Research Article

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Ecological risk assessment of toxic metal pollution in the industrial zone on the northern slope of the East Tianshan Mountains in Xinjiang, NW China

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Abstract: The ecological risks of six toxic metals (Zn, Cu, Cr, Pb, Hg, and As) in the industrial zone on the northern slope of the East Tianshan Mountains in Xinjiang, northwest (NW) China, were assessed. The results showed that the soil toxic metal contents of Zn, Pb, Hg, and As exceeded the regional background values, and concentrations of Zn, Cu, Pb, and As exceeded the national soil environmental quality standards of China (GB15618-1995). The Cu and Cr contamination levels were lower than the limits of both soil standards and mainly originated from the parent material, Pb mainly originated from agricultural activity and traffic emissions, and Hg mainly originated from the coal burning and chemical industries. As contamination originated from automobile exhaust emissions, and Zn contamination was influenced by a combination of natural factors and human activities. The mean geo-accumulation index (I_{geo}) values of As, Hg, and Pb ranged from unpolluted to moderately polluted. There was an area not polluted by Zn, Cu, and Cr. The pollution index (PI) value of the six heavy metals showed that the mean PI values of Zn, Cr, and Cu showed no pollution, As and Pb presented medium pollution, and Hg presented heavy pollution. The results of the potential ecological risk analysis in this region showed that Zn, Cu, Cr, and Pb in all sample sites presented a low risk, while Hg presented a high ecological risk. Therefore, it is necessary to prevent further Hg contamination in this region.

Keywords: soil, toxic metal contamination, pollution index, risk assessment, industrial zone

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1 Introduction

Toxic metals are one of the major pollutants that cause potential hazards in the soil system. Toxic metal contamination is the main factor influencing the quality of agricultural products [1–3]. Owing to their poor mobility and long residence time in soils, toxic metal contaminants may ultimately affect human health through consuming water and plants [4–6]. A high concentration of soil toxic metals can cause significant degeneration of an ecosystem's structure and function [7–11]; therefore, it has become a topic of great concern [12–16]. Generally, both human activities and natural processes lead to heavy metal contamination in soils [3], although human activities are typically the main contributor [17,18].

Coal mining meets the demand for energy and promotes regional economic growth. Nevertheless, excessive coal exploitation has resulted in negative effects on local ecological sustainability [19]. The migration and sedimentation of wastewater, waste slag, coal gangue, and fly ash during coal mining and coal transportation have caused the toxic metal contamination of soils [20]. Therefore, effective monitoring and the management of toxic metal pollution in soils caused by coal mining are important areas of study.

The industrial belt on the northern slope of the Tianshan Mountains is located in Xinjiang, northwestern China. The major industries include coal mines, coking plants, metal manufacturing aluminum smelting, heating power plants, and coal chemical plants. The coal mines are widely distributed and have abundant reserves. The total mining area is about 280 km^2, and the coal reserves are approximately 8.4 billion tons. There are 28 coal mines in Fukang city, with a production of 8.49 million tons/year, and the coal yield is about 3.05 million tons [21]. With the increasing demand for energy and regional economic development in recent years, the intensity of the exploitation of coal resources has continued to rise. Although industrial activities have greatly promoted social and economic development, they have also caused environmental problems, especially the destruction of soil and vegetation caused by industrial exhaust emissions. They have also changed the physicochemical properties of natural soils [22]. The toxic metals in soils are relatively stable and remain for a long period of time [23]. Ore mining, transportation, smelting, refining, tailings wastewater treatment, and agricultural activities directly affect the soil, thereby inhibiting soil microbial activity and reducing the nutrient supply efficiency [24–26]. The total area of farmland is approximately 59196.7, 44946.89, and 133,400 ha in Jimsar County, Qitai County, and Fukang City, respectively. The main crops included to the cotton, wheat, sugar beet and sunflower. To manage and control the soil pollution of the study area, it is necessary to understand the contamination degree and sources of toxic metals in this area [27,28]. Therefore, clarifying the spatial distribution and risk assessment of soil toxic metal pollution in this area plays an important role in restoring damaged ecosystems, protecting soil environmental quality, and providing a scientific basis for sustainable regional development.

The main objectives of this study were to (1) determine the spatial variation of soil toxic metals (Zn, Cu, Cr, Hg, As, and Pb) in the industrial zone; (2) identify their sources using multivariate analysis and geo-statistics; and (3) characterize their spatial variability for ecological risk assessment.

2 Data sources and methods

2.1 Study area

The study area was located in Fukang city, Jimsar county, and Qitai county on the northern slope of the East Tianshan mountains (44°20′–45°10′N, 88°36′–89°50′E) in the Xinjiang Uyghur Autonomous Region of northwestern China (Figure 1). It is surrounded by the Gurbantonggut Desert in the north and the Tianshan Mountains in the south, and slopes downward from the southeast to the northwest. Study area is located in the inner land of Northwest of china, and it has characteristics of the arid land eco-environment, climate, and topographical feature. Due to eco-environments of this region fragile, therefore the ecosystem easily affected by the influences of the climate change and anthropogenic activity. The local climate is semi-arid with an average rainfall of about 140–400 mm/year and evaporation of about 2,000–2,100 mm/year. The ecosystem is fragile, easily damaged, and difficult to repair. Soil types in this area mainly consisted chernozem, chestnut soil, sierozem, brown calcic, and gray desert soil.

