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Distribution Characteristics and Pollution Assessment of Soil Heavy Metals under Different Land-Use Types in Xuzhou City, China

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Abstract: Xuzhou, as a mining city in China, has been experiencing 130 years of coal mining and processing. To explore the spatial distribution characteristics and pollution status of soil heavy metals (Cr, Cd, As, Hg, Zn, and Pb) under different land-use types, a total of 2697 topsoil samples were collected in all of the areas (except for water) of Xuzhou in 2016. Overall, the mean concentrations of Cr (70.266 mg/kg), Cd (0.141 mg/kg), As (10.375 mg/kg), Hg (0.036 mg/kg), Zn (64.788 mg/kg), and Pb (24.84 mg/kg) in Xuzhou soils were lower than the environmental quality standard for soils (GB15618-1995). However, the mean concentrations of Cr, Hg, and Pb exceeded their corresponding background values, with the mean concentration of Hg being almost three times its background value. For different land-use types, the highest mean concentration of Cr was concentrated in grassland soils. The mean concentrations of Cd, As, Zn, and Pb in mining area soils were higher than those in the other soils. The mean concentration of Hg was the highest in the built-up area soils. Based on the potential ecological risk assessment, the forestland, garden land, grassland, and others were at low and moderate risk levels, the farmland and mining area were at low, moderate, and high risk levels, and the built-up area was at various risk levels in Xuzhou. There was a significant positive correlation between Cr, Pb, and Hg concentrations and the corresponding organic carbon contents in the farmland, built-up area, garden land, forestland, and other soils ($p < 0.01$). A high degree of correlation was found between Cr and Hg concentrations, as well as organic carbon contents in grassland soils, with values of $p < 0.05$ and $p < 0.01$, respectively. An obvious correlation could be seen between Hg concentrations and organic carbon contents in mining area soils ($p < 0.01$).

Keywords: coal mine city; land-use type; soil heavy metals; multivariate statistical analysis; potential ecological risk assessment; Xuzhou

1. Introduction

In China, the main types of land use are farmland, built-up area, mining area, forestland, garden land, grassland, water, and others [1]. Cities that have traditionally been dominated by the coal mining industry, such as Fushun, Datong, Tangshan, Pingdingshan, Xuzhou, Huaibei, and so on [2,3], are in the main grain-producing areas [4]. Farmland, forestland, and grassland play a major role in grain production and ecological safety in these cities. Sewage irrigation, large-scale coal-fired power generation, and the accelerated urban growth during the last few decades have been responsible for the degradation of the soil quality of different land types. Soil is one of the basic environmental media, and it can be contaminated through the accumulation of heavy metals through the discharge of effluents from mine tailings, coal combustion, sewage sludge, the disposal of high-metal wastes, and land application of fertilizers. Moreover, metal-contaminated crops from contaminated soils pose a threat to human health as a consequence of inhalation or ingestion through the food chain [5,6].

Land-use type has an impact on the migration and accumulation of soil heavy metal [7,8]. In terms of farmland soils, anthropogenic metal inputs, mainly including sewage irrigation and the application of fertilizers, have resulted in the increase of heavy metal concentration [9]. Meanwhile, crops (e.g., wheat, corn) can contribute to the migration and transformation of heavy metal by their enrichment capacity [10,11]. Industrial and domestic waste, vehicle exhaust, and slag have been proven to the major sources of soil heavy metals of the built-up area and mining area. Also, compared with physical and chemical remediation, bioremediation is an effective and environment-friendly method for the disposal of contaminated soils [12,13]. As for grassland, garden land, and forestland, the concentrations of Mn, Zn, and Cu in soils have decreased significantly through the enriched plants, such as tall fescue, alfalfa, and camphor tree [14,15].

