land derived from the soil environmental quality in China (GB 36600-2018).

All statistical analyses were performed using IBM SPSS Statistics version 19.0 and Excel 2013 for Windows. The correlations between the concentrations of different heavy metals in the soil samples were assessed by Pearson correlation coefficients.

2.3 Index of geo-accumulation for soil samples

Soil is a critical layer due to its connecting functions between solid waste pollution sources and groundwater. The soil risk was further assessed as follows. The environmental risk of the soil from the abandoned mine tailing was assessed using the geo-accumulation index (I_{geo}) calculated using the original equation by Muller (1969):

$$I_{geo} = log_2\left(\frac{C_n}{K \cdot B_n}\right),$$

where C_n is the total concentration of metal n in the soil sample and B_n is the background concentration of this metal in the studied

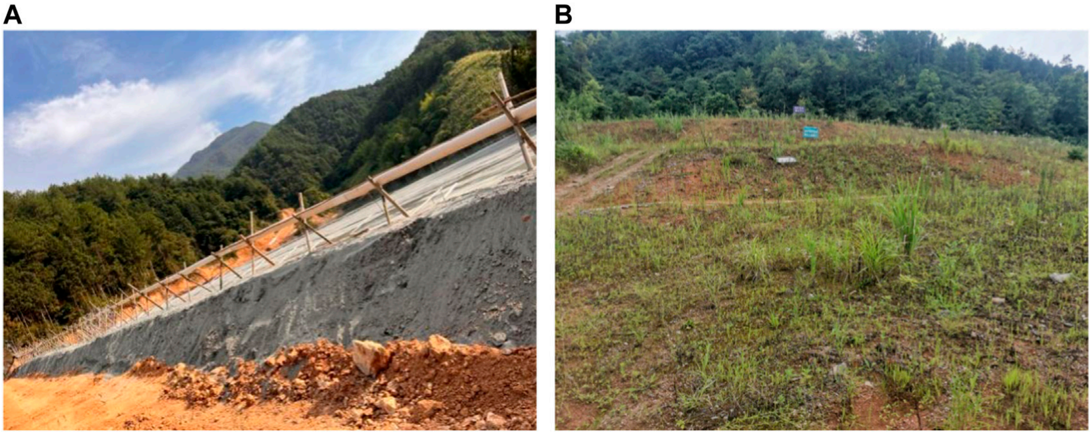

FIGURE 1
Typical lead–zinc mine tailing pile **(A)** and surrounding soil **(B)** in Fujian.

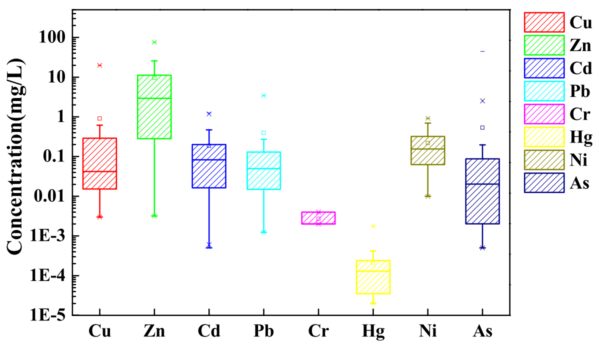

FIGURE 2
Concentrations of heavy metals in the leaches of mine tailings by acid solutions.

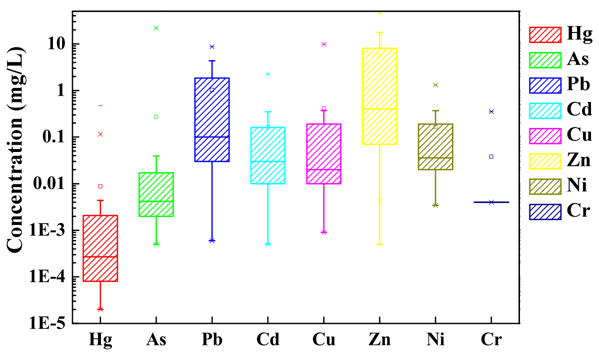

FIGURE 3
Concentrations of heavy metals in the leaches of mine tailings by pure water.

region. The regional background value is determined according to the background sample analysis. The constant K is 1.5 due to potential variations in the baseline data (Li et al., 2014). Based on the calculated values of I_{geo}, the soil samples were classified into seven classes in Table 1.