2.2 Soil sampling and chemical analysis

Depending on the topographic features of the study area, as the center of the coal mining region and with many chemical plants, and considering the direction of pollutant emission from industrial areas, 68 soil samples were collected from the field using a systematic random sampling method. A total of 68 topsoil (0–20 cm) samples were collected using a hard plastic shovel in October 2016 from the surroundings of a coal-fired power plant, coal plant, coal yard, electrolytic aluminum plant, and coal chemical plant. The sampling sites were recorded using a global positioning system (GPS). Each soil sample was placed into a sampling bag, numbered, and sealed. Samples were brought to the laboratory, air-dried, and passed through a 2.0 mm mesh sieve to remove plant roots, stones, and other substances, and then passed through a 0.25 mm nylon sieve.

Soil solutions were prepared using 0.5 g of the soil sample and concentrated $HCl–HNO_3–HF–HClO_4$ acid [29] for measuring the concentration of the toxic metals using an atomic absorption spectrometer (Hitachi-Z2000, Tokyo, Japan). Atomic fluorescence spectrometry (PF6-2 dual channel automatic atomic fluorescence spectrometer, Beijing, China) was used to measure the concentrations of Hg and As [30], and inductively coupled plasma atomic emission spectrometry was used to measure the concentrations of Zn, Cu, Cr, and Pb [31]. The quality assurance and quality control (QA/QC) protocols we followed complied with the Chinese Soil Standard Reference (GBW07401, GSS-1). Accepted recoveries ranged from 91.2 to 105%. For each set of samples, analytical methods were evaluated in blank (n = 10) and duplicate samples (n = 15).

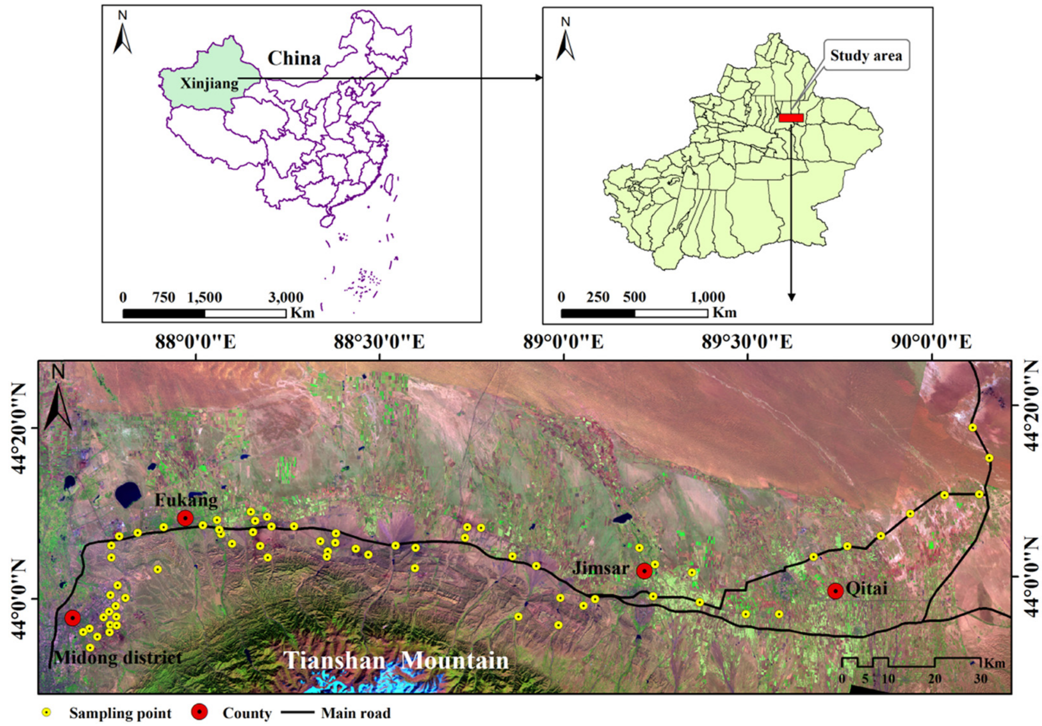

Figure 1: Sketch map of the study area.

2.3 Data analyses

2.3.1 Descriptive statistical analyses

Descriptive statistics, Pearson's correlation coefficient analysis, and principal component analysis (PCA) were performed using SPSS 20.0 software. The geo-accumulation index (I_{geo}) and potential ecological risk index (PRI) were processed using Microsoft Excel 2019. The spatial variation of the toxic metals in the soil was performed using Arc GIS 10.2 software.