Scholars have always paid attention to the distribution characteristics and pollution assessment of soil heavy metal in coal-mining cities [16,17]. On the basis of 30 coal-mining city samples from Deng et al. [18], existing research about soil heavy metal has mainly focused on the partial land-use types of these cities, including the built-up area (e.g., Tongchuan, Fuxin, and Jinchang) [19–21], mining area (e.g., Xinzhuangzi mine and Panyi mine in Huainan, Suxian district in Chenzhou) [22,23], and farmland (e.g., Huaibei, Fuxin, and Shuangyashan) [24–26]. The sampling sites mostly adopted a triangular shape, hexagon shape, "S" shape, and "X" shape. Statistical indicators (e.g., mean, median, max, min, standard deviation, coefficient of variation, kurtosis, and skewness) showed the metal concentrations and other key soil properties. The geographical information system (GIS)/statistical integrated methods have been mostly used to analyze the spatial patterns of soil heavy metals. To determine the degree of soil contamination, researchers employed various factors and indices consisting of a geoaccumulation index (Igeo), contamination factor (CF), enrichment factor (EF), Nemerow Integrated pollution index (NIPI), and potential ecological risk (RI). CA was used to classify the heavy metals into clusters or groups based on their similarities. PCA identified the factors that were responsible for variations of heavy metals in soils.

In contrast, there is currently little research on the concentration characteristics of soil heavy metals under different land-use types within the whole coal mine city. Is the metal concentration the highest in mining area soils? Is there widespread metal contamination in other types of land use? The objectives of this study are to (1) obtain an overview of the soil heavy metal concentration of Xuzhou, (2) investigate the concentration characteristic and pollution status of soil heavy metal under different land-use types, (3) analyze the correlation between metal concentration and organic carbon content in soils under different land-use types, and (4) provide important management information for soil pollution under different land-use types in Xuzhou.

2. Materials and Methods

2.1. Study Area

Xuzhou is in the northwest of Jiangsu Province (latitude 116°22′–118°40′N, longitude 33°43′–34°58′E) (Figure 1), which has a history of coal mining and processing that dates back more than 130 years. The city is located in the Xu-Huai alluvial plain, covering Pei County, Feng County, Pizhou City, Xinyi City, Suining County, Jiawang District, Tongshan District, Gulou District, Quanshan District, and Yunlong District. The area is dominated by alluvial soils. There is a sub-humid warm temperate continental monsoon and four seasons, with an annual average temperature of 14 °C. The annual average precipitation ranges from 800 to 930 mm. The total area of Xuzhou is 11259 km^2, consisting of farmland (5989.33 km^2), built-up area (2434 km^2), forestland (248 km^2), garden land (556.67 km^2), grassland (61.33 km^2), mining area (97.33 km^2), water (1739.67 km^2), and others (132.67 km^2). The data of land-use types in 2016 (Figure 1) was provided by the Xuzhou Land Resources Bureau. The mining area mainly distributed in Pei County, Jiawang District, and Tongshan District accounts for 0.86% of the total area.

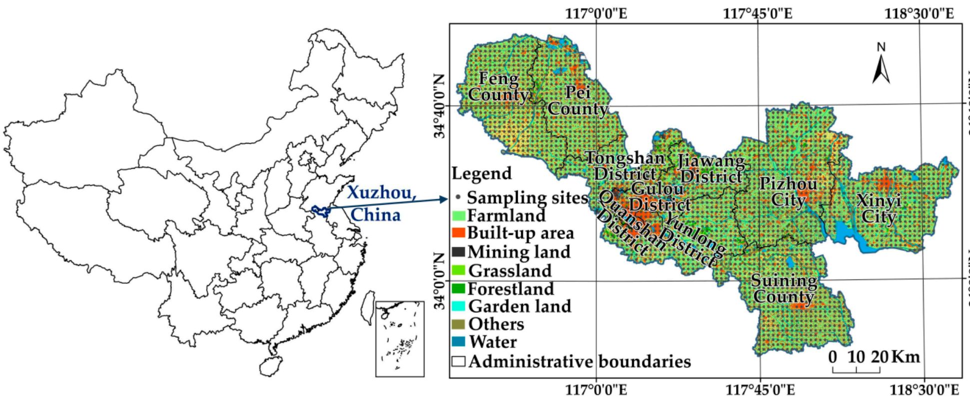


Figure 1. Map of soil sampling sites of Xuzhou.