TABLE 1 Seven classes comprising the geo-accumulation index.

Class	Value	Soil quality
0	$I_{geo} \leq 0$	Practically unpolluted
1	$0 < I_{geo} \leq 1$	Unpolluted to moderately polluted
2	$1 < I_{geo} \leq 2$	Moderately polluted
3	$2 < I_{geo} \leq 3$	Moderately to strongly polluted
4	$3 < I_{geo} \leq 4$	Strongly polluted
5	$4 < I_{geo} \leq 5$	Strongly to extremely polluted
6	$5 < I_{geo}$	Extremely polluted

3 Results and discussion

3.1 Identification of hazardous waste

Hazardous material screening was conducted to reveal the properties of the mine tailings as the contamination sources of soils and groundwater in abandoned mining areas. A total of 105 samples were analyzed; the results are shown in Figure 2 and Supplementary Table S1. Zinc showed the highest average concentration (9.68 mg/L) for the acid leaches, compared to <1 mg/L for the other metals. The As and Cd contents in several acid leaches were above the hazardous waste control limits, exceeding the standards of 0.95% and 1.9%, with the highest contents of 44.5 mg/L and 1.25 mg/L, respectively. Therefore, parts of the solid wastes still pose serious threats in some mining sites, although the heavy metals in 98% of the collected samples met the hazardous waste identification standard (GB 5085.3-2007).

TABLE 2 Pearson correlations of different heavy metals in soils.

Correlation	As	Cd	Cu	Pb	Hg	Ni	Zn	Cr
As	1	.135[a]	.036	.138[a]	.357[a]	.054	.462[a]	.209
Cd		1	.071	.490[a]	.179	−.097	.793[a]	.043
Cu			1	.016	.291[b]	.823[a]	.014	.529[a]
Pb				1	.129[b]	−.147[a]	.621[a]	.102
Hg					1	.248[b]	.271[a]	.454[a]
Ni						1	−.136[b]	.557[a]
Zn							1	.120
Cr								1

[a]Correlation significant at the 0.01 level.
[b]Correlation significant at the 0.05 level.

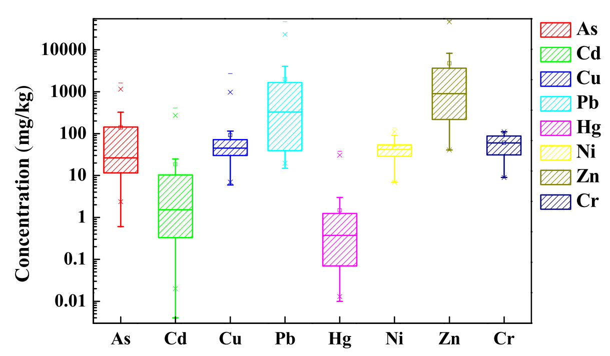

FIGURE 4
Concentration characteristics of heavy metals in soils.

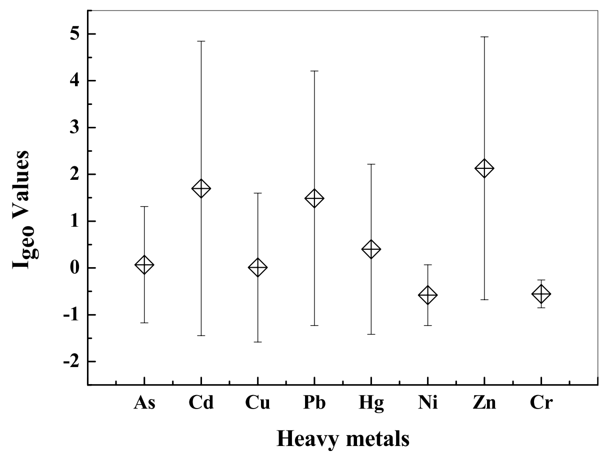

FIGURE 5
Average I_{geo} values of heavy metals from soils.

