Potentially toxic metal(loid) distribution and migration in the bottom weathering profile of indigenous zinc smelting slag pile in clastic rock region

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Abstract

26 **Background.** There are contaminated by potentially toxic metal(loid)s (PTMs) that the surface
27 soil and the weathering profiles around the indigenous zinc smelting slag piles or smelters in the
28 smelting area. However, few systematic studies are currently focusing on the PTM distribution
29 and migration among the slag and its bottom weathering profile.
30 **Methods.** This research determined the concentrations of PTMs and pH values. And we
31 analyzed PTM distribution in the two weathering profiles (slag-covered and slag-absent) with a
32 small horizontal distance in the clastic rock region in the smelting area.
33 **Results.** The soil As and Pb contents respective within the 30-centimeter and 50 cm depth in the
34 slag-covered section are higher than those in the slag-absent profile. And all soil Cd and Zn
35 contents of the slag-covered core are significantly higher than those in the slag-absent
36 weathering section.
37 **Conclusions.** Compared with the slag-absent weathering section, some PTMs (i.e., As, Cd, Pb,
38 and Zn) in the bottom weathering profile are polluted by these elements in the covered slag in the

39 clastic rock region. And their depths are influenced by the slag to varying degrees. Additionally,
40 with time, some PTMs (especially Cd and Zn) of the slag might finally contaminate the
41 groundwater by leaching and infiltration through its bottom weathering profile in the clastic rock
42 region.
43
Introduction

45 Northwestern Guizhou is a concentrated region of the indigenous zinc smelting actives in
46 Guizhou Province, with a long smelting history of more than 300 years (Wei et al., 2020; Yang
47 et al., 2009; Zhou et al., 2020). And there is still a vital and hot study on the contamination of
48 potentially toxic metal(loid)s (PTMs: i.e., arsenic (As), cadmium (Cd), chromium (Cr), copper
49 (Cu), mercury (Hg), lead (Pb), and zinc (Zn)) in this region. Because there might be
50 contaminating the surrounding environment and even endanger the health of animals or human
51 beings due to PTMs of indigenous zinc slag. Randomly stacked and untreated slag has resulted in
52 severe environmental pollution and risks in the indigenous zinc smelting region (Peng et al.,
53 2018a). Although indigenous zinc smelting active has been banned by the local government for
54 more than ten years (Peng et al., 2018b), there cannot be neglected the PTM contamination of the
55 slag to their surrounding environment. The smelting slag-contaminated soils could increase the
56 PTMs access by crops and vegetables (Liu et al., 2018). And the smelting activities are the
57 dominant contribution to the Pb contamination in the mean of tissues of the maize from the Pb-
58 Zn smelting area in southwest China (Wei et al., 2020). PTMs originated from smelter-originated
59 wastes that are transferred into the soil, and then that might be finally caused to urgent health
60 risks of the exposure of local residents (Zhou et al., 2020).

61 PTM contamination exists in the surface soil and soil profiles around the smelters or slag
62 heaps in indigenous zinc smelting areas. Some researchers have investigated the surface soil
63 surrounding the smelters or slag heaps (Verner et al., 1996; Ullrich et al., 1999; Bi et al., 2006;
64 Yang et al., 2009; Li et al., 2015; Wang et al., 2015). They concluded that some PTMs were
65 exceeded their risk-based screening values for the soil contamination of agricultural land (MEE
66 and SAMR, 2018). Additionally, in indigenous zinc smelting areas, soil profiles exhibit pollution
67 by PTMs (especially in the surface soil), and the depths to which these elements migrate
68 downward are significantly different. The Cd and Zn contamination depths could reach 2 meters
69 surrounding a Pb and Zn smelter in the north of France (Sterckeman et al., 2000). The Cu, Pb,
70 and Zn contents of the soil profile were close to constant around a Pb-Zn smelter in Baoji City,

71 Northwest China (Wang et al., 2015). With increasing soil depths, the decreasing trend of Cd in
72 the whole soil profile was unclear, and soil Pb and Zn contents decreased abruptly and
73 respectively reached regional background levels at depths of 30 and 50 cm in Hezhang County,
74 China (Bi et al., 2006). The Pb, Zn, Cu, Cr, As, Cd, and Hg contents decreased to their
75 background levels at a depth of approximately 150 cm around a smelter (Liu et al., 2015).
76 Besides, comparing with the surface soil at depths ranging from 0 to 10 cm, there are polluted
77 and enriched by Pb, Zn, and As of the subsoil (depths ranging from 40 to 50 cm) of some
78 locations near the town of Bytom where is an area of Pb/Zn mining and smelting in Upper
79 Silesia, Poland (Ullrich et al., 1999). So there are many reports on the PTMs distribution of soil
80 profiles, and most of them only focus on the soil profiles around the slag piles in indigenous zinc
81 smelting areas (Scokart et al., 1983; Ullrich et al., 1999; Bi et al., 2006; Wang et al., 2015; Liu et
82 al., 2015). But few studies are currently focusing on PTMs distribution and migration in the
83 bottom weathering profile of the slag.

84 Additionally, to better understand the PTMs pollution in the bottom weathering profile
85 caused by indigenous zinc smelting slag, it is necessary to take the control profile. A diagnosis of
86 element soil pollution requires its pedogeochemical background content (Sterckeman et al.,
87 2000). The pedogeochemical background content generally means the corresponding horizons of
88 noncontaminated and same type soils (Baize, 1994; Sterckeman et al., 2000). Under the
89 condition of no contamination, the contents of elements in the soil and soil profile depend on the
90 composition of the parent material and the degree of soil formation (Zhou et al., 2002). There are
91 differences in parent materials formed by natural weathering with different bedrock (Yang et al.,
92 2011; Peng et al., 2014).

93 Therefore, to better understand their contamination, distribution and migration of the soil
94 section, we investigated the PTMs in the two weathering profiles (slag-covered and slag-absent)
95 in the clastic rock region (where is one of the main stacking areas of the indigenous zinc
96 smelting slag). Thus, there could help us better understand their PTMs contamination and
97 provide some reasonable suggestions for better treating contamination of PTMs in the bottom
98 weathering profile of the slag in the clastic rock.

99

100 **Materials & Methods**
101 **2.1 Soil profile sampling**

102   In August 2016, we collected 22 samples (approximately 1 kg each sample) from two
103   weathering profiles (slag-covered and slag-absent) in an indigenous zinc smelting area in
104   Honghualing of Dongfeng Town in Weining County, northwestern Guizhou Province, China.
105   The soil is sandy loam weathered from the clastic rock. And the two weathering profiles had the
106   same type of bedrock-weathered soil and were close to each other, which indicates that the two
107   weathering profiles were under the same climatic and environmental conditions. So, their
108   physical and chemical properties are similar.

109   As shown in Table S1, there were collected from the slag-covered weathering profile that a
110   total of 12 samples (one slag sample and 11 soil samples). Ten soil samples from a slag-absent
111   soil profile, which was well covered by natural vegetation and not covered by slag,
112   approximately 100 m away from the slag-covered section, were collected. Except that two upper
113   soil sampling thicknesses of two weathering profiles (slag-covered and slag-absent) were several
114   10 cm and 20 cm, other soil sampling thicknesses of two sections were respective 20 cm and 25
115   cm until the dark gray sandy soil containing black granulating coal in their bottom layers.