2.3.2 Geo-accumulation index

The I_{geo} is the quantitative standard for evaluating toxic metal pollution in deposited substances, and it was proposed by Müller in 1969 [32]. The I_{geo} is classified into seven classes, and the categories represent levels of heterogeneity [33]. It is widely used for evaluating toxic metal contamination [34,35], and we estimated it using the following formula:

$$I_{geo} = \log_2[C_n/(1.5 \times B_n)], \tag{1}$$

where I_{geo} is the geo-accumulation index, C_n is the measured value of the toxic metals in the soil, and B_n is the background value of the soil. In this study, we used the background value of Xinjiang [29]. I_{geo} was classified as follows: <0, practically unpolluted; 0–1, unpolluted to moderately polluted; 1–2, moderately polluted; 2–3, moderately to strongly polluted; 3–4, strongly polluted; 4–5, strongly to extremely polluted; and >5, extremely polluted [32].

2.3.3 Pollution index

The pollution index (PI) was defined as the ratio of the element concentration in the soil sample to the background concentration of the corresponding element in regional soils [36]. The PI of each element was calculated and classified as low (PI ≤ 1), medium (1 < PI ≤ 3), or high (PI > 3) [37]. To obtain an assessment of the overall pollution status for a sample, the pollution load index (PLI) of heavy metals was calculated using the following equation:

$$\text{PLI} = (\text{PI}_1 \times \text{PI}_2 \times \text{PI}_3 \times \ldots \times \text{PI}_n)^{1/n}. \tag{2}$$

According to the contamination level, the PLI was classified as no pollution (PLI ≤ 1), no pollution to moderate pollution (1 < PLI ≤ 2), moderate pollution (2 < PLI ≤ 3), moderate to high pollution (3 < PLI ≤ 4), high pollution (4 < PLI ≤ 5), and very high pollution (PLI > 5) [38].

2.3.4 Potential ecological risk index

The PRI was proposed by the Swedish scientist Hakanson in 1980 to assess the ecological risk of soil toxic metals [39]. The PRI can be used to show the pollution level of a single toxic metal and evaluate the ecological risk of several elements [40,41], and we calculated it using the formulas below:

$$PRI = \sum_{i}^{n} E_r^i, \quad (3)$$

$$E_r^i = T_n^i \times C_r^i, \quad (4)$$

$$C_r^i = \frac{C^i}{C_n^i}, \quad (5)$$

where PRI is the sum of the potential ecological risk index of the toxic metals in the soil, E_r^i is the potential ecological risk coefficient of a certain toxic metal, T_n^i is the toxicity coefficient, C_r^i is the pollution factor of the toxic metal, C^i is the measured value of the toxic metals in the soil, and C_n^i is the background value of the toxic metals.

Grading standards of the toxicity coefficient of eight toxic metals were proposed in Hakanson's report, and the PRI was calculated based on the sum of the maximum toxic coefficient of eight toxic metals [42,43]. Because only six metals (Zn, Cu, Cr, Pb, Hg, and As) were analyzed, the PRI classification thresholds were modified. The toxicity coefficients of Zn, Cu, Cr, Pb, Hg, and As were 1, 5, 2, 5, 40, and 10, respectively [44]. First, we confirmed that the grading value of the toxicity coefficient of the toxic metals PRI = 150 (for low risk)/133 (the total value of the toxicity coefficient of the eight toxic metals) = 1.13. The toxic metal with the largest toxicity coefficients was Hg (40) in this study, and the sum of the toxicity coefficient of the six metals ($\sum E_r^i$) was equal to 63. Hakanson defined five categories for E_r^i and four categories for PRI, as shown in Table 1.

3 Results and discussion

3.1 Toxic metal concentrations in soil

The concentrations of Zn, Cu, Cr, Pb, Hg, and As are given in Table 2. The concentrations of Zn, Cu, Cr, Pb, Hg, and As varied between 44.95 and 233.11, 12.98 and 66.25, 28.02 and 68.26, 8.00 and 90.17, 0.016 and 0.24, and 5.20 and 78.02 mg kg^{-1}, respectively, with average concentrations of 82.2, 24.71, 46.48, 40.94, 0.05, and 32.5 mg kg^{-1}, respectively. The mean value of the total toxic metal contents in the soils was as follows: Zn > Cr > Pb > As > Cu > Hg. The mean values of Zn, Cu, Pb, and As were higher than the soil background values of Xinjiang by 1.20, 2.11, 2.94, and 2.90 times, respectively. The elements Zn, Cu, Pb, and As exceeded the second grade national soil quality standards (GB15618-1998) by 1.11, 1.09, 1.57, and 2.9 times, respectively. The mean concentrations of Cu and Cr were lower than both standards, yet the ranges of some of the soil samples in some areas were higher than the two standards. The coefficient of variance (CV) analysis showed that the CV values of Zn, Cu, Cr, Pb, Hg, and As were 38.20, 27.37, 14.60, 50.77, 58.49, and 53.60%, respectively, indicating medium variation (10% < CV < 100%). The concentrations of Hg coupled with its high coefficient of variation suggested that anthropogenic inputs may be the primary source.