2.2. Sample Collection and Chemical Analysis

For this study, the sampling sites were uniformly located in the whole area (except for water) of Xuzhou based on a regular grid of 1 × 1 km^2 in 2016. We collected a total of 2697 topsoil samples (0–20 cm in depth), which included farmland (1642 samples), the built-up area (608 samples), the mining area (21 samples), forestland (60 samples), garden land (168 samples), grassland (21 samples), and others (177 samples). Each sample was gathered by mixing four sub-samples obtained in different directions using a stainless steel hand spade. All of the soil samples were air-dried at room temperature, and then passed through a 0.154-mm nylon sieve. Then, a 0.2 g (±0.0001 g) dried and powdered soil sample was digested using a mixture of concentrated acids consisting of 5 mL of HCL and 5 mL of HNO_3 at a temperature of 105 °C for 6 h [27]. The concentrations of soil heavy metals (Cr, Cd, As, Hg, Zn, and Pb) were measured using inductively coupled plasma-mass spectrometry (ICP-MS, Agilent, Palo Alto, CA, USA). A soil sample was oxidized by potassium dichromate and heated to about 170–180 °C for five minutes, and then excess potassium dichromate ($K_2Cr_2O_7$) was determined by titration with standard 0.2 mol L^{-1} of ferrous sulfate ($FeSO_4$). We obtained the organic carbon content based on the potassium dichromate consumed [28].

2.3. Statistical Analysis and Spatial Distribution Maps

Statistical indicators of metal concentration, such as the mean, median, min, max, standard deviation (SD), coefficient of variation (CV), kurtosis, and skewness were achieved by using Excel software (Version 14, Microsoft, Inc., Redmond, Washington, DC, USA). Then, correlation analysis based on samples was used as an indicator of the relationships between heavy metal concentration and organic carbon content in soils using IBM SPSS statistics software (Version 19.0, Armonk, NY, USA). Ordinary kriging (OK) interpolation was performed on the potential ecological risk index (RI) of soil heavy metals using ArcGIS software (Version 10.2, ESRI, Inc., Redlands, CA, USA).

2.4. Pollution Index

Originally used with bottom sediments [29], the geoaccumulation index (I_{geo}) could also be applied to the assessment of soil contamination [30–32]. I_{geo} is computed using the following equation:

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

where C_n is the concentration of heavy metal i, and B_n is the geochemical background value of the same metal. In the study, the background values of the metals in the topsoil of the Xu-Huai alluvial plain were used as the geochemical background. The geochemical background values of Cr, Cd, As, Hg, Zn, and Pb were 73 mg/kg, 0.149 mg/kg, 11.1 mg/kg, 0.034 mg/kg, 68 mg/kg, and 23.8 mg/kg, respectively [33]. Based on the Igeo value for each heavy metal, the contamination degree was classified into seven categories: $I_{geo} \leq 0$ (practically uncontaminated), $0 < I_{geo} \leq 1$ (uncontaminated to moderately contaminated), $1 < I_{geo} \leq 2$ (moderately contaminated), $2 < I_{geo} \leq 3$ (moderately to heavily contaminated), $3 < I_{geo} \leq 4$ (heavily contaminated), $4 < I_{geo} \leq 5$ (heavily to extremely contaminated), and $I_{geo} > 5$ (extremely contaminated) [30].

The potential ecological risk index (RI) was used to quantitatively express the potential ecological risk posed by a variety of toxic heavy metals [34]. The RI is calculated by the following formulas:

$$\mathrm{RI} = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} T_i \times C_f^i = \sum_{i=1}^{n} T_i \times C_i / C_O \quad (2)$$

where E_i is the potential ecological risk factor for a given heavy metal, i; T_i is the toxic coefficient of a heavy metal, i; C_i is the concentration of the heavy metal; and C_O is the background value of the corresponding heavy metal in Xuzhou [35]. Based on previously published research, the toxic coefficients of Cr, Cd, As, Hg, Zn, and Pb were 2, 30, 10, 40, 1, and 5, respectively [36,37]. The potential ecological risk (RI) posed by heavy metals was classified into four grades (see Table 1): RI < 150 (low ecological risk), $150 \leq$ RI < 300 (moderate ecological risk), $300 \leq$ RI < 600 (high ecological risk), and RI ≥ 600 (serious ecological risk) [38].

Table 1. Criteria of the potential ecological risk index (RI).