3.2 Identification of non-hazardous waste

The water leaching experiment was conducted to determine the environmental transport ability and risk of heavy metals in the abandoned solid waste in natural environmental effects like raining and leaching. A total of 165 mine tailing samples were collected and analyzed. The results were shown in Figure 3. Zinc showed the highest average concentration (5.37 mg/L) in the water leaches. The percentages of heavy metals exceeding the limits were 28.05%, 18.18%, 15.15%, 13.94%, 6.87%, 2.44%, and 2.24% for Zn, Mn, Cd, Pb, Cu, Ni, and Hg, respectively. Cr and As were less than the limit standard. Therefore, nearly 80% of the collected solid wastes were class I according to the Chinese solid waste management policy. The other samples were classified as type II waste, which poses a more serious environmental risk and requires more attention.

3.3 Soil pollution characteristics

The heavy metal contents of the soils are shown in Figure 4. Among the 369 collected soil samples, the As concentrations ranged from below the detection threshold to 1,608 mg/kg (average, 147.38 mg/kg). The Zn concentrations ranged from 40.7 to 49521 mg/kg, (average, 5574.67 mg/kg), showing the highest mean value among all heavy metals. The Cd concentrations ranged from below the detection threshold to 410 mg/kg (average, 21.02 mg/kg). The Pb concentration ranged from 14.8 to 47000 mg/kg (average, 2034.88 mg/kg). The percentages of heavy metal samples exceeding the intervention value limits were as follows: As (25.90%)> Pb (20.44%) > Zn (14.94%) > Cd (2.49%) > Hg (0.67%). Therefore, contaminated sites containing heavy metal concentrations exceeding the standard limits require remediation. However, the other heavy metals including Cr, Ni, Cu, Ti, and Mn, met the soil quality standards. Regarding the screening value standards, 39.78%, 34.43%, 14.94%, 0.67%, and 2.17 of the Pb, As, Zn, Hg, and Ti samples, respectively, exceeded the limits. The environmental risk assessments are needed to determine whether the related sites require remediation for the heavy metals with concentrations below the limit value and above the screening value. According to the total analysis mentioned previously,

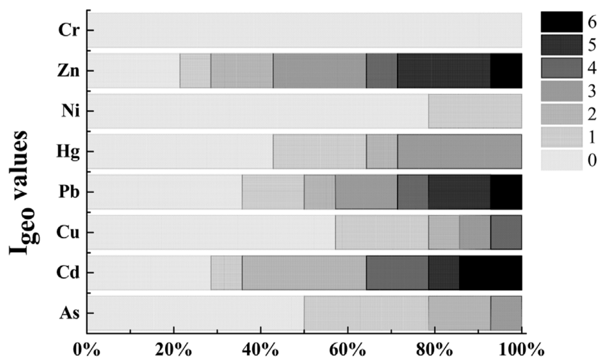

FIGURE 6
Class distributions of the geo-accumulation index for heavy metals.

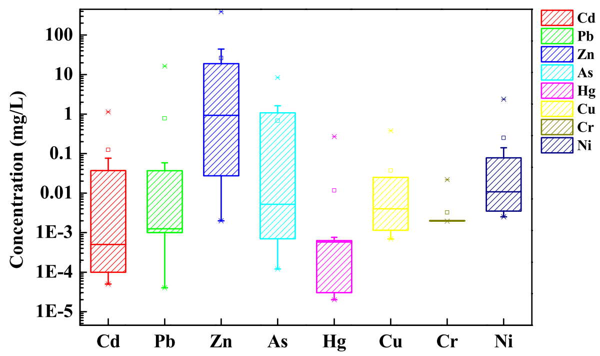

FIGURE 7
Concentrations of heavy metals in groundwater.

compared with the soil quality limits, Pb, Zn, Cd, and As are critical heavy metals in soils in the vicinity of the mine tailing areas that require more attention, while Cr, Ni, and Cu exhibited the lowest risk levels. This finding is similar to those of other reports showing pollution indices of Pb, Zn, and Cd ranging from high to intense contamination, compared to mild and moderate pollution levels for other heavy metal pollution levels for soils from lead/zinc mining sites in Vietnam (Vuong et al., 2022).