116   **2.2 Soil and slag sample analyses**

117   The soil and slag samples were halved by applying the quartering method after removing
118   foreign substances. One-half of each sample was dried at 30 °C to a constant weight in a
119   thermostatic air-blower-driven drying closet and then sieved with a 10-mesh nylon sieve. The pH
120   of each dry sieved sample (10.00 g of sample mixed with 25 ml deionized water) was determined
121   by a pen pH meter (SX620 type, Instrument Factory of Shanghai Sanxin, Shanghai, China) (Peng
122   et al., 2018a, 2017, 2018b).

123   And then the contents of PTMs (i.e., As, Cd, Cr, Cu, Hg, Pb, and Zn) and Al are determined
124   by an ICP-AES (America, Varian VISTA) and an ICP-MS (America, Agilent 7700x) in an
125   accredited laboratory (ALS Minerals – ALS Chemex (Guangzhou) Co. Ltd.) (Peng et al., 2018a,
126   2017, 2018b). After grinding to 200-mesh (0.074 mm), each soil and slag sample was digested in
127   two methods (Zhang et al., 2020). Firstly, 0.25 g of each sample was digested by a concentrated
128   acid mixture (a ratio of 1: 2.5: 2: 2.5 for the $HClO_4$: HNO_3: HF: HCl) in an oven at ~190 °C for
129   48 h, cooled to room temperature, heated on a preheated hot plate (150 °C) under a fume hood to
130   get rid of excess acid until crystalline solid was formed, and then diluted to a steady volume
131   (12.5 mL) with 2% hydrochloric acid. Secondly, 0.5 g of each sample was dissolved in aqua
132   regia method (a ratio of 1:3 for HNO_3: HCl) in an oven at ~190 °C for 48 h, and then was placed

133 and heated on a preheated hot plate (150 °C) under a fume hood until white fumes appeared and

134 crystalline solid was formed. Afterward, the crystalline solid was dissolved and precisely

135 adjusted to a stable volume (12.5 mL) with deionized water.

136 **2.3 Data statistics and analyses**

137 **2.3.1 Pollution index**

138 Pollution index (PI) is a useful tool to express the degree of harm that is the ratio of the

139 measured PTM content in the soil to the standard value of the PTM as follows:

140 $$PI = \frac{C_i}{C_0}$$

141 where C_i and C_0 represent the PTM content of the soil sample and its standard value of the PTM,

142 respectively. Although many researchers used their local geochemical background as the element

143 standard values, we selected the risk-based screening values for the soil contamination of

144 agricultural land (MEE and SAMR, 2018) (Table S1) as the element standard values. Because

145 the former is its average value of the research area and maybe cause more errors to estimate the

146 pollution. And the latter is the limited value for the soil contamination of agricultural land and

147 could judge its contamination.

148 **2.3.2 Enrichment factor**

149 Enrichment factor (EF) is the relative abundance of an element, and it is a useful tool to

150 differentiate the source of a chemical element, i.e., whether the source is anthropogenic or

151 natural (Zhang et al., 2014; Peng et al., 2017, 2018b). The EF is calculated as follows:

152 $$EF = \frac{\left(\frac{Me}{Al}\right)_{soil}}{\left(\frac{Me}{Al}\right)_{crust}}$$

153 Here, $(Me/Al)_{soil}$ and $(Me/Al)_{crust}$ refer to the soil and mean crustal content (Taylor, 1964) (Table

154 S1) ratios, respectively, of a PTM and Al.

155 **2.3.3 Transfer coefficient**

156 Transfer coefficient (TC) is a useful tool to understand the element changes in a soil profile

157 during natural weathering and the degree of element migration or enrichment. It could be used to

158 calculate the loss or increase of elements in rock and soil during weathering (Nesbitt, 1979,

159 Nesbitt et al., 1980; Brimhall et al., 1985; Brimhall and Dietrich, 1987; Brimhall et al., 1991,

160 1992; Brantley and White, 2009; Zhang et al., 2018). The TC is calculated as follows:

161 $$TC = \frac{C_{ip}}{C_{iw}}\frac{C_{jw}}{C_{jp}} - 1$$

162   Here, the TC < 0 and TC > 0 is respective the fraction of a mobile element or mineral j lost

163 or gained assuming that element or mineral i is immobile. C is the parent and weathered material

164 element concentration (w and p present to the weathered and parent material respectively). The

165 soil element content could be normalized by the content of an assumed immobile element Ti

166 (Anderson et al., 2002; Brantley and White, 2009; Hausrath et al., 2009), Zr (Tian and Liu, 1995;

167 Anderson et al., 2002; Brantley and White, 2009; Hausrath et al., 2009), Nb (Anderson et al.,

168 2002; Brantley and White, 2009), Fe (Hausrath et al., 2009), Sc (Zhang et al., 2019) or Al (Tian

169 and Liu, 1995; Hausrath et al., 2009) to calculate the fractional mineral loss or enrichment

170 (Anderson et al., 2002; Brantley and White, 2009). In the chemical weathering process, Al is

171 highly stable, and it is a good reference by which to measure the geochemical behavior of other

172 elements (Chen et al., 1997). Therefore, Al is assumed to be the immobile element in this study.

173

174 **Results**

175 **3.1 PTM concentrations and soil pH value in the weathering profiles (slag-covered and**

176 **slag-absent)**

177   The soil Cd, Pb, Zn concentrations might be mainly affected by these of the covered slag,

178 other soil PTM contents and soil pH values are little or no affected by the covered slag. As

179 shown in Table S1, the concentrations of soil As, Cd, Cr, Cu, Hg, Pb, and Zn in the slag-covered

180 section respectively range from 0.5 to 14.8 (mean 4.45), 0.61 to 4.59 (1.79), 59 to 77 (68.09),

181 102.0 to 164.0 (146.36), 0.025 to 0.090 (0.058), 7.7 to 191.5 (41.82) and 127 to 367 (231.36)

182 mg/kg, and its pH values ranges from 4.42 to 5.22 (4.82). And their concentrations in the slag-

183 absent section respectively range from 0.2 to 7.8 (mean 4.95), 0.14 to 1.82 (0.45), 49 to 94

184 (73.40), 84.5 to 135.0 (125.35), 0.027 to 0.110 (0.068), 5.7 to 19.6 (12.97), 61 to 202 (137.70)

185 mg/kg, and its pH values ranges from 4.46 to 5.12 (4.94). These show that the soil Cd, Pb, Zn

186 concentrations of the slag-covered section are notable higher than these of the slag-absent section,

187 and the As, Cr, Cu and Hg concentrations and pH values of the soil in the slag-covered section

188 are smilar to these of the slag-absent section. Additionally, the concentrations of As, Cd, Cr, Cu,

189 Hg, Pb, Zn of the slag are respective 636, 192.0, 68, 499, 0.098, 10550.0, and 16450 mg/kg, and

190 its pH value is 6.83. The slag As, Cd, Cu, Hg, Pb, Zn concentrations are more than these in the

191   soil, and its pH value is very higher than the soil pH values of its bottom weathering profile. So,

192   the slag Cd, Pb, Zn concentrations might impact these of its bottom weathering profile, and other

193   PTM contents and pH value of the slag might be a little or no impact to these of its bottom

194   weathering profile.

