Factors on the distribution, migration, and leaching of potential toxic metals in the soil and risk assessment around the zinc smelter

Qing Xie\textsuperscript{a}, Bozhi Ren\textsuperscript{a,}\textsuperscript{*}, Xiyang Shi\textsuperscript{a}, Andrew Hursthouse\textsuperscript{b}

\textsuperscript{a} School of Resource, Environment and Safe Engineering, Hunan University of Science and Technology, Xiangtan 411201, China
\textsuperscript{b} School of Computing Engineering & Physical Sciences, University of the West of Scotland, Paisley PA1 2BE, Scotland, UK

\textbf{1. Introduction}

Soil pollution caused by PTEs residues from mining activities may cause harm to the ecological environment and humans (Huang et al., 2019). The distribution situation of PTEs in the soil was the basis of public policy, such as public health (McKinley et al., 2013) and agriculture (She et al., 2021). Many researchers have tried to propose models to describe or predict their distribution (Yang et al., 2015). Leaching toxicity was a criterion for the evaluation of hazardous waste, including water leaching and acid leaching (Huabo et al., 2005). The former one represented the water-soluble state of PTEs in the soil (Zimmerman and Weindorf, 2010). Water-soluble state was one of the available forms and the most “available” part for PTEs (de la Fuente et al., 2011), which was closely related to plant absorption (Zeng et al., 2011). The original intention of acid leaching was to simulate leaching in acid precipitation (Alghanmi et al., 2015).

It was important to study the factors that affected the total PTEs concentration in soils and the PTEs concentration during leaching. But many studies were conducted in a laboratory setting, focusing on specific environments and specific reactants. For example, a study simulated the influence of citric acid, malic acid, tartaric acid, and fumaric acid on the migration of PTEs in the laboratory (Schwab et al., 2008). The actual environment contained varieties of reactions, and the field distribution needed to be taken into consideration. In addition, many studies have insufficient sampling depth or few samples, resulting in a lack of credibility in the analysis results of migration ability. For example, a study on the distribution of soil PTEs from a mining area in Spain sampled at a depth of 20 cm (Rodríguez et al., 2009). A study about the soils in a historical smelting site were collected four sets of samples taken from 2 locations (Maskall et al., 1995). pH was one factor noticed quickly to affect the soil PTEs, but how to affect did not have fixed conclusions. A study about French forest soil reported copper, zinc, cadmium, and lead were not significantly correlated to pH in a forest soil study (Hernandez et al., 2003). But some studies had confirmed that pH would affect the total concentration, water leaching concentration (Qiao et al., 2019), and acid leaching (Li et al., 2015).

This article would use a small area of data to ensure that the sampling points could be regarded as repeated random sampling. The soil parameters and PTEs migration process at sampling points in a small area were similar. This study used variance analysis and power analysis to...
analyze the data, the results included significance test and confidence interval. The purposes of this study were: (1) to analyze the relationship between pH, depth, and the total PTEs concentration of soil, and evaluate the PTEs migration ability; (2) to analyze the relationship between water leaching concentration, acid leaching concentration and depth of soil PTEs; (3) to assess the risk of PTEs to the local ecosystem and human body.

2. Materials and methods

2.1. Target area overview

As Fig. 1, the study area was located in the Xikuangshan of Hunan Province, China. The study area was about 0.1 square kilometers, with a longitude of about 111°29'E and a latitude of about 27°45'N. The climate was a continental subtropical monsoon humid climate. The precipitation was abundant, and the local soil was mainly red loam (Li et al. 2016). The Qilijiang zinc smelter on the southwest was set in the 1990s and shut down in the 2010s. In addition, there are scattered residents and working antimony smelter in the west of the area. Long-term mining and smelting activities has caused the natural ecological balance of the land, and soil pollution had led to the livelihood difficulties of the locals.

2.2. Sample collection and processing

Due to the different types of slag stacked in the past, the degree of pollution and other factors likes topography, land use type and planting system in the study area, the grid method was used to sampling. The sampling points were 30 points with a 40 m square grid. After scraping off the surface, took three soil layers of samples from 0–30, 30–100, 100–200 cm at each point, and a total of 90 samples were collected. The Global Positioning System (GPS) was used to record the sampling locations accurately. All the soil samples were sent to the laboratory, air-dried naturally at room temperature, stripped of debris, ground, passed through a 100-mesh sieve (100 holes per inch screen) and bottled for the subsequent processing.