Values of the RI	**RI**<150	150≤**RI**<300	300≤**RI**<600	**RI**≥600
Grades	Low	Moderate	High	Serious

3. Results and Discussion

3.1. Overview of Concentrations of Soil Heavy Metals in Xuzhou

The statistical characteristics of soil heavy metal concentrations in Xuzhou are summarized in Table 2. The Cr, Cd, As, Hg, Zn, and Pb concentrations were respectively in the ranges of 34.7 to 182 mg/kg, 0.033 to 0.830 mg/kg, 3.72 to 37.3 mg/kg, 0.01 to 0.64 mg/kg, 21.2 to 346 mg/kg, and 13 to 76.099 mg/kg. The coefficient of variation (CV) shows the degree of relative variability within the concentrations of heavy metals in all of the soil samples. If the CV $\leq$ 20, it indicates low variability; 21% < CV $\leq$ 50% is considered moderate variability; 50% < CV$\leq$ 100% is observed as high variability; and a CV above 100% is regarded as exceptionally high variability [39]. The CV of heavy metals decreased in the order of Hg (0.778) > Cr (0.334) > Zn (0.285) > Cd (0.276) > Pb (0.270) > As (0.232). The large CV value for Hg indicated that there was a high variability of Hg between all of the sampling sites in Xuzhou. There was a moderate degree variability of Cr, Zn, Cd, Pb, and As with the CV values (21% to 50%). The coefficient of skewness and kurtosis reflect the normal distribution characteristics of soil samples [40]. The skewness values for all metals were greater than three, revealing that these metals positively skewed toward lower concentrations. Also, the kurtosis values of all of the metals were greater than zero, showing that the statistical distribution of these elements was steeper than normal.

Table 2. Descriptive statistics of heavy metal concentrations in soils of Xuzhou (mg/kg).

Heavy Metal	**Mean**	**Median**	**SD**	**Max**	**Min**	**Kurtosis**	**Skewness**	**CV**	**BGV**	**EQS**
Cr	70.266	68.9	23.469	182.000	34.700	16.243	1.500	0.334	55.5	400
Cd	0.141	0.13	0.039	0.830	0.033	39.914	4.213	0.276	0.29	1.0
As	10.375	9.95	2.407	37.300	3.720	17.748	1.938	0.232	11.2	40
Hg	0.036	0.03	0.028	0.640	0.010	107.48	7.409	0.778	0.01	1.5
Zn	64.788	62.6	18.465	346.000	21.200	44.409	3.524	0.285	91.1	500
Pb	23.840	22.75	6.437	76.099	13.000	10.984	1.838	0.270	16.3	500

SD: Standard deviation; CV: Coefficient of variation; BGV: Background values of Xuzhou; EQS: Environmental quality standard for soils (GB15618-1995).

The mean concentrations of Cr, Cd, As, Hg, Zn, and Pb were less than the national environmental quality standards for soils (GB15618-1995) (EQS) [41], with the mean values of 70.266 mg/kg, 0.141 mg/kg, 10.375 mg/kg, 0.036 mg/kg, 64.788 mg/kg, and 23.840 mg/kg, respectively. When compared with the soil background values of Xuzhou (BGV) [35], the mean concentrations of Cr, Hg, and Pb were greater, and presented obvious pollution. Among these three heavy metals, the mean concentration of Hg was almost three times its corresponding background value.

3.2. Concentration Distributions of Soil Heavy Metals under Different Land-Use Types

The mean concentrations of soil heavy metals under different land-use types of Xuzhou are presented in Table 3. The Cr concentration in grassland soils was the highest, with the mean of 76.781 mg/kg. The highest values of Cd, As, Zn, and Pb mean concentrations were found in mining area soils, which were 0.16 mg/kg, 13.55 mg/kg, 71.495 mg/kg, and 24.54 mg/kg, respectively. The Hg mean concentration (0.045 mg/kg) in the built-up area soils was greater than that in the other land-use type soils.

Table 3. Descriptive statistics of soil heavy metals under different land-use types (mg/kg).