195   **3.2 PTM distribution in the weathering profiles (slag-covered and slag-absent)**

196   The soil As and Pb respective within 30 cm and 50 cm depth, and all soil Cd and Zn in the

197   slag-covered weathering profile are remarkably contaminated by the indigenous zinc smelting

198   slag. And the soil Cr, Cu, and Hg of the slag-covered weathering profile might be little or no

199   impacted by their covered slag. As shown in Figure 1, the soil As and Pb contents respective

200   within 30 cm and 50 cm depth, and all soil Cd and Zn concentrations in the slag-covered

201   weathering profile are notably greater than those in the soil of the slag-absent section. These

202   show that soil As and Pb respective within 30 cm and 50 cm depth, all soil Cd and Zn in the

203   slag-covered weathering core, are remarkably polluted by the covered slag. However, there is

204   little difference in the contents and change trends of Cr, Cu and Hg in the two weathering

205   profiles (slag-covered and slag-absent). It shows that Cr, Cu and Hg in the whole slag-covered

206   weathering profile might be little or no impacted by the covered slag.

207   Figure 1 Potentially toxic metal(loid) distribution in both slag-covered and slag-absent weathering profile in

208   the study area

209

210   Moreover, the soil As, Cd, Pb, and Zn distribution of the slag-covered profile show they

211   have an abrupt change with increasing soil depths, and they are different abrupt depths with

212   different PTMs (Figure 1). These abrupt changes might be caused by the As, Cd, Pb, and Zn

213   downward in the slag. There are different PTM mobility of the soil in different soil depths due to

214   the soil physical and chemical properties (pH, texture, etc. (Ettler et al., 2007)). It might be the

215   reason why these PTMs have different abrupt depths in this research area.

216   Additionally, the soil Hg distribution of the two weathering profiles is similar to the Liu et

217   al. (2006) result. It shows a convex or irregular distribution (enrichment in the surface, middle,

218   and bottom layers to a certain extent). These explain that the soil Hg is polluted by industrial

219   actives. Also, this similarity might be caused by Hg contamination from the soot produced

220   during the smelting process is more seriously than Hg contamination from the slag (Protano and

221   Nannoni, 2018). Because Hg in the original ore mainly evaporates first and diffuses into the

222   surrounding environment through the indigenous zinc smelting soot due to the low melting point

223   and boiling point of Hg. Therefore, the soil Hg concentration in the two weathering profiles is

224   mainly contaminated by the indigenous zinc smelting soot but not the slag.

225   **3.3 PTM migration in the weathering profiles (slag-covered and slag-absent)**

226   The absolute content change of elements could not reflect their authentical geochemical

227   behavior in the weathering and soil formation process. The mobile element leaching could make

228   the immobile element enrich (Chen et al., 1997). It explains that the immobile element content

229   might not reflect the authentical phenomenon of element migration or enrichment during the

230   chemical weathering process. The $TC > 0$, $TC < 0$, and $TC = 0$ indicate that the element is

231   enriched, depleted, and immobile relative to the parent, respectively (Brantley and White, 2009;

232   Hausrath et al., 2011). Also, the PTM proportion of the parent soil materials is on the foundation

233   of their TC calculation of soil profiles. So there should be regarded theoretically as the effect of

234   the element migration and redistribution in the soil geochemical process during the soil

235   formatting and weathering process of the soil cores that any circumstance beyond the range of

236   the TC value deviating from the total error due to analysis and determination (Tian and Liu,

237   1995). Therefore, when $TC \approx 0$, the proportion of the element to its reference element in the soil

238   maintains the parent material characteristics. And there is no notable element migration during

239   the process of soil formation. When TC is significantly greater than 0, it indicates that the

240   element is notably enriched relative to the parent. When TC is significantly lower than 0, it

241   means that the element is remarkably depleted relative to the parent.

242   According to field observations, there is spring water near the weathering profile. And its

243   elevation slightly lower than at the bottom layer elevation of the soil profile. These indicate that

244   the groundwater level is relatively shallow (approximately the dept at 240cm) in this research

245   area. So, their bottom layer might be easily affected by the rising effect of groundwater capillary

246   water. Additionally, the soil texture and color of the two bottom layers of the two weathering

247   profiles are significantly different from their upper layers (Table S1). The two bottom layers of

248   the soil profiles (slag-covered and slag-absent) are dark gray soil. These might be caused by the

249   lower coal layer becoming soaked with upward capillary movement from a shallow water table

250   (Huang and Xu, 2010; Weil and Brady, 2016). Therefore, the penultimate layer might be a little

251   affected by the bottom layer. And we chose the reciprocal third layer in the slag-absent profile as

252   the reference of the parent layer in this study. The transfer coefficients of the PTMs in the two

253   weathering profiles are presented in Figure 2.

254   Figure 2 Transfer coefficients of potentially toxic metal(loid)s in both slag-covered and slag-absent weathering

255   profile in the study area

256

257   The soil As distribution is notably enriched within 110 cm depth in the slag-covered

258   weathering profile. And its enrichment within 30 cm depth is remarkably higher than that in the

259   slag-absent section. Additionally, the soil As content at soil depths between 50 and 190 cm in the

260   slag-covered core is less than that in the slag-absent profile. The soil As is prominently depleted

261   at soil depths ranged from 110 to 190 cm in the slag-covered core but not in the slag-absent

262   section. According to yield observations, some plants are growing in the lower part of the slag-

263   covered profile but not in the slag-absent section. Therefore, the soil As distribution difference

264   might be related to the redistribution and biological absorption of As in the soil profile (Brantley

265   and White, 2009).

266   The soil Cd is significantly enriched to varying enrichment degrees in the slag-covered

267   profile, and the Cd content and enrichment degree are higher than those of the slag-absent core.

268   The soil Cr is completely depleted except for some enrichment in the bottom layer of the

269   slag-covered core. It is no significant migration phenomenon in the slag-absent profile except for

270   the soil layer at depths of 30 to 55 cm and 55 to 80 cm, and in the bottom layer.

271   The soil Cu shows no notable migration of the whole slag-covered profile. And it also

272   shows no significant migration in the slag-absent section, except for a slight depletion at a depth

273   of 30 to 130 cm and a light enrichment in the bottom layer.

274   The soil Hg is notably enriched within 110 cm depth and the bottom soil layer of the slag-

275   covered core, and its enrichment degree is not higher than that in the slag-absent profile.

276   The soil Pb is remarkably enriched throughout the two soil profiles, and the Pb enrichment

277   degree within 50 cm depth in the slag-covered core is higher than that in the slag-absent section.

278   The soil Zn is prominently enriched in the whole slag-covered profile, and its enrichment

279   degree is higher than those in the slag-absent core.