The soil samples were pretreated by the acid decomposition method. Air-dried soil (0.5 g) was weighed accurately in the Poly Tetra Fluoro Ethylene crucible, 10 ml of concentrated HCl was added after moistening it with drops of water, and the mixture was heated at a low temperature on an electric heating plate until the solution evaporated to approximately 5 ml. At this point, 15 ml of concentrated HNO₃ was added, heat was continuously applied until the mixture was nearly viscous, and then 10 ml of HF was added. To achieve good results, it was necessary to shake the crucible frequently and gently, wash it sinner wall, and then cover it with water, dissolve the residue at a warm temperature, cool it, and attain a volume of 100 or 50 ml depending on the components to be measured.

Acid leaching used Chinese Solid Waste-Extraction procedure for leaching toxicity-Sulfuric acid and nitric acid (SEPA, 2007). The acid leaching process was designed to simulate the process of toxic substances entering acid underground or surface water. The air-dried soil (100 g) was weighed in a 2L extraction bottle, then added the extraction solvent (water, GB/T 6682, level 2) with the liquid–solid ratio of 10:1 (L/kg). Tighten the cap and fixed it vertically on the horizontal oscillation device, then shook for 8 h at room temperature with a fluctuating frequency of 110 ± 10 times/min and swing of 40 mm. After left it stand for 16 h, filtered and collected the leaching solution, and stored the solution for measured.

The water leaching process used the Chinese Solid Waste-Extraction procedure for leaching toxicity-Horizontal vibration method (NJDEP,
The water leaching process was designed to simulate the process of toxic substances entering underground or surface water. The air-dried soil (150 g) was weighed in a 2L extraction bottle, then added the extraction solvent (1L water with two drops of solution that mixed with concentrated sulfuric acid and concentrated nitric acid at a mass ratio of 2:1, \( pH = 3.20 \pm 0.05 \)) with the liquid-solid ratio of 10:1 (L/kg). Tighten the cap and fixed it vertically on the horizontal oscillation device, then shook for 18 ± 2 h with a speed of 30 ± 2 r/min at 23 ± 2°C. Then washed the filter and membrane with dilute nitric acid, discarded the eluent. Filtered and collected the leaching solution, and stored the leaching solution at 4°C for measured.

The concentration of Pb, Cd, As, Cr, and Sb in the soil is determined by flame atomic absorption spectrophotometry. In the process of analysis, reagent blank, 20 % parallel and national standard soil standard samples were used for quality control. The determination coefficient of calibration curve was greater than 0.999, and the standard recovery rate of metals was between 110 % and 120 %, which met the quality control standard.

### 2.3. Data processing
#### 2.3.1. Correlation analysis
Correlation analysis was widely used in the source analysis and potential relationships between pollutants. For example, a study about the polycyclic aromatic hydrocarbon in Shanghai soil used correlation analysis as a part of source analysis (Wang et al., 2015). A study on PTEs deposition in the Alps used correlation analysis to study the relationship between PTEs concentrations and precipitation (Zechmeister, 1995). This study did not assume that the data were normally distributed, so the Spearman correlation analysis was applied (de Winter et al., 2016). And the total concentration and pH of all the samples were taken as the variables to preliminarily discuss the relationship and source of PTEs. The SPSS 24.0 software did the correlation analysis.

#### 2.3.2. Variance analysis
In this study, the variance analysis was used to determine whether a factor had a significant effect on other variables. It was also used to compare whether the mean values of continuous variables of different categories were the same (Larson, 2008). MINITAB, LLC. stated that when grouping into 2 to 9 and each group had at least 15 samples, the test also performed well for skewed and nonnormal distributions (MINITAB, 2021). This study did not assume the variance of data was homogenous by used Welch’s variance analysis. The null hypothesis of all analysis of variance in this article was that the means of all categories were equal, and the alternative hypothesis was that not all population means were equal. When the P-value was less than 0.05, the null hypothesis was rejected (Tomarken and Serlin, 1986). When the means of all categories were not equal, it was considered that the factors of the category had a significant impact on continuous variables. When the P-value was greater than 0.05, the null hypothesis was accepted. The mean values of all categories are equal, and it was believed that the factors of classification had no significant effect on continuous variables. Factors were the criteria for classification. The variance analysis was conducted by the software MINITAB. The factors and variables used in this article were as follows:

1. The depth of three layers was taken the factor, and the total concentration of each PTE was taken as the variable. 2. The depth of three layers was taken as the factor, and the pH value of the soil was taken as the variable. 3. The higher value and lower value of 50 % pH were labelled as “high” and “low”. The two categories of pH were not equal, it was considered that the factors of the category had a significant impact on continuous variables. When the P-value was greater than 0.05, the null hypothesis was accepted. The mean values of all categories were equal, and it was believed that the factors of classification had no significant effect on continuous variables. Factors were the criteria for classification. The variance analysis was conducted by the software MINITAB. The factors and variables used in this article were as follows:

#### 2.4. Soil pollution risk assessment
The potential ecological risk index (PERI) can evaluate the ecological toxicity of PTEs (Liu et al., 2018). The formula was given by Hakanson (1980).

\[
\text{PERI} = \frac{C \times EF \times ED \times IR}{BW \times AT \times 365d/yr}
\]

where BW is 15 kg, A is 6 years, RfD is oral reference dose (mg/kg/d), EF is 350 d/year, ED is 6 years, and IR is 200 mg/d. For RfD, Sb is 4 × 10⁻⁴ mg/kg/d, Cd is 1 × 10⁻³ mg/kg/d, As is 3 × 10⁻⁴ mg/kg/d, Cr is 5 × 10⁻³ mg/kg/d (USEPA, 2021), and Pb is 1.4 × 10⁻² mg/kg/d (Zolfaghari, 2018). When Hazard Quotient was greater than 1, the soil is a threat to human health.

### 3. Result and discussion
#### 3.1. Descriptive statistics
As Table 1, the pH varies from 6.45 to 8.56 with the average value of 7.48, indicating that soil is moderate to weakly alkaline. The average concentration of Pb, Cr, As, Cd, and Sb were 28.39, 35.59, 134.99, 0.90, and 74.19, respectively, with a descending order of As > Sb > Cr > Pb > Cd. Compared with the mountain soil background values of Hunan Province (Pb = 38, Cr = 54, As = 14, Cd = 0.11, and Sb = 2.98) (Pan and Yang, 1988), the concentrations of Pb and Cr were lower, whereas the As, Cd and Sb concentrations were 9.64, 8.18 and 24.92 times higher, respectively. Although the samples were near an abandoned zinc smelter, As concentration was the highest and Cd concentration was the lowest, the Cd concentrations of seven samples were below the detection limits. Both water leaching and acid leaching results showed a large number of samples below the detection limits. The numbers of samples below the detection limit in As and Sb results were fewer than others. Like common sense, the leaching concentration of the samples with high
PTEs concentration was higher than that with low PTEs concentration. As and Sb often existed in the Sb deposit simultaneously (Okkenhaug et al., 2012), so the average concentration of As and Sb was higher than the others. The concentrations of water leaching for As and Sb were 0.07 and 0.12, and the concentrations of acid leaching were 0.07 and 0.34, while the concentrations of Pb, Cr, and Cd of two methods were all below the detection limited values. But the Sb leaching concentrations were always higher than the As, even if the As concentration in soils were much higher than the Sb in soils.

3.2. The relationship between pH and total concentration of PTEs

As Fig. 2, the correlation coefficients among the five PTEs are all above 0.82, and the significance level are at the 0.05 level. The correlation of Pb and Cr was the strongest, while Cd-Pb and Cd-Cr were the weakest, which indicated the highly homology of the five PTEs. A study on grassland soil in the Baicheng-Songyuan area of Jilin Province reported strong correlations between As, Cr, Cu, Ni, and Zn, and the correlation coefficients were greater than 0.748, pointing out their similar sources (Chai et al., 2015). Combined with the research background, it could be considered that the main source of the five PTEs was the local mining industry. Besides, many researchers pointed out that parts of the PTEs in the soil came from the soil parent material (Xie et al., 2022; Askari et al., 2020; Baltas et al., 2020). As Fig. 2, there is no significant correlation between pH and PTEs concentration. Other studies also reported there were no high correlations between PTEs and pH. A study of paddy soils in Hangzhou, China, reported the correlation coefficients of Zn-pH and Pb-pH were 0.185, and 0.13, respectively, and Cu, Cr, Cd, and pH were not significantly correlated (Liu et al., 2006). A soil study in Heilongjiang, China, reported that the correlation coefficients between PTEs and pH were smaller than 0.272 (Shan et al., 2013). Therefore, it was preliminarily confirmed that pH had no significant effect on the distribution of PTEs in the soil of the study area.