3.2 Results of the I_{geo} and PI

The I_{geo} values of six toxic metals in soil are shown in Figure 2. The I_{geo} ranged from −1.20 to 1.17 (mean −0.41) for Zn, −1.63 to 0.73 (mean −0.74) for Cu, −1.40 to −0.12 (mean −0.69) for Cr, −1.86 to 1.63 (mean 0.28) for Pb, −0.86 to 3.05 (mean 0.68) for Hg, and −1.70 to 2.22

Table 1: Classification of ecological risk coefficient (E_r^i) and PRI of toxic metals

Ranges of E_r^i	Ecological risk levels	Ranges of PRI	Ranges of modified PRI	Potential ecological hazard
$E_r^i < 40$	Low risk	PRI < 150	PRI < 70	Low risk
$40 \le E_r^i < 80$	Moderate risk	150 ≤ PRI < 300	70 ≤ PRI < 140	Moderate risk
$80 \le E_r^i < 160$	Considerable risk	300 ≤ PRI < 600	140 ≤ PRI < 280	Considerable risk
$160 \le E_r^i < 320$	High risk	PRI ≥ 600	PRI ≥ 280	Very high risk
$E_r^i \ge 320$	Very high risk			

Table 2: Descriptive statistics of heavy metals in the soil

Elements	Ranges (mg kg^{-1})	Median (mg kg^{-1})	Average (mg kg^{-1})	Standard deviation (mg kg^{-1})	Coefficient of variation (%)	Kurtosis	Skewness	The background values in Xinjiang (mg kg^{-1})	National standard (mg kg^{-1})
Zn	44.95–233.11	72.97	82.2	31.40	38.20	7.08	2.17	68.8	74.20
Cu	12.98–66.25	23.98	24.71	6.76	27.37	20.56	3.38	26.7	22.60
Cr	28.02–68.26	46.87	46.48	6.78	14.60	1.70	0.20	49.3	61.00
Pb	8.00–90.17	37.56	40.94	20.78	50.77	−0.70	0.42	19.4	26.00
Hg	0.016–0.24	0.05	0.05	0.03	58.49	20.71	3.57	0.017	0.065
As	5.20–78.02	32.5	32.5	17.42	53.60	0.29	0.74	11.2	11.20

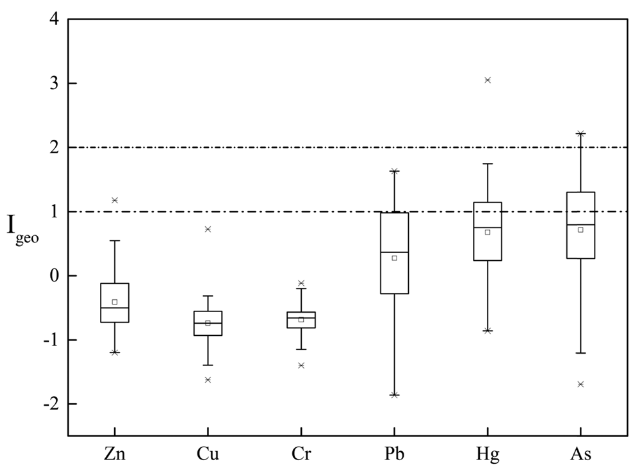

Figure 2: Box plots of the I_{geo} of soil toxic metals: Boxes depict 25th, 50th (median), and 75th percentiles and "whiskers" indicate the minimum and maximum values. Mean values (O); outliers (*).

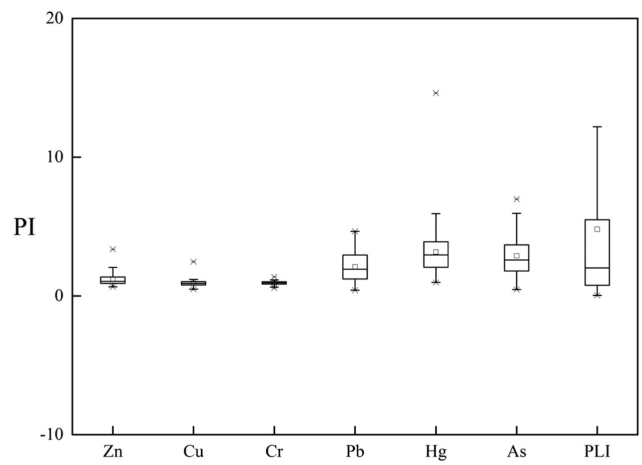

Figure 3: Box plots of the PI of soil toxic metals: Boxes depict 25th, 50th (median), and 75th percentiles, and "whiskers" indicate the minimum and maximum values. Mean values (O); outliers (*).

(mean 0.71) for As. The mean values of I_{geo} were As > Hg > Pb > Zn > Cr > Cu. The mean I_{geo} values of As, Hg, and Pb indicated that the soil was unpolluted to moderately polluted. The mean I_{geo} values of Zn, Cu, and Cr were < 1, so this area was not polluted by these elements.

The PI was calculated using the soil background values of Xinjiang. The PIs of the six toxic metals were different (Figure 3). The ranges of the PI values for the different metals were 0.65–2.39 (Zn), 0.49–2.48 (Cu), 0.57–1.38 (Cr), 0.41–4.65 (Pb), 0.97–14.63 (Hg), and 0.46–6.97 (As). According to our results, the average PI value for all metals followed a decreasing order: Hg (3.18) > As (2.90) > Pb (2.11) > Zn (0.98) > Cr (0.94) > Cu (0.93). Zn, Cr, and Cu were in the unpolluted (PI ≤ 1) range, while As and Pb showed a medium amount of pollution (1 < PI ≤ 3). The mean of the Hg values was higher than 3 (PI > 3), and their PI values indicated heavy pollution. The PLIs in all soil samples ranged from 0.04 to 18.48 with an average of 4.80, illustrating the high soil toxic metal pollution (Figure 6).