280   These results show that the soil As and Pb respective within at least 30 cm and 50 cm depth,

281   all soil Cd and Zn in the slag-covered core are affected by the downward migrations of those

282   elements from the slag. However, the soil Cr, Cu and Hg of the slag-covered section might not

283   be affected by the slag. Therefore, the slag PTM migration depths are different in the slag-

284   covered weathering profile (i.e., the soil As and Pb correspond to within at least 30 cm and 50
285   cm depth, all soil Cd and Zn in the slag-covered core).
286

Discussion

287

288   **4.1 PTM contamination in the soil profile impacted by the slag**

289   The PI was introduced to evaluate and better understand the PTM contamination of soil
290   profiles in indigenous zinc smelting areas in this research. A PI value greater than 1 indicates
291   that the soil sample is polluted, while a PI value less than 1 suggests that the soil sample is
292   unpolluted (Li et al., 2006). The $1 < PI < 3$, $3 < PI < 5$, and $PI > 5$ suggest that the soil is slightly
293   polluted, moderately polluted, and seriously polluted, respectively (Wu et al., 2015).

294   As shown in Table 1, the PIs of the slag As, Cd, Cu, Pb, and Zn are greater than 5. It
295   indicates that these PTM contents of the slag reach seriously polluted levels. If crops are planted
296   on the slag, these PTMs are at risk of causing obvious pollution. The PIs of the slag Cr and Hg
297   are less than 1, which indicates that their contents are required for their risk-based screening
298   values for the soil contamination of agricultural land and that their contents are unpolluted. In the
299   slag-covered soil profile, the PIs of soil As, Cr, and Hg are less than 1, which indicates that their
300   contents do not exceed the screening values of environmental pollution risk for agricultural land
301   and do not reach the pollution level. The PIs of soil Cd and Cu are distributed in the ranges of 1
302   to 3, 3 to 5, and greater than 5, indicating that these PTMs are slightly, moderately, and
303   moderately polluted, respectively. The PIs of soil Pb within 30 cm depth and Zn in most soil
304   samples range from 1 to 3, which indicate that their contents exceed the screening value of
305   pollution risk in soil environmental quality and reach a slight contamination level. In the slag-
306   absent soil profile, the PIs of soil As, Cr, Hg, and Pb in the whole core and Cd and Zn in most
307   soil samples are all less than 1. These mean that their contents do not exceed the screening value
308   of pollution risk in soil environmental quality and do not reach a pollution level. There indicate
309   that their contents are at a slight contamination level that the PIs of Cu in the whole core, Cd in
310   soil within 30 cm depth, and Zn in surface soil range from 1 to 3. Therefore, the soil Cd and Cu
311   in the whole profile, the soil Pb within 30 cm depth, and Zn in most soil samples are
312   contaminated to a certain extent in the slag-covered weathering profile. And the soil Cd within
313   30 cm depth, the Zn of surface soil, and all soil Cu in the slag-absent weathering core are slightly

314   polluted.

315   Table 1 Pollution index of potentially toxic metal(loid)s in both slag-covered and slag-absent weathering

316   profile in the study area

317

318   **4.2 PTM source in the soil profile impacted by the slag**

319   According to Sutherland (2000) and Chen et al. (2007), $EF<1$, $1\leq EF<3$, $3\leq EF<5$,

320    $5\leq EF<10$, $10\leq EF<25$, $25\leq EF<50$ and $EF\geq 50$ correspond to no enrichment, minor

321   enrichment, moderate enrichment, moderately severe enrichment, severe enrichment, very severe

322   enrichment, and extremely severe enrichment, respectively. The EFs of the PTMs could help

323   further trace their sources in the soil (Hu et al., 2013; Peng et al., 2017). Although the element

324   contents are mainly affected by parent rock types (Yang et al., 2010; 2011; Peng et al., 2017),

325   elemental anomalies are mainly affected by specific natural geographical backgrounds (Yu et al.,

326   2014) and by the effects of anthropogenic activities (Yu et al., 2014; Peng et al., 2017). The soil

327   PTM contaminations might also be easily affected by anthropogenic activities, especially in

328   surface soil (Peng et al., 2017). Moreover, an EF of less than one or greater than three indicates

329   that the element originated predominantly from natural sources and anthropogenic activities,

330   respectively (Hu et al., 2013). An EF value between 1 and 3 shows that the element is affected

331   by both natural sources and anthropogenic activities.

332   As shown in Table 2, in the slag-covered weathering profile, the EFs of the soil As within

333   30 cm depth, the soil Pb and Zn within 50 cm depth, Cd in most soil samples are greater than 3;

334   the EFs of As, Cd and Pb in a few soil samples, all soil Cu, and Zn in most soil samples range

335   from 1 to 3; other EFs are less than 1. In the slag-absent soil core, the EFs of the soil As within

336   105 cm depth and the soil Cd in the surface and bottom layers are greater than 3, the EFs of As,

337   Cd, Hg, and Pb in a few soil samples and Cu and Zn in the whole section range from 1 to 3, and

338   other EFs are less than 1. These results show that As, Cd, Pb, and Zn are mainly from

339   anthropogenic activities contamination (i.e., the indigenous zinc smelting slag) at different

340   depths of the slag-covered profile in the clastic rock district. Additionally, the As, Cd, and Pb in

341   a few soil samples, the Cu in the whole core, and the Zn in most soil samples of the slag-covered

342   profile are mainly affected by human activities and natural weathering sources. Moreover, the

343   soil Cd, Cr, Cu, Hg, and Pb contents of the bottom layer are higher than those in the reciprocal

344   third soil layer of the two weathering profiles. And the soil texture and color of the two bottom

345   layers are significantly different from the upper soil in the weathering profiles. These might be

346   caused by the upward capillary movement contaminations of the coal seam (below the bottom

347   layer of the two weathering profiles). Therefore, the contents of PTMs (i.e., Cd, Cu, Pb, and Zn)

348   in the slag-covered profile are greatly affected by human activities (especially by the slag), while

349   the Cd, Cu, Hg, Pb, and Zn contents of the upper part in the slag-absent core might be affected

350   by smelting activities.

351   Table 2 Enrichment factors of potentially toxic metal(loid)s in both slag-covered and slag-absent weathering

352   profile in the study area

353

354   **4.3 PTM migration and its influence in the soil profile impacted by the slag**

355   Some PTMs might be released by natural weathering and entered into the surrounding

356   environment by leaching rain. Some PTMs (i.e., As, Cd, Cu, Hg, Pb, and Zn) of the slag are very

357   high and more than these in the soil of its bottom weathering profile (Table S1)**.** Although most

358   of the slag PTMs are generally dominated by polymetallic or other phases (Ettler et al., 2003;

359   Scokart et al., 1983; Sobanska et al., 2016), they could be easily transported to the surrounding

360   circumstances due to long-term natural weathering (Sobanska et al., 2016; Tyszka et al., 2014;

361   2018) or other processes occurring in acidic environments (Scokart et al., 1983; Sobanska et al.,

362   2016; Warchulski et al., 2019; Yang et al., 2006). There adds to the bioavailability of Cd that a

363   possible transformation of Cd from metal oxides in smelting slags to adsorbed phases and

364   carbonates (Wang et al., 2020). Warchulski et al. prove the importance of rainfall-induced

365   weathering on PTMs mobilization and migration (Warchulski et al., 2019).