The correlations of the contents of the heavy metals in soils are shown in Table 2. As levels were positively correlated with Zn, with a Pearson correlation coefficient of 0.462 ($p<0.01$). Cd was positively correlated with Pb and Zn, with Pearson correlation coefficients of 0.490 and 0.793 ($p<0.01$), respectively. Pb was positively correlated with Zn, with a Pearson correlation coefficient of 0.621. Therefore, Cd is a typical contaminant in lead–zinc mining polluted soils as it is correlated with Pb and Zn levels.

The geo-accumulations index values for the heavy metals are listed in Figure 5. The average I_{geo} index values for heavy metals from different study sites are shown in Supplementary Table S4. The mean indices were >1 for Cd, Zn, and Pb, of which the maximum value was >6, demonstrating the highest contamination level. The average indices of As, Hg, and Cu ranged from 0.01 to 0.4, indicating moderate contamination. The mean I_{geo} values of Cr and Ni were all <0, representing the lowest contamination. The I_{geo} values of Zn, Cd, and Pb in this study were similar to those of samples for other legacy contaminated industrial sites in China (Yang et al., 2018; Peng et al., 2022); however, the average I_{geo} values of the other six heavy metals were much lower than those from other industries by comparison, demonstrating the predominance of Zn, Pb, and Cd as pollutants in lead–zinc mine industries. The I_{geo} values in the present study were higher than those of soils from agricultural regions in China (Yang et al., 2018), especially for Cd and Pb, implying relatively higher environmental risks.

The class distribution of the geo-accumulation index based on the classification system was shown in Figure 6. The I_{geo} values and the percentage distribution of different heavy metals varied significantly. The indices of all samples for Cr were below class 0, meaning practically uncontaminated. For Ni, nearly 80% of the I_{geo} values fell into class 0; the rest are <1. Regarding Hg, >60% of the indices were <1 and the others were <3. Similarly, nearly 80% of the indices were <1 for Cu, although 7% of the soil samples were class 4. Indices <0 were observed for <35.71% of Cd, Pb, and Zn samples, respectively. In contrast, >30% of indices were >4, ranging from "heavily contaminated" to "extremely contaminated." Extremely contaminated classes with indices >6 were observed for approximately 7%–14% of Cd, Pb, and Zn samples. The I_{geo} values for the other heavy metals were all <4. The As pollution level was relatively moderate compared to the I_{geo} values shown in Figure 6. Therefore, the contamination levels of the heavy metals are ranked in the following order: Cd>Zn>Pb>Cu>Hg>Ni>Cr.

3.4 Groundwater pollution characteristics

The groundwater quality investigation included 43 groundwater samples collected from 43 wells located in the vicinity of the side and downstream regions of the sites. The detection results were compared with the groundwater quality standard (III) in China (GB/T 148148-2017). The results demonstrated that all eight heavy metals were detected in groundwater samples from the 43 wells as shown in Figure 7. The mean concentrations of the contaminating heavy metals were generally in the order of Zn>As>Pb>Ni>Cd>Cu>Hg>Cr. In this study, 43.24%, 42.5%, 37.5%, and 27.5% of the Zn, Cd, As, and Pb samples, respectively, exceeded the standard limits.

The Zn concentrations ranged from below the detection limit to 388 mg/L (average, 23.35 mg/L), with 27.91% of samples showing concentrations above the standard value and the highest concentration 388 times the standard value. The Pb concentrations ranged from below the detection limit to 16.4 mg/L (average, 0.7 mg/L), with 27.5% of samples exceeding the standard value and the highest concentration 1,640 times the standard value. The Cd concentrations ranged from below the detection limit to 1.14 mg/L (average, 0.11 mg/L), with 42.25% of samples exceeding the standard value is 42.25% and the highest concentration 228 times the standard value. The Ni concentrations ranged from 0.0025 to 2.37 mg/L (average, 0.25 mg/L), with 42.11% of samples exceeding the standard value and the highest concentration 118 times the limit value.

The heavy metals in the groundwater around the mining and tailing contaminated sites included Cd, Pb, Zn, As, and Ni due to the higher content and percent above the standard rate (>27%).

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TABLE 3 Concentrations of heavy metals in soils in the vicinity of lead–zinc mining areas in other countries and regions (mg/kg).