3.3 Spatial distribution of toxic metals

The spatial distributions of six toxic metals in soil are shown in Figure 4. The large circle represents a high concentration and the small circle represents a low concentration. High amounts of Zn were distributed alongside the roads in Qitai County, the southern parts of Jimsar and Fukang city, and also appeared in most of the sampling sites of the Midong District. The PCA results showed that the loading capacities of Zn were 0.58, 0.34, and 0.12 in PCA1, PCA2, and PCA3, respectively. Previous research showed that Zn may have been derived from the mechanical abrasion of vehicles [45] and from the lubricating oils and tires of motor vehicles [46,47]. In this

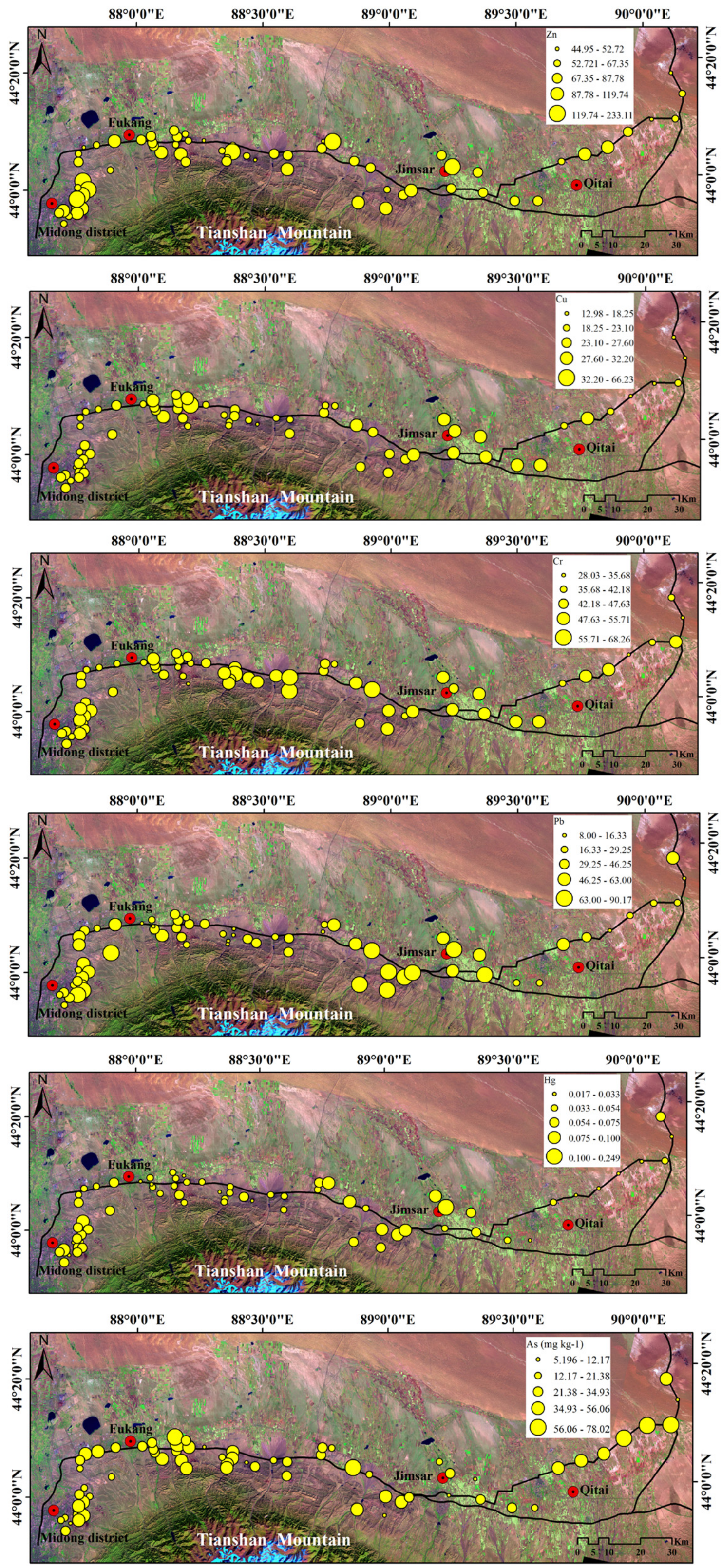

Figure 4: Spatial distribution of soil toxic metals.

study, whole traffic has passing the main roads during transportation, and which including variety of cars, the emission from the lubricating oil and tires of motor vehicle contribute to the concentration of Zn in this region. Therefore, automobile emission is the one of the main pollution sources contamination of Zn pollution. Jimsar, Qitai, and Fukang are the main production base of large amounts of grain every year. During the agricultural activity these regions use large amounts of pesticides. Related studies have shown that the commonly used pesticides contain Zn [48]. It can be supposed that pesticides may be another pollution source of the Zn accumulation in soil. Research results showed that the elements of Zn in the soil comes from parent material in Zhundong coal mining region in Xinjiang northwest of China [49]. The location of the study area close to the Zhundong pit coal mining area, and the soil types and eco-environments consist with the Zhundong, hence, Zn in the soil may be comes from the parent material. Comprehensive analysis of the pollution sources of Zn can be seen that, it was comes from the mixed pollution sources.