366   Some PTMs of the slag might be migrated downward and contaminated the groundwater by

367   leaching and infiltration through the soil profile in the clastic rock distribution district. The

368   contents of some PTMs (i.e., Cd, Cu, Pb, and Zn) in the slag-covered weathering profile are

369   greatly affected by the covered slag in this research area. As described in Figure 2, the soil As

370   and Pb respective within at least 30 cm and 50 cm depth, all soil Cd and Zn in the slag-covered

371   weathering profile are affected by the slag. And the groundwater level is relatively shallow

372   (approximately the dept at 240cm) in the research area through field observations. Additionally,

373   many leaching experiments show that some PTMs in the slag could easily migrate into the

374   surrounding environment (Zhu et al., 2012; Piatak et al., 2015; Liu et al., 2018; Tyszka et al.,

375   2018; Warchulski et al., 2019). The Cd and Zn migrate with organic matter that brings about

376 more potential hazards of the groundwater movements near zinc smelters in acidic sandy soils
377 (Scokart et al., 1983). Groundwater quality is mostly poor near the Pb-Zn mining and smelter
378 and coal mining districts in Hezhang County where borders on Weining Prefecture in Guizhou
379 Province (Zhao et al., 2016). The heavy Zn isotopic signatures in the groundwater might be
380 concerned to seepage from the slag piles by the advective or diffusive transport of pore water
381 from the polluted soil at the smelting site (Yin et al., 2016).
382   Therefore, over time, some slag PTMs (especially Cd and Zn) would be released by natural
383 weathering and re-migrated into the soil of its bottom weathering profile by leaching rain, and
384 eventually infiltrate into deeper soil, and even might contaminate the groundwater.
385
386 **Conclusions**
387   In the clastic rock region, the soil Cd and Cu in the whole profile, the soil Pb within 30 cm
388 depth, and Zn in most soil samples are to a certain extent at pollution levels in the slag-covered
389 weathering profile. All soil Cu, the soil Cd within 30 cm depth, and Zn in the surface soil in the
390 slag-absent section are slightly contaminated. The contents of PTMs (i.e., Cd, Cu, Pb, and Zn)
391 are greatly affected by human activities (especially by the slag) in the slag-covered profile. And
392 the contents of PTMs (i.e., Cd, Cu, Hg, Pb, and Zn) in the upper part of the slag-absent core
393 might be affected by the indigenous zinc smelting activities.
394   Additionally, the contents of the soil As and Pb respective within 30 cm and 50 cm depth,
395 all soil Cd and Zn in the slag-covered weathering core are higher than those in the slag-absent
396 profile. And the soil As is enriched within 110 cm depth (especially within 30 cm depth). All soil
397 Cd, Pb, and Zn are enriched to varying degrees in the whole slag-covered profile (especially the
398 soil Pb within 50 cm depth).
399   Moreover, the soil As, Cd, Pb, and Zn of the slag-covered soil profile are affected by the
400 slag in the clastic rock region, and their affected depths and degrees are different. The soil As
401 and Pb respective within 30 cm and 50 cm depth, and all soil Cd and Zn in the slag-covered
402 profile are remarkably affected by the downward migration of these PTMs from the slag. All soil
403 Cr, Cu, and Hg of the slag-covered section are not or are little affected by the slag. Additionally,
404 with time, some PTMs (especially Cd and Zn) of the slag might contaminate the groundwater by
405 leaching and infiltration through the soil profile in the clastic rock region. Therefore, there
406 should be an urgency to manage untreated, scattered stacking slag to further prevent the

407   contamination of the soil and the groundwater in the research area by PTMs.

408

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419

References

421   Anderson, S. P., Dietrich, W. E., Jr, G. H. B., 2002. Weathering profiles, mass-balance analysis,
422   and rates of solute loss: Linkages between weathering and erosion in a small, steep
423   catchment. Geological Society of America Bulletin, 114(9), 1143-1158.

424   Baize, D., 1994. Teneurs totales en métaux lourds dans les sols français. Le Courrier de
425   l'environnement de l'INRA, **22**(22), 37-46.

426   Bi, X., Feng, X., Yang, Y., Qiu, G., Li, G., Li, F., Liu, T., Fu, Z., Jin, Z., 2006. Environmental
427   contamination of heavy metals from zinc smelting areas in Hezhang County, western
428   Guizhou, China. Environment international, **32**(7), 883-890.

429   Brantley, S. L., White, A. F., 2009. Approaches to Modeling Weathered Regolith. Reviews in
430   Mineralogy & Geochemistry, **70**(1), 435-484.

431   Brimhall, G. H., Alpers, C. N., Cunningham, A. B., 1985. Analysis of supergene ore-forming
432   processes and ground-water solute transport using mass balance principles. Economic
433   Geology, **80**(5), 1227-1256.

434   Brimhall, G. H., Chadwick, O. A., Lewis, C. J., Compston, W., Williams, I. S., Danti, K. J.,
435   Dietrich, W. E., Power, M. E., Hendricks, D., Bratt, J., 1992. Deformational mass
436   transport and invasive processes in soil evolution. Science, **255**(5045), 695.

437   Brimhall, G. H., Dietrich, W. E., 1987. Constitutive mass balance relations between chemical
438   composition, volume, density, porosity, and strain in metasomatic hydrochemical
439   systems: Results on weathering and pedogenesis. Geochimica et Cosmochimica Acta,
440   **51**(3), 567-587.

441   Brimhall, G. H., J, L. C., Ford, C., Bratt, J., 1991. Quantitative geochemical approach to
442   pedogenesis: importance of parent material reduction, volumetric expansion, and eolian
443   influx in lateritization. Geoderma, **51**(1), 51-91.

444   Chen, C. W., Kao, C. M., Chen, C. F., Dong, C. D., 2007. Distribution and accumulation of
445   heavy metals in the sediments of Kaohsiung Harbor, Taiwan. Chemosphere, **66**(8), 1431-
446   1440.
447   Chen, J., Ji, J., Qiu G., Lu, H., Zhu, H., 1997. Geochemistry study on chemical weathering
448   degree of loess in in Luochuan County, Shuanxi Province. Science in China Series D-
449   earth Sciences. 27(6): 531-536. (In Chinese)
450   Ettler, V., Piantone, P., Touray, J. C., 2003. Mineralogical control on inorganic contaminant
451   mobility in leachate from lead-zinc metallurgical slag: experimental approach and long-
452   term assessment. Mineralogical Magazine, **67**(6), 1269-1283.
453   Ettler, V., Rohovec, J., Navrátil, T., Mihaljevič, M., 2007. Mercury Distribution in Soil Profiles
454   Polluted by Lead Smelting. Bulletin of Environmental Contamination and Toxicology,
455   **78**(1), 13-17.
456   Hausrath, E. M., Navarre-Sitchler, A. K., Sak, P. B., Williams, J. Z., Brantley, S. L., 2011. Soil
457   profiles as indicators of mineral weathering rates and organic interactions for a
458   Pennsylvania diabase. Chemical Geology, **290**(3-4), 89-100.
459   Hausrath, E. M., Neaman, A., Brantley, S. L., 2009. Elemental release rates from dissolving
460   basalt and granite with and without organic ligands. American Journal of Science, **309**(8),
461   633-660.
462   Hu, Y., Liu, X., Bai, J., Shih, K., Zeng, E. Y., Cheng, H., 2013. Assessing heavy metal pollution
463   in the surface soils of a region that had undergone three decades of intense
464   industrialization and urbanization. Environmental Science and Pollution Research, **20**(9),
465   6150-6159.
466   Huang, C., Xiu, J., 2010. Pedology (Third Edition). Beijing: China Agriculture Press. (in
467   Chinese)
468   Li, J., Xie, Z. M., Xu, J. M., Sun, Y. F., 2006. Risk assessment for safety of soils and vegetables
469   around a lead/zinc mine. Environmental Geochemistry and Health, **28**(1), 37-44.
470   Li, P., Lin, C., Cheng, H., Duan, X., Lei, K., 2015. Contamination and health risks of soil heavy
471   metals around a lead/zinc smelter in southwestern China. Ecotoxicology and
472   Environmental Safety, **113**, 391-399.
473   Liu, H., Li, L., Pan, G., 2006. Profile distribution of total Cu, Pb, Hg, As in some paddy soils
474   from the southern Jiangsu, China and the Influencing Factors. Journal of Agro-
475   Environment Science. 25(5): 1221-1227. (in Chinese with English Abstract)
476   Liu, T., Li, F., Jin, Z., Yang, Y., 2018. Acidic leaching of potentially toxic metals cadmium,
477   cobalt, chromium, copper, nickel, lead, and zinc from two Zn smelting slag materials
478   incubated in an acidic soil. Environmental Pollution, **238**, 359-368.
479   Liu, Y., Wang, C., Liu, H., Ma, H., Zhang, Q., Feng, T., Sun, D., 2015. Spatial distribution and
480   ecological risk assessment of heavy metals in soil around a lead and zinc smelter.
481   Chinese Journal Environmental Engineering. **9**(1): 477-484. (in Chinese with English
482   Abstract)