Country	As		Cd		Cr		Cu		Ni		Pb		Zn		Hg		Reference
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	
Vietnam	3.7–489	228	0.66–56.2	12.6	/	/	11.9–697	147	/	/	273–23300	4010	231–8,430	3540	/	/	Hien et al. (2012)
Tunisia	/	/	1–186.17	20.26	/	/	/	/	/	/	1–3457.1	549.72	2.36–14180	2297.4	/	/	Sebei et al. (2020)
Sweden	700–900	800	0.5–0.7	0.6	1.0–2.0	1.6	18–400	64	2.7–4.5	3.7	1.1–4.6	3.1	8.5–33	16	/	/	Bhattacharya et al. (2006)
Poland	/	/	/	/	/	/	/	/	/	/	69–5260	/	42–12100	/	/	/	Ullrich et al. (1999)
Morocco	/	/	/	/	/	/	/	/	/	/	41–17250	/	51–276500	/	/	/	Iavazzo et al. (2012)
Jamaica	/	/	2–220	2.4	/	/	/	/	/	/	6–38000	170	66–39582	494	/	/	Anglin-Brown et al. (1995)
Greece	4.7–369.8	/	0.9–174.1		/	/	12.8–1,201	/	/	/	31–12567	/	47.4–22291	/	/	/	Nikolaidis et al. (2010)
Nigeria	/	/	/	/	/	/	/	/	/	/	13–16	14.25	156–246	186.75	/	/	Oje et al. (2010)
Spain	100–1,600	/	/	/	/	/	500–1,000	/	/	/	3100–62500	/	3000–38500	/	/	/	Gonzalez-Fernandez et al. (2011)
China	ND-1608	147.38	ND-410	21.02	9–1,450	89.85	ND-2698.16	95.66	ND-136	46.43	14.8–47000	2034.88	40.7–49521	5574.67	ND-102	2.12	This study

Note: "/," data not available or not detected; ND, content below the detection limit.

TABLE 4 Heavy metal concentrations in groundwater surrounding the lead–zinc mines regions in other studies.

Region	As		Cd		Cr		Cu		Ni		Pb		Zn		Hg		Reference
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	
Vietnam	2–8	5.1	ND-2	0.5	/	/	2–54	29	/	/	ND-121	30	ND-155	71	/	/	Hien et al. (2012)
Nigeria	0–2.06	0.13	0–0.51	0.24	0–10.10	0.43	0–2.42	0.13	0–1.26	0.09	0–4.29	2.18	0–1.72	0.14	0–2.3	0.50	Oje et al. (2010)
Korean	7–187	0.0667	0.005–0.021	0.0088	21–50	0.0264	/	/	/	/	/	/	1.758–10.550	4.176	/	/	Lee et al. (2005)
China	ND-8.45	0.68	ND-1.14	0.11	ND-0.022	0.008	ND-0.38	0.03	0.0025–2.37	0.25	ND-16.4	0.70	ND-388	23.35	0.00002–0.27	0.01	This study

Note: "/," data not available or not detected; ND, content below the detection limit.

The higher concentration and percent above the standard limit of As were attributed to its higher mobility in soil and water (Zhang et al., 2019), although it showed lower soil contamination compared to the other heavy metals. Similar phenomena were also reported in other studies, where river water in mine tailing areas showed As concentrations exceeding 10 μg/L but low concentrations of Pb and Cd due to the different mobilities of Cd, As, and Pb (Baasansuren et al., 2020). The environmental and health risks to groundwater should be given more emphasis, especially for mining sites located in farmland and residential areas.

3.5 Correlations of priority heavy metals in different matrices and running time

The correlation matrix between heavy metal concentrations in mine tailings, soils, groundwater, and piling time is included in the Supporting Materials. As shown in Supplementary Tables S7–S10, the Zn, Pb, As, and Cd contents in solid mine tailings, soil, and groundwater were positively correlated. These results demonstrate the migration pathways from solid waste to groundwater via soil matrices, especially for mine tailing piles lacking leaching protection measures. The Cd and Pb contents in different matrices were positively related to the running time of the mine tailings; thus, more metals were released into the environment with increasing time that the mine tailings remained in piles. Thus, remediation measures should be taken as soon as possible because solid waste could easily release these metals into the environment. Meanwhile, the other heavy metals including Zn and As were weakly related to the running time of the mine tailing pond.