As Fig. 3a, the P-values of Welch’s test are all greater than 0.05 in the one-way variance analysis between the total concentration and pH. It meant that all the mean values were equal and the pH value had no significant effect on the total concentration of PTEs in the soil. In the power analysis, the population was divided into two groups, each group had 45 samples, and the power was 0.96, indicating I enough power. As

Table 1

<table>
<thead>
<tr>
<th>Species</th>
<th>Type*</th>
<th>Concentration (mg/kg) or pH</th>
<th>Sample quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Total</td>
<td>8.56 6.45 7.48</td>
<td>90 0</td>
</tr>
<tr>
<td>Pb</td>
<td>total</td>
<td>79 5 28</td>
<td>90 0</td>
</tr>
<tr>
<td>Cr</td>
<td>total</td>
<td>97 9 36</td>
<td>90 0</td>
</tr>
<tr>
<td>As</td>
<td>total</td>
<td>589 15 135</td>
<td>90 0</td>
</tr>
<tr>
<td>Cd</td>
<td>total</td>
<td>4 &lt;DL 1</td>
<td>90 7</td>
</tr>
<tr>
<td>Sb</td>
<td>total</td>
<td>286 16 74</td>
<td>90 0</td>
</tr>
<tr>
<td>pH</td>
<td>Water</td>
<td>8.56 6.34 7.44</td>
<td>90 0</td>
</tr>
<tr>
<td>Pb</td>
<td>water</td>
<td>&lt;DL &lt;DL &lt;DL</td>
<td>90 90</td>
</tr>
<tr>
<td>Cr</td>
<td>water</td>
<td>&lt;DL &lt;DL &lt;DL</td>
<td>90 90</td>
</tr>
<tr>
<td>As</td>
<td>water</td>
<td>0.31 &lt;DL 0.07</td>
<td>90 12</td>
</tr>
<tr>
<td>Cd</td>
<td>water</td>
<td>&lt;DL &lt;DL &lt;DL</td>
<td>90 90</td>
</tr>
<tr>
<td>Sb</td>
<td>water</td>
<td>0.75 0.01 0.12</td>
<td>90 0</td>
</tr>
<tr>
<td>Pb</td>
<td>acid</td>
<td>&lt;DL &lt;DL &lt;DL</td>
<td>90 90</td>
</tr>
<tr>
<td>Cr</td>
<td>acid</td>
<td>&lt;DL &lt;DL &lt;DL</td>
<td>90 90</td>
</tr>
<tr>
<td>As</td>
<td>acid</td>
<td>0.63 &lt;DL 0.07</td>
<td>90 36</td>
</tr>
<tr>
<td>Cd</td>
<td>acid</td>
<td>&lt;DL &lt;DL &lt;DL</td>
<td>90 90</td>
</tr>
<tr>
<td>Sb</td>
<td>acid</td>
<td>2.75 &lt;DL 0.34</td>
<td>90 9</td>
</tr>
</tbody>
</table>

*: “total” means the concentration of PTEs in the soil; “water” means the concentration of PTEs by water leaching. “acid” means the concentration of PTEs by acid leaching.
Fig. 3. P-value bar plot and 95% confidence concentration interval plots of different pH values at all depths.

Fig. 3b, c, d, and f, the 95% confidence intervals of PTEs are overlapped. It was confirmed again that the pH value had no significant effect on the total concentration of PTEs in the soil. As Fig. 3b, c, d, and f, the category with lower pH values has high averages, but these differences are not statistically significant. A soil PTEs pollution review in regional scale found that soil type, pH, organic matter, and land use type were determining factors on PTEs distributions (Hou et al., 2017). In different situations, the pH could affect the chemical reaction process of PTEs in the soil at different degrees. A soil study found that the higher the pH was, the higher the Cd adsorbed by soils, but the increased rate would be greatly slowed down when the pH value exceeded 7 (NAIDU et al., 1994). The soil samples in this study were mainly alkaline, consistent with this situation. A adsorption study about soil PTEs found that all the added metals would be adsorbed at the environment of low PTEs concentration (Tabatabai et al., 1992). In brief, pH had no significant effect on the total concentration of PTEs in the alkaline red loam soil of this study.

In a, P-values are from Welch’s variance analysis. In b, c, d, e, and f, high means the samples’ pH values exceed half of all samples, and low means the samples’ pH values are lower than half of all samples.