483 Ministry of Ecology and Environment of the People's Republic of China (MEE), State
484   Administration for Market Regulation of the People's Republic of China (SAMR), 2018.
485   Soil environmental quality risk control standard for soil contamination of agricultural
486   land. GB 15168－2018, China Environment Press. (In Chinese)
487 Nesbitt, H. W., 1979. Mobility and fractionation of rare earth elements during weathering of a
488   granodiorite. Nature, **279**(5710), 206-210.
489 Nesbitt, H. W., Markovics, G., Price, R. C., 1980. Chemical processes affecting alkalis and
490   alkaline earths during continental weathering. Geochimica et Cosmochimica Acta,
491   **44**(11), 1659-1666.
492 Peng, Y., Chen, J., Wei, H., Li, S., Jin, T., Yang, R., 2018a. Distribution and Transfer of
493   Potentially Toxic Metal(loid)s in *Juncus effusus* from the Indigenous Zinc Smelting Area,
494   Northwest Region of Guizhou Province, China. Ecotoxicology and Environmental Safety
495   **152**, 24-32.
496 Peng, Y., Chen, R., Yang, R., 2017. Analysis of heavy metals in *Pseudostellaria heterophylla* in
497   Baiyi Country of Wudang District. Journal of Geochemical Exploration, **176**, 57-63.
498 Peng, Y., Han, X., Chen, R., 2014. Ecological geology environment of pepper planting base in
499   Dafang County of Guizhou Province. Guangdong Agriculture Science. **41**(18): 127-131.
500   (in Chinese with English Abstract)
501 Peng, Y., Yang, R., Jin, T., Chen, J., Zhang, J., 2018b. Risk assessment for potentially toxic
502   metal(loid)s in potatoes in the indigenous zinc smelting area of northwestern Guizhou
503   Province, China. Food and Chemical Toxicology, **120**, 328-339.
504 Piatak, N. M., Parsons, M. B., Ii, R. R. S., 2015. Characteristics and environmental aspects of
505   slag: A review. Applied Geochemistry, **57**, 236-266.
506 Protano, G., Nannoni, F., 2018. Influence of ore processing activity on Hg, As and Sb
507   contamination and fractionation in soils in a former mining site of Monte Amiata ore
508   district (Italy). Chemosphere, **199**, 320-330.
509 Scokart, P. O., Meeus-Verdinne, K., De Borger, R., 1983. Mobility of heavy metals in polluted
510   soils near zinc smelters. Water, Air, & Soil Pollution, **20**(4), 451-463.
511 Sobanska, S., Deneele, D., Barbillat, J., Ledésert, B., 2016. Natural weathering of slags from
512   primary Pb-Zn smelting as evidenced by Raman microspectroscopy. Applied
513   Geochemistry, **64**, 107-117.
514 Sterckeman, T., Douay, F., Proix, N., Fourrier, H., 2000. Vertical distribution of Cd, Pb and Zn
515   in soils near smelters in the North of France. Environmental Pollution, **107**(3), 377-389.
516 Sutherland, R., 2000. Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii.
517   Environmental Geology, **39**(6), 611-627.
518 Taylor, S. R., 1964. Abundance of chemical elements in the continental crust: a new table.
519   Geochimica Et Cosmochimica Acta, **28**(8), 1273-1285.
520 Tian, J., Liu, P., 1995. Preliminary study on relative migration intensity of elements in soil
521   profile of Loess Plateau. Research of Soil and water conservation, **2**(4): 51-55. (in
522   Chinese)

523 Tyszka, R., Kierczak, J., Pietranik, A., Ettler, V., Mihaljevič, M., 2014. Extensive weathering of
524   zinc smelting slag in a heap in Upper Silesia (Poland): potential environmental risks
525   posed by mechanical disturbance of slag deposits. Applied Geochemistry, **40**, 70-81.
526 Tyszka, R., Pietranik, A., Kierczak, J., Zieliński, G., Darling, J., 2018. Cadmium distribution in
527   Pb-Zn slags from Upper Silesia, Poland: Implications for cadmium mobility from slag
528   phases to the environment. Journal of Geochemical Exploration, **186**, 215-224.
529 Ullrich, S. M., Ramsey, M. H., Helios-Rybicka, E., 1999. Total and exchangeable concentrations
530   of heavy metals in soils near Bytom, an area of Pb/Zn mining and smelting in Upper
531   Silesia, Poland. Applied Geochemistry, **14**(2), 187-196.
532 Verner, J. F., Ramsey, M. H., Helios-Rybicka, E., Jeˆdrzejczyk, B., 1996. Heavy metal
533   contamination of soils around a Pb-Zn smelter in Bukowno, Poland. Applied
534   Geochemistry, **11**(1), 11-16.
535 Wang, J., Jiang, Y., Sun, J., She, J., Yin, M., Fang, F., Xiao, T., Song, G., and Liu, J., 2020.
536   Geochemical transfer of cadmium in river sediments near a lead-zinc smelter.
537   Ecotoxicology and Environmental Safety, **196**, 110529.
538 Wang, L., Lu, X., Li, L. Y., Ren, C., Luo, D., Chen, J., 2015. Content, speciation and pollution
539   assessment of Cu, Pb and Zn in soil around the lead–zinc smelting plant of Baoji, NW
540   China. Environmental Earth Sciences, **73**(9), 5281-5288.
541 Warchulski, R., Mendecki, M., Gawęda, A., Sołtysiak, M., and Gadowski, M., 2019. Rainwater-
542   induced migration of potentially toxic elements from a Zn–Pb slag dump in Ruda Śląska
543   in light of mineralogical, geochemical and geophysical investigations: Applied
544   Geochemistry, **109**, 104396.
545 Wei, X., Zhou, Y., Jiang, Y., Tsang, D.C.W., Zhang, C., Liu, J., Zhou, Y., Yin, M., Wang, J.,
546   Shen, N., Xiao, T., and Chen, Y., 2020, Health risks of metal(loid)s in maize (*Zea mays
547   L.*) in an artisanal zinc smelting zone and source fingerprinting by lead isotope: Science
548   of the Total Environment, **742**, 140321.
549 Weil, R.R., and Brady, N.C., 2016. The Nature and Properties of Soils, 15th edition: England,
550   Pearson Education Limited, 1-1105.
551 Wu, S., Peng, S., Zhang, X., Wu, D., Luo, W., Zhang, T., Zhou, S., Yang, G., Wan, H., Wu, L.,
552   2015. Levels and health risk assessments of heavy metals in urban soils in Dongguan,
553   China. Journal of Geochemical Exploration, **148**, 71-78.
554 Yang, R., Ren, H., Long, J., Lang, X., 2011. Trace element and rare earth element content
555   inmain rock-type weathering soil in Guizhou Province and eco-environment effect. J.
556   Guizhou U. (Nat. Sci.) **28**(6): 110–119 (In Chinese with English abstract).
557 Yang, T., Zhu, Z., Gao, Q., Rao, Z., Han, J., Wu, Y., 2010. Trace element geochemistry in
558   topsoil from East China. Environmental Earth Sciences, **60**(3), 623-631.
559 Yang, Y.-G., Jin, Z.-S., Bi, X.-Y., Li, F.-L., Sun, L., Liu, J., Fu, Z.-Y., 2009. Atmospheric
560   Deposition-Carried Pb, Zn, and Cd from a Zinc Smelter and Their Effect on Soil
561   Microorganisms. Pedosphere, **19**(4), 422-433.