3.6 Comparisons of results with other studies

The comparisons of heavy metal concentrations in the soils and groundwater from this study with those found in other countries and regions are listed in Tables 3, 4.

To compare the heavy metal pollution levels of the soils in this paper to those of studies from other countries, the heavy metal content of soils surrounding lead–zinc mine areas om other countries were collected. These regions included Vietnam, Tunisia, Sweden, Poland, Morocco, Jamaica, Greece, Nigeria, and Spain across the European, Asian, African, and North American continents. Table 1 shows that Zn, Pb, and Cd had the highest detection frequencies in other studies among eight heavy metals, with Zn and Pb detected in all studies. As and Cr showed intermediate levels, with detection frequencies of 40%–50%. Ni and Hg were the least commonly identified, with nearly no content data in soils from other studies. Therefore, Zn, Pb, and Cd were the most concentrated related to the detection frequency; moreover, they were detected in all samples. The total Pb and Zn concentrations showed a wide range of values (Pb: 1–62500 mg/kg; Zn: 8.5–276500 mg/kg), with samples from Morocco and Spain showing the highest concentrations (references). The mean soil concentration of Zn in the present study, 5574.67 mg/kg, was higher than the value reported in other regions, although the maximum value was observed in Morocco. These results illustrate the higher potential environmental risk of Zn in China compared to the soils in the vicinity of lead–zinc mining areas in other regions. The mean Pb values ranked in the middle in the present study compared to other studies. The highest mean value from the soil samples was reported in Vietnam, which was attributed to the long mining operations, which generated considerable amounts of heavy pollution (Ha et al., 2011). The total pollution level of Cd in this study was comparable to that reported in Tunisia and higher than the mean concentrations of other regions. The results of the aforementioned analysis showed that the contamination levels and environmental risks of Zn, Pb, and Cd in this study ranked highest compared to other regions.

Few reports have reported on the association of groundwater contamination surrounding lead–zinc mine areas, implying that groundwater is less concentrated compared to soil. As illustrated in Table 1, only three studies in other countries and regions reported on this subject, including studies in Vietnam, Nigeria, and Korea. The groundwater surrounding the lead–zinc mines from Vietnam contained the highest heavy metal concentrations, with a mean value of 71 mg/L among four selected studies, owing to the higher heavy metal content in soils in the vicinity of lead–zinc mines (Ha et al., 2011; Hien et al., 2012). The mean concentration of the eight heavy metals in groundwater in this study was moderate compared to those of the other three studies. However, the risk of Zn cannot be ignored owing to the maximum value of 388 mg/L in the site measured in the present study.

4 Conclusion

This study systemically investigated heavy metal pollution in mine tailings, soils, and groundwater based on a database of 27 abandoned lead–zinc mine tailing sites in China.

1) Zn, Pb, and Cd were the dominant pollutants among the eight heavy metals studied.
2) Hazardous wastes were identified in 1% of the mine tailing samples although most of the waste was non-hazardous. Nearly 20% of the solid mine tailings were class II non-hazardous waste. Meanwhile, 20% of the soil and 10% of the groundwater samples exceeded the corresponding quality limits; thus, remediation measures must be made as soon as possible.
3) The index of I_{geo} of eight heavy metals ranged from −3.62 to 7.67, where Zn, Pb, and Cd exhibit the highest environmental risk level which requires more government attention and control.
4) Heavy metal concentrations in soil, groundwater, and waste mine tailing were positively correlated, demonstrating the main pollution source and transportation paths.
5) The pollution level of the heavy metals in soil and groundwater around the lead–zinc mine tailing areas are ranked foremost and moderate compared to other studies from other countries and regions, respectively.
6) For contaminated sites where the content of heavy metals exceeds the standard limits, remediation and management measures are urgently needed to reduce the environmental levels and assure the health of nearby human populations.

Data availability statement

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

Author contributions

WH completed the main data analysis and the main writing. RZ and WL participated in data processing and result calculation. YW determined the logical structure of the paper and provided scientific research funding. SZ, KZ, and JN provided valuable suggestions for the paper. All authors contributed to the paper and approved the submitted version.

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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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2023.1082714/full#supplementary-material

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