The spatial distribution characteristics of Cu and Cr were similar, and a high amount of the two elements appeared around the coal mining area and near the industrial area, indicating that these metals have the same pollution sources. Researchers found that the soil parent material is an important source of Cu and Cr accumulation in soil [50,22]. In this study, the concentrations of Cu and Cr were lower than the soil background values of Xinjiang, and these two elements' loading capacity (Cu [0.71] and Cr [0.83] in PCA2) mostly came from soil parent materials.

High concentrations of Pb were mainly distributed around the coal mining area, chemical plants, and road. Previous research showed that burning coal dust and the emissions of the tail gas caused by the traffic transportation are main reasons for the accumulation of Pb [51,52]. There are varieties of manufacturing in our study area, including a coking plant, cement manufacturing, aluminum smelting, heating power, coal mining, a metal manufacturing plant, and a coal chemical plant. Large amounts of automobiles move on the road to transport industrial products throughout the year, and waste gas emissions from vehicles lead to accumulations of Pb in the soil. Therefore, automobile emissions are one of the main reasons for Pb pollution. Research has shown that pesticides contain Pb, and this is absorbed by soils and accumulated [53,49]. In this study, the soil was polluted by the pesticides during agricultural activities. Therefore, anthropogenic factors were considered the main influencing factors of Pb distribution.

High amounts of Hg were significantly accumulated in the surroundings of the mining and chemical plants, which are located in Jimsar County in Midong District. Previous research showed that the concentration of Hg can be attributed to the emissions of the steel industry [31], coal burning, and subsequent atmospheric deposition [54–56]. Chemical plants are an important source of Hg emissions [57,58], as well as the coal washery, coal mines, and coal-fired power plants located in and around the sampling sites in Jimsar County. The sampling sites of the Midong District are close to chemical plants, machinery factories, coal mines, and metal smelting manufactories, and these industries emit a large amount of waste gas, waste water, and waste residue. Industrial activities, such as industrial atmospheric emissions, metal smelting, and coal burning, were the main sources of Hg concentration in this region.

Compared with other areas, higher concentrations of As were found near the roadside in Qitai County in the southern part of the Jimsar County and Midong District. Arsenic is easily affected by anthropogenic factors [59]. The concentration of As may also potentially be related to traffic and coal combustion [60]. Anthropogenic emissions of As to the atmosphere are about three or four times higher than those from natural sources [61]. The toxic metal contents of most of the sampling sites located in roadsides were higher than those in other areas. Therefore, As pollution in this region has mainly been affected by the influence of automobile exhaust emissions.

3.4 Source of toxic metals

The results showed that a significant moderate positive correlation existed between Zn and Hg (R^2 = 0.51, P < 0.01) and between Pb and Hg (R^2 = 0.67, P < 0.01) (Figure 5). This finding indicated that these metals possibly come from the same pollutant sources. There was a weak correlation between Zn–Cu, Zn–Cr, Zn–Pb, and Cu–Cr, and the correlation coefficients were 0.18, 0.22, 0.27, and 0.27, respectively. The correlations of these heavy metals were all less than 0.30 (P < 0.01), demonstrating relatively weak correlations.

PCA is a statistical procedure often used to identify trace metal sources in different environmental settings [62]. The results of PCA by applying Varimax rotation with Kaiser Normalization for the total metal concentrations in soil are shown in Figure 6. There were three principal components. The loading capacities of Pb and Hg were 0.83 and 0.87 in PCA1, respectively, and the

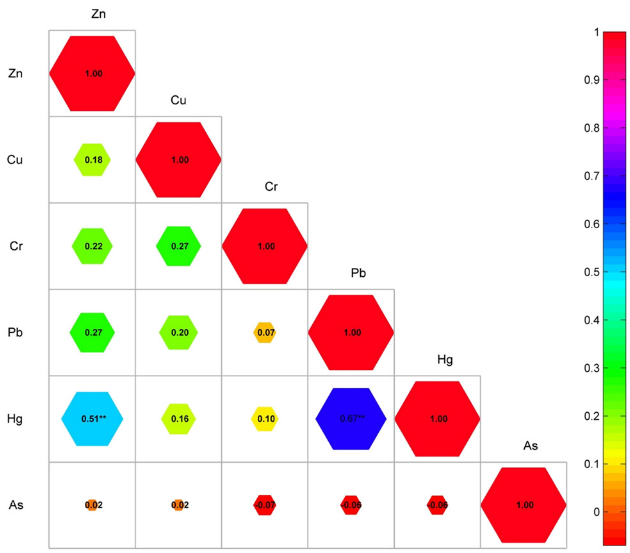

Figure 5: Correlation coefficients of soil toxic metals.