562 Yang, Y.-G., Liu, C.-Q., Wu, P., Zhang, G.-P., Zhu, W.-H., 2006. Heavy metal accumulation
563   from zinc smelters in a carbonate rock region in Hezhang County, Guizhou Province.
564   Water, Air, & Soil Pollution, **174** (1), 321-339.
565 Yin, N.-H., Sivry, Y., Benedetti, M. F., Lens, P. N. L., van Hullebusch, E. D., 2016. Application
566   of Zn isotopes in environmental impact assessment of Zn–Pb metallurgical industries: A
567   mini review. Applied Geochemistry, **64**, 128-135.
568 Yu, H., Ni, S.-J., He, Z.-W., Zhang, C.-J., Nan, X., Kong, B., Weng, Z.-Y., 2014. Analysis of the
569   spatial relationship between heavy metals in soil and human activities based on landscape
570   geochemical interpretation. Journal of Geochemical Exploration, **146**, 136-148.
571 Zhang, J., Yang, R., Li, Y.C., Peng, Y., Wen, X., and Ni, X., 2020, Distribution, accumulation,
572   and potential risks of heavy metals in soil and tea leaves from geologically different
573   plantations: Ecotoxicology and Environmental Safety, **195**, 110475.
574 Zhang, H., Chen, J., Zhu, L., Yang, G., Li, D., 2014. Anthropogenic mercury enrichment factors
575   and contributions in soils of Guangdong Province, South China. Journal of Geochemical
576   Exploration, **144**, 312-319.
577 Zhang, K., Ji, H., Zhu, H., Song, C., Wu, Y., 2018. Material sources and element migration
578   characteristics of red weathering crusts in Southwestern Guizhou. Earth Environment, **46**,
579   257-266. (in Chinese with English Abstract)
580 Zhang, W., Yu, R., Yang, Y., Hu, G., Cui, J., Yan, Y., Huang, H., 2019. Migration and source
581   analysis of heavy metals in vertical soil profiles of the drylands of Xiamen City.
582   Environment Science, **40**, 3764-3773. (in Chinese with English Abstract)
583 Zhao, G., Xie, Y., Hong, T., Yu, Q., Tang, X., 2016. Spatial characteristics of mining and
584   smelting effects on groundwater quality in Hezhang County, Guizhou Province, China,
585   Earth and Environment. **44**(2): 237-242. (in Chinese with English Abstract)
586 Zhou, G., Ma, S., Yu, J., Zhu, L., Wang, H., 2002. Vertical distribution of elements in soil
587   profiles and their significance for geological and environmental. Geology and
588   Exploration. **38**(6): 70-75. (in Chinese with English Abstract)
589 Zhou, Y., Wang, L., Xiao, T., Chen, Y., Beiyuan, J., She, J., Zhou, Y., Yin, M., Liu, J., Liu, Y.,
590   Wang, Y., Wang, J., 2020. Legacy of multiple heavy metal(loid)s contamination and
591   ecological risks in farmland soils from a historical artisanal zinc smelting area. Science of
592   the Total Environment, **720**, 137541.
593 Zhu, J., Liu, F., Wang, L., Li, J., 2012. Release characteristics of heavy metals from different
594   types of waste residue in indigenous lead-zinc mining area in western Guizhou.
595   Environmental Chemistry, **31**(9), 1452-1453. (in Chinese with English Abstract)
596

Pollution index of potentially toxic metal(loid)s in both slag-covered and slag-absent weathering profile in the study area

1 Table 1 Pollution index of potentially toxic metal(loid)s in both slag-covered and slag-absent weathering profile in the study area

Soil profile	Sample number and sampling depth (cm)	As	Cd	Cr	Cu	Hg	Pb	Zn
Slag-covered	Slag	15.90	640.00	0.45	9.98	0.08	150.71	82.25
	S1(0～10)	0.37	15.30	0.47	3.27	0.07	2.74	1.84
	S2(10～30)	0.24	4.10	0.43	3.28	0.06	1.12	1.27
	S3(30～50)	0.15	6.47	0.49	3.13	0.04	0.66	1.35
	S4(50～70)	0.07	2.50	0.39	2.94	0.04	0.18	1.06
	S5(70～90)	0.09	2.50	0.44	3.13	0.07	0.22	0.93
	S6(90～110)	0.13	3.30	0.45	2.91	0.06	0.64	1.00
	S7(110～130)	0.03	7.20	0.41	3.18	0.03	0.15	1.71
	S8(130～150)	0.04	9.63	0.47	2.68	0.02	0.25	1.25
	S9(150～170)	0.01	4.00	0.44	2.67	0.02	0.11	0.77
	S10(170～190)	0.04	2.03	0.50	2.97	0.02	0.26	0.93
	S11(190～210)	0.07	8.47	0.51	2.04	0.06	0.26	0.64
Slag-absent	S1(0～10)	0.17	6.07	0.52	2.64	0.08	0.28	1.01
	S2(10～30)	0.17	2.13	0.48	2.55	0.08	0.21	0.75
	S3(30～55)	0.17	0.63	0.49	2.66	0.08	0.21	0.72
	S4(55～80)	0.20	0.57	0.63	2.70	0.05	0.23	0.72
	S5(80～105)	0.19	0.50	0.51	2.68	0.04	0.22	0.71
	S6(105～130)	0.14	0.47	0.51	2.58	0.05	0.22	0.70
	S7(130～155)	0.09	0.57	0.51	2.61	0.03	0.12	0.65
	S8(155～180)	0.05	0.67	0.48	2.60	0.02	0.08	0.68
	S9(180～205)	0.07	0.70	0.45	2.36	0.04	0.13	0.67
	S10(205～225)	0.01	2.77	0.33	1.69	0.04	0.15	0.31