3.3. Migration ability and relationship between depth and total concentration in soils

The P-value of in the one-way variance analysis between the total concentration of PTEs in soils and the sampling depth was less than 0.01, so the null hypothesis was rejected. The depth had a significant effect on the total concentration of PTEs in the soil. As Fig. 4a–e, it shows that as the depth increases, the PTEs concentrations decrease. The P-value in the variance analysis of soil pH and depth was 0.425. Furthermore, as Fig. 4f, the depth has no significantly effect on soil pH. The power analysis process of the two series was the same. The population was divided into three groups, each with 30 samples, and the power was 0.926, which was enough. A soil study that observed the continuous acceptance of smoke and dust for about six years reported that during the vertical migration of Zn in the soil, the concentration on the surface was the highest (Z. Li and Shuman, 1996). Substances containing high concentrations of PTEs moved downward from the surface, so the total concentration of PTEs on the surface was the largest. However, with the migration of PTEs, the pH value did not change significantly. As Fig. 4f, there is a trend that the deeper the depth is, the higher the pH value. The
significant difference of total concentration at different depths indicated that the soil depth was the most direct factor which could give a long reaction time to protect the groundwater from contamination by PTEs leakage accident. When the local groundwater level was shallow, it was necessary to be more careful about pollution accidents.

As Fig. 4g, in the interval plot of 100 cm depth, Cd average value is the largest, and the average values of Cr and As are the smaller than others. The interval of Cd is the largest, followed by As, and the interval of Cr is the narrowest. As Fig. 4f, in the interval plot of 200 cm depth, the average values of Pb and Sb are larger than others, and the average value of As is the smallest. The interval of Cd is the largest, followed by Sb, and the interval of Cr is the narrowest. As Fig. 4i, in the interval plot of the difference between 100 cm and 200 cm, Cd average value is the largest. The average values of Cr and Sb are smaller than others. The intervals of As and Cd are larger than others, and the interval of Cr is the smallest. In Fig. 4g, 4h and 4i, the Cd range varies greatly, indicating that the migration of Cd in the soil is more severe than other elements.

Studies have pointed out that sediment pH, oxidation-reduction potential, particle size, and humic acid exerted strong influences on Cd immobilized by the sediment (Jin et al., 2022; Jin et al., 2021), the composition could also affect the complexation of toxic metals with other substances, thereby influencing their mobility and bioavailability (Ding et al., 2021). If the factors which affected Cd migration were found, it was likely to delay the migration speed of Cd in the soil artificially. The interval change of Cr is the smallest, which met this assumption mentioned above that parts of Cr contents in the soil came from the soil parent material. The average values indicated the migration ability of arsenic in the soil was lower than other elements. As Fig. 4h and 4i, the average values of Pb and Sb are larger than others, and the differences between 100 cm and 200 cm are smaller than others. Except for Cr, Pb and Sb had stronger migration ability than others. If PTEs contamination accident occurred in the study area, Pb and Sb would contaminate deeper soil at the same time than As. To control As pollution in other regions with strongly acidic or alkaline soil, adjusting the pH to close to seven was an alternative method.

3.4. Relationship between depth and leaching concentration

The P-values in the variance analysis of the water leaching were greater than 0.05. As Fig. 5a and b, the depth had no significant effect on As and Sb leaching concentration. The power analysis processes of the two elements were the same. The population was divided into three groups, each with 30 samples, and the power was 0.926, which was enough. In the water leaching process, concentrations of Pb, Cr, and Cd
in a large amount of samples were below the detection limits. The concentrations of As and Sb were higher than others, and only few were below the detection limits. The reason for many test results below the detection limit was that the available form of PTEs accounted for a small proportion of the total. The available form was usually defined as the PTEs extracted by 0.01 mol/L of CaCl$_2$ (Zhong et al., 2020), or 0.05 mol/L of EDTA (Yao et al., 2017). A soil study in the Greek plains reported the average total concentration of Cr, Zn, and Pb were 80.0 mg/kg, 177.2 mg/kg, and 129.1 mg/kg, but the available concentration of these metals was 0.6 mg/kg, 7.4 mg/kg, 7.8 mg/kg, respectively (Massas et al., 2013). The PTEs through water leaching in this study were a part of the available form. As previously mentioned, the As and Sb concentrations in the soil of the study area were much higher compared with the background values. However, the water leaching concentration was low and had no significant relationship with the depth. It had been proved that the depth of this area was positively correlated with the total concentration of PTEs in the soil. The water leaching procedure was originally intended to be used for garbage classification. According to the China Identification Standards for Hazardous Wastes- Identification for Extraction Toxicity, the limit concentration was 5 mg/L. Therefore, the soil was unlikely to become hazardous waste. It remains to be study that why the water-soluble As and Sb in the soil had no significant relationship with the total concentration. But as far we can tell, these low concentrations of As and Sb might be leached into the groundwater directly, although the total concentration in the deeper layer exposed to the groundwater was already very low.