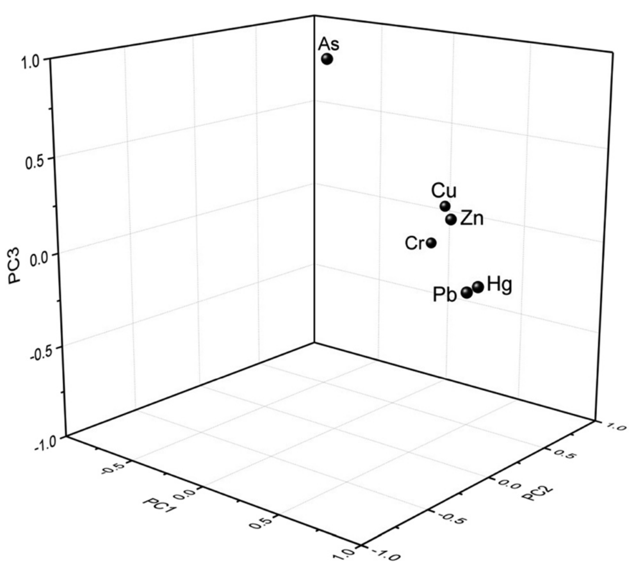

Figure 6: Principal component plot of the elements in the rotated factor matrix of the soil toxic metals.

average amounts of these elements in the soil exceeded the background values of Xinjiang and the national standards value. There was a high correlation between them, and these elements are sensitive to external factors. The exploitation of open pit coal mining and other human activities had a great influence on these elements; Related research showed that coal combustion are primarily pollution sources of Hg contamination in this research area [63], and recent research results revealed that traffic emissions, roadways, and transportation have been considered the primary sources of Pb soil pollution in these region [64]. Therefore, these two metals mainly originated from human activity. The loading capacities of Cu and Cr in PCA2 were 0.71 and 0.83, respectively. The average amounts of these two elements were close to the soil background values of Xinjiang and both had a lower CV; therefore, they likely originated from the soil parent material. The loading capacities of Zn were 0.58, 0.34, and 0.12 in PCA1, PCA2, and PCA3, respectively. The loading capacity was affected by natural and human factors. The loading capacity of As was 0.98 in PCA3. The amount of the As exceeded the two standards. Abliz et al. found that most of the As contaminations in a coal-mining region of northwestern China came from traffic emissions [19]. A comprehensive analysis after combining the spatial distributions of As revealed that automobile exhaust emissions were the main sources of As contamination in soils in this region.

3.5 Potential ecological risk of soil toxic metals

The frequency distribution is used to describe the proportion of different grades of potential ecological harm points accounting for total sample points [44]. The distribution percentages of the potential ecological risk coefficients (E_r^i) of single heavy metals in soil are shown

Table 3: Distribution percentage of the potential (E_r^i) of single toxic metals in soil

Element	Low risk (%)	Moderate risk (%)	Considerable risk (%)	High risk (%)	Very high risk (%)
Zn	100				
Cu	100				
Cr	100				
Pb	100				
Hg	1.47	20.59	55.88	20.59	1.47
As	81	19			

in Table 3. The distribution status of the E_r^i values of different soil toxic metals from the sampling sites revealed that the E_r^i values of Zn, Cu, Cr, and Pb were lower than 40, showing that there was low ecological risk in the study area for these elements. The E_r^i values of 19% of As were larger than 40 and presented a moderate risk. The E_r^i values of 81% of As were at a low risk status. The E_r^i value of Hg (127.2) was the highest, and the percentages of Hg samples in different levels were 1.47, 20.59, 55.88, 20.59, and 1.47%. The percentage of moderate to very high risk Hg was 98.53%. This indicated that there was a high ecological risk in the study area.

From the analysis of the PRI of toxic metals in soils (Table 4), it can be seen that the percentages of polluted sites with low risk, moderate risk, considerable risk, and very high risk for soil were 1.47, 30.88, 61.76, and 5.88%, respectively.

Because the concentration of Hg exceeded the soil background value of Xinjiang, the PRI values showed that most of the sampling sites present a risk. To assess the risk and understand the distribution pattern of Hg in the study area, we analyzed the spatial distributions of E_r^i for Hg in the soil (Figure 7). The high-risk region was located in Jimsar County and the Midong District. The risk levels of Hg in Qitai County and Fukang City were

Table 4: Statistical analysis of the PRI of toxic metals in soil

Potential ecological risk level	PRI < 70	70 ≤ PRI < 140	140 ≤ PRI < 280	PRI ≥ 280
Level	Low risk	Moderate risk	Considerable risk	Very high risk
Frequency	1	21	42	4
Percentage	1.47	30.88	61.76	5.88