Enrichment factors of potentially toxic metal(loid)s in both slag-covered and slag-absent weathering profile in the study area

1   Table 2 Enrichment factors of potentially toxic metal(loid)s in both slag-covered and slag-absent weathering profile in the study

2   area

Soil profile	Sample number and sampling depth (cm)	As	Cd	Cr	Cu	Hg	Pb	Zn
	Slag	537.51	1460.41	1.03	13.80	1.86	1283.94	357.50
Slag-covered	S1(0~10)	6.57	18.34	0.56	2.38	0.87	12.24	4.19
	S2(10~30)	4.29	4.89	0.51	2.37	0.81	4.97	2.89
	S3(30~50)	2.66	7.87	0.59	2.31	0.53	3.00	3.13
	S4(50~70)	1.18	2.95	0.46	2.10	0.54	0.81	2.39
	S5(70~90)	1.48	2.94	0.52	2.23	0.88	0.97	2.07
	S6(90~110)	2.29	4.09	0.55	2.18	0.84	2.94	2.35
	S7(110~130)	0.48	8.51	0.48	2.28	0.34	0.64	3.85
	S8(130~150)	0.74	12.02	0.59	2.03	0.33	1.15	2.97
	S9(150~170)	0.24	5.29	0.58	2.14	0.28	0.54	1.93
	S10(170~190)	0.63	2.49	0.61	2.20	0.31	1.17	2.17
	S11(190~210)	1.86	15.19	0.92	2.22	1.12	1.76	2.17
Slag-absent	S1(0~10)	3.11	7.72	0.66	2.04	1.17	1.33	2.45
	S2(10~30)	3.13	2.69	0.61	1.95	1.10	0.99	1.79
	S3(30~55)	3.11	0.77	0.59	1.96	1.07	0.97	1.66
	S4(55~80)	3.45	0.68	0.75	1.95	0.69	1.03	1.64
	S5(80~105)	3.45	0.61	0.61	1.97	0.58	1.01	1.64
	S6(105~130)	2.47	0.56	0.61	1.89	0.69	0.98	1.60
	S7(130~155)	1.73	0.72	0.64	2.00	0.46	0.57	1.55
	S8(155~180)	0.92	0.92	0.66	2.18	0.31	0.42	1.78
	S9(180~205)	1.37	1.00	0.64	2.03	0.60	0.69	1.80
	S10(205~225)	0.18	6.70	0.79	2.48	0.93	1.33	1.41

Figure 1

Potentially toxic metal(loid) distribution in both slag-covered and slag-absent weathering profile in the study area.

A, B, C, D, E, F, and G respectively represent the content distribution of As, Cd, Cr, Cu, Hg, Pb, and Zn in the slag-covered weathering profile. And H, I, J, K, L, M, and N represent the concentration distribution of As, Cd, Cr, Cu, Hg, Pb, and Zn in the slag-absent weathering profile, respectively.
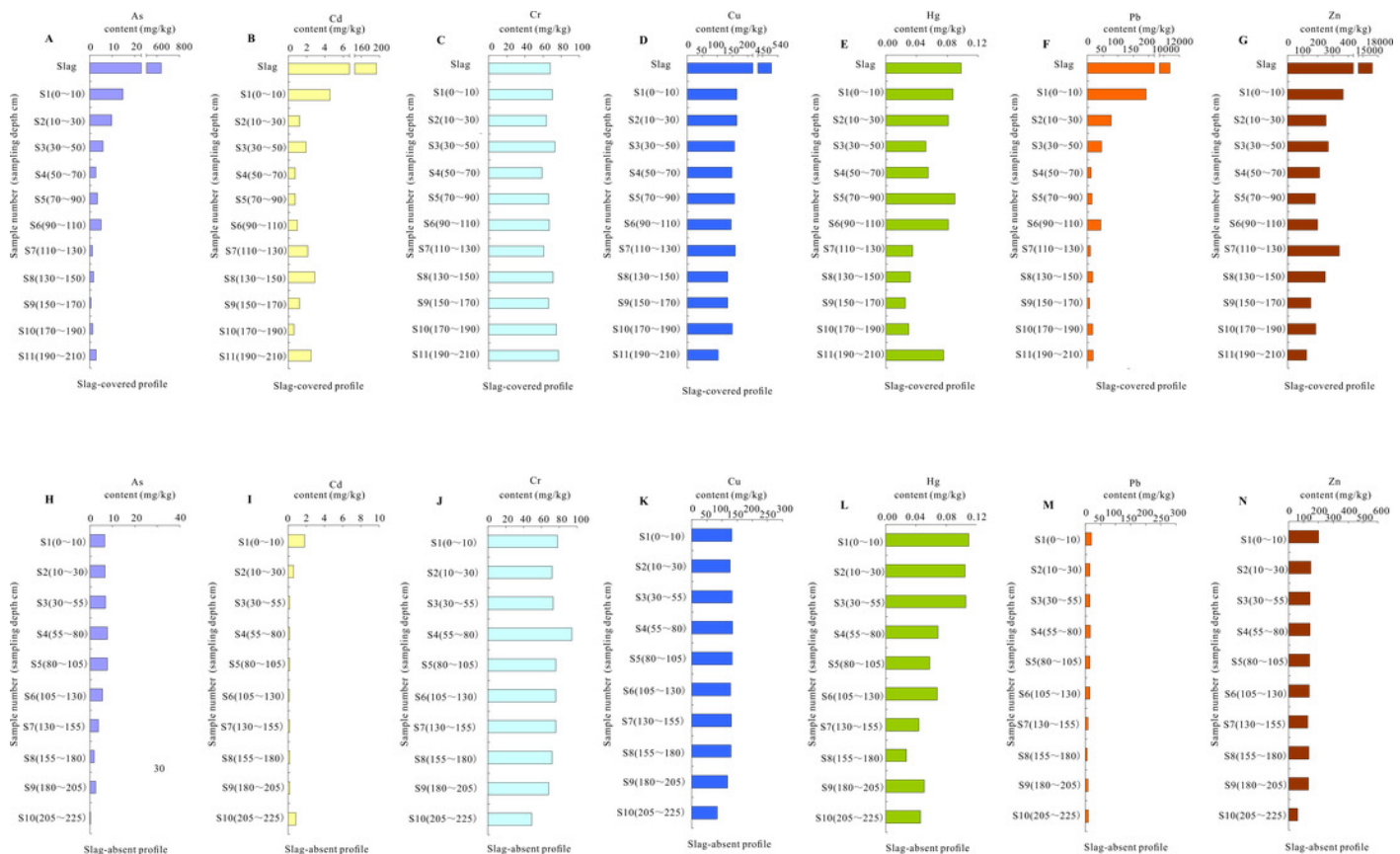
Figure 2

Transfer coefficients of potentially toxic metal(loid)s in both slag-covered and slag-absent weathering profile in the study area.

A, C, E, G, I, and K respectively represent the transfer coefficient of As, Cd, Cr and Cu, Hg, Pb, and Zn in the slag-covered weathering profile. And B, D, F, H, J, and L respectively represent the transfer coefficient of As, Cd, Cr and Cu, Hg, Pb, and Zn in the slag-absent weathering profile.