As Fig. 5c and d, the results through acid leaching are like the water leaching. Depth had no significant effect on the concentration of PTEs by acid leaching. The power analysis results of the two leaching methods were the same. It meant that it was acceptable to take samples from the shallow soil in the garbage classification procedure.

### 3.5. Risk assessment

As Fig. 6, the potential ecological risk indexes (PERI) of Pb and Cr are less than 40 in the whole area, which belongs to the low risk level. The PER of As is greater than 320 in the central area, which belongs to the severe risk level. The As pollution degree gradually decreases from the center to the periphery. Except for the northeast edge area, the study area are above the considerable risk level. Cd also poses a severe risk in the central area. Except for the northeast edge area, most of the study area are at high to severe risk level. Sb pollution is the most serious, and the central area is at an extremely high risk almost the entire area belongs to high risk. The requested potential ecological risk index (RERI) in the central region is greater than 600, which belongs to extremely high pollution risk area. The local ecological environment had been seriously threatened, and it is necessary to carry out ecological restoration in the study area, especially the pollution of Sb, Cd, and As.

As Fig. 7, the Hazardous Quotient (HQ) values of Pb and Cd are less than one in the whole area, which belongs to no risk. The HQ of Cr is between two and three in a small part of the west. Furthermore, the index gradually decreases from west to east. Except for the edge area of the northeast corner, the indexes of Cr are greater than one. As has the highest value, and the indexes of the central area are greater than 200 with a trend of decreasing gradually from the center to the periphery. Except for the edge area of the northeast corner, the indexes are all
higher than 25. The HQ values of Sb in the central area are greater than
50 and less than 100, and gradually decrease from the center to the
periphery. Except for the edge area of the northeast corner, the indexes
of Sb in other area are greater than 10. A review about PTEs pollution of
industrial and agricultural soils in China pointed out that the carcino-
genic risk of As in most regions was within a relatively unacceptable
range (Yang et al., 2018). The non-carcinogenic risk of As in this study
area was more serious than Sb. As was a special element that needed be
paid more attention on the harm to humans. As mentioned above, As and
Sb are associated elements. Therefore, in the Sb mining area of Hunan
Province, it was necessary to consider both of them when evaluating
humans’ threats from soil, rivers, groundwater, and plants. Industrial
companies needed to choose processes that emit less As and Sb. When
the local soil was used for housing and other purposes closely related to
humans, it is necessary to treat As and Sb pollution. But Cr pollution was
relatively slight, which could reduce the priority or leave it alone.

4. Conclusion

This paper reported that the soils in the study area are the weakly
alkaline red loam with an average pH value of 7.68. And the average
concentration of Pb, Cr, As, Cd, and Sb were 28.39, 35.59, 134.99, 0.90,
and 74.19, with a descending order of As > Sb > Cr > Pb > Cd. Variance
analysis and power analysis indicated that pH had no significant effect
on the soil pH. But the deeper the soil was, the greater the total
concentration of PTEs in the soil. The migration of Cd in the soil was
more severe than other elements. The migration ability of As in the soil
was lower than other elements. Except for Cr, migration abilities of Pb
and Sb were stronger than others. The water-soluble As and Sb in the soil
had no significant relation with soil depth and total PTEs concentration.
The results through acid leaching were the same as water leaching. From
the potential ecological risk index Pb and Cr had low or no risk. From
Hazardous Quotient, Pb, Cr, and Cd had low or no non-carcinogenic risk.

If the study area was used for residential purposes, the As and Sb
pollution problems need to be solved. If used to construct gardens and
other purposes, it was necessary to solve As, Sb, and Cd pollution.
Furthermore, places with thick soil had more opportunities to be resolve
before the groundwater was contaminated if an accidental spill
occurred. But the concentrations of As and Sb at different depths
through water leaching and acid leaching could keep the same, indic-
ating that As and Sb might directly be leached into the groundwater
even though the total concentrations of soil PTEs around the ground-
water were already very low.

CRediT authorship contribution statement

Qing Xie: Methodology, Writing – original draft, Investigation.
Bozhi Ren: Conceptualization, Supervision. Xi Yang Shi: Investigation,
Resources. Andrew Hursthouse: Writing – review & editing,
Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References


Fig. 7. Hazardous Quotient of the study area.


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