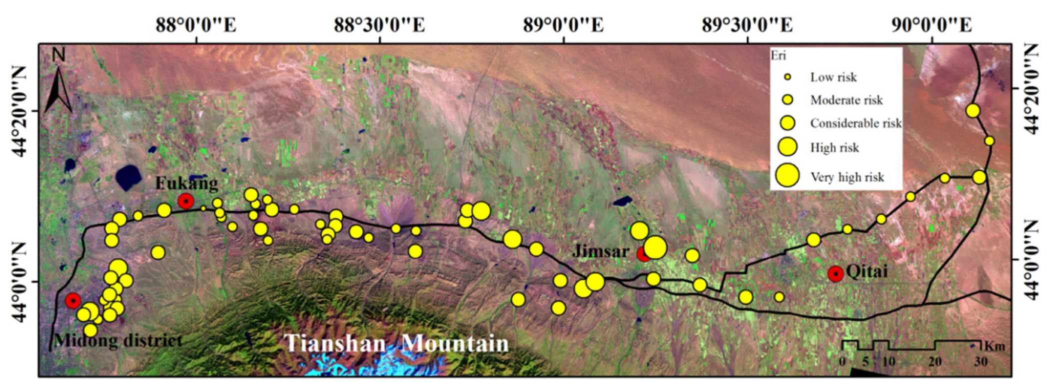

Figure 7: Spatial distribution of potential E_r^i for Hg in soil.

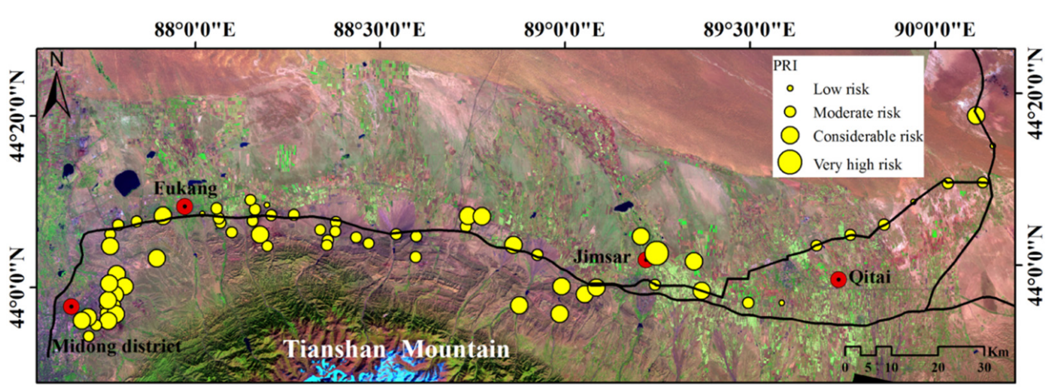

Figure 8: Spatial distribution of PRI for all toxic metals in soil.

relatively lower than in the other regions of the study area. High-risk soil was mainly located in areas with intensive human activity, such as the coal mining areas, chemical plants, and industrial parks.

As shown in Figure 8, the spatial distribution of PRI exhibited the same trends as E_r^i: the high PRI values were in the surrounding coal mining area and other industrial areas. The potential ecological risk in these areas was higher than in the other areas. The spatial variation pattern map showed that most of the regions are at considerable risk.

4 Conclusion

Our results showed that the soil toxic metal contents of Zn, Pb, Hg, and As exceeded the regional background values by 1.2, 2.11, 2.94, and 2.9 times, respectively, and the elements Zn, Cu, Pb, and As exceeded the Chinese national soil environmental quality standards (GB15618-1995) by 1.1, 1.09, 1.57, and 2.9 times, respectively. The concentrations of Cu and Cr were lower than the limits of the soil standards.

The I_{geo} values of toxic metals revealed that the mean I_{geo} values of As, Hg, and Pb were in the range of unpolluted to moderately polluted. This area is not polluted by other three elements. The PI values of the six toxic metals revealed that the mean PI values of Zn, Cr, and Cu showed that they are not causing pollution in this region ($PI \le 1$), while As and Pb presented medium pollution levels ($1 < PI \le 3$). The mean of the Hg values was higher than 3 ($PI > 3$), and the PI indicated heavy pollution. The PLI value of Hg was higher than 4, indicating that the soil status was at a high toxic metal pollution level.

The source analysis of the toxic metals showed that Cu and Cr mainly originated from parent material. Pb and Hg originated from human activities, such as coal burning, chemical industries, traffic emissions, and agriculture. As originated from automobile exhaust emissions. The Zn concentration in the soil was influenced by the combination of both natural factors and human activities.

The results of the potential ecological risk assessment in this region showed that Zn, Cu, Cr, and Pb in all sample sites presented a low risk. Approximately 1.47, 20.59, 55.88, 20.59, and 1.47% of the soil samples had a low to very high ecological risk of Hg pollution. This indicated that the soil was at a certain level of ecological risk, and Hg is considered to be the most hazardous toxic metal in this region. The high-risk regions of the study area were in the Jimsar County and the Midong District. The high-risk soil was mainly in regions with intensive anthropogenic activities, such as coal mining areas, chemical plants, and industrial parks. Because of the large amount of industries located in the study area, the pollution sources in this area are complicated. Therefore, it is necessary to perform more soil sampling and further analyze the pollution sources in this region. The study area in this research is the most important industrial region in the East Tianshan Mountains Economic belt, and the research results demonstrated that the human activity is the main pollution source. Hg is the main high-risk element in this region, and it is necessary to control and monitor Hg pollution to obtain early warnings of further soil contamination because of Hg. These research results provide important data and a scientific basis for the local environmental protection bureau to improve the understanding of the toxic metal contamination status of this region.

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