Heavy Metal	Farmland				Built-up Area				Mining Area			
	Mean	**Max**	**Min**	**PbB**	**Mean**	**Max**	**Min**	**PbB**	**Mean**	**Max**	**Min**	**PbB**
Cr	70.167	106	37.5	97.32%	70.339	182	34.7	97.37%	76.02	131	51.5	99.99%
Cd	0.141	0.72	0.033	0.79%	0.148	0.83	0.038	2.63%	0.158	0.23	0.068	0.00%
As	10.489	22.9	4.49	29.35%	10.286	27.9	4.03	25.99%	13.55	47.299	6.42	38.10%
Hg	0.034	0.27	0.01	99.99%	0.045	0.64	0.013	100%	0.042	0.082	0.021	100%
Zn	64.396	277	23.7	5.18%	67.273	346	26.4	7.89%	71.495	101	42.099	19.05%
Pb	23.732	53.099	14	98.66%	24.518	76.099	13	99.18%	24.54	33.9	16.6	100%
Heavy Metal	**Forestland**				**Garden Land**				**Grassland**			
	Mean	**Max**	**Min**	**PbB**	**Mean**	**Max**	**Min**	**PbB**	**Mean**	**Max**	**Min**	**PbB**
Cr	70.995	88.9	38	96.67%	67.186	97	36.7	93.45%	76.781	88.099	54	98.33%
Cd	0.128	0.26	0.055	0.00%	0.118	0.32	0.056	0.09%	0.127	0.19	0.056	0.00%
As	10.457	16.4	4.37	36.67%	8.943	18.5	3.72	11.31%	11.177	14.9	4.25	57.14%
Hg	0.035	0.14	0.015	100%	0.034	0.24	0.014	100%	0.030	0.05	0.012	100%
Zn	60.667	107	23.2	1.67%	57.704	108	21.2	1.19%	64.548	84.199	49.099	0.00%
Pb	23.686	15.9	15.9	98.33%	21.454	33.7	15.7	95.83%	23.657	65.199	19.2	100%
Heavy Metal	**Others**											
	Mean	**Max**	**Min**	**PbB**								
Cr	70.744	111	42.599	97.18%								
Cd	0.136	0.26	0.054	0.00%								
As	10.354	21	4.08	26.55%								
Hg	0.032	0.13	0.013	100%								
Zn	63.620	106	30.799	3.95%								
Pb	23.603	33.9	15.8	99.99%								

PbB: Percentage of sampling sites above the BGV.

PbB refers to the percentage of sampling sites above the BGV. The PbB values of six heavy metals in soils displayed a decreasing trend of Hg > Pb > Cr > As > Zn > Cd in all of the land-use types. As shown in Table 3, in the farmland, built-up area, and garden land soils, there were some sampling sites at which the concentrations of the six heavy metals were higher than the BGV. For farmland soils, the concentrations of Hg, Pb, and Cr in 99.99%, 97.32%, and 98.66% of the sampling sites were above the BGV, respectively. In terms of built-up area soils, the Hg concentration of all of the sampling sites was higher than the BGV with the PbB value of 100%. Also, the Pb and Cr concentrations in more than 97% of the sampling sites exceeded the BGV. For garden soils, the Hg, Pb, and Cr concentrations in more than 93% of the sampling sites were above the BGV. In the mining area, forestland, grassland, and other soils, the Cd concentration of all the sampling sites was lower than the BGV with the PbB value of 0.00%. For mining area soils, the Hg, Pb, and Cr concentrations in more than 99% of the sampling sites were above the BGV. For forestland soils, there were more than 96% sampling sites with higher Hg, Pb, and Cr concentrations than the BGV. For grassland soils, the Hg, Pb, and Cr concentrations in more than 98%

of the sampling sites exceeded the BGV. For others soils, there were more than 97% sampling sites at which the Hg, Pb, and Cr concentrations were higher than the BGV. In the soils of all of the land types in Xuzhou, the factors affecting the concentration distribution difference of heavy metals may include soil nutrient, grain size [42], and human activity (e.g., mechanize, fertilize, mining, transport) [43–45].

3.3. Pollution Assessment of Soil Heavy Metals under Different Land-Use Types

The geoaccumulation indices (Igeo) of soil heavy metals under different land-use types are presented in Figure 2. In farmland soils, Cr, Cd, Pb, Zn, and Hg presented as "uncontaminated to moderately contaminated" in 3.90%, 5.12%, 2.80%, 1.89%, and 8.28% of the sampling sites, respectively (Figure 2a). In built-up area soils, Cr, Cd, Pb, and Hg showed "uncontaminated to moderately contaminated" levels in 3.33%, 6.43%, 4.93%, and 12.99% of the sampling sites, respectively. Also, Hg in 4.61% and 1.64% of the sampling sites presented as "moderately contaminated" and "moderately to heavily contaminated", respectively (Figure 2b). In mining area soils, Cr, Pb, and Hg appeared "uncontaminated to moderately contaminated" in 4.76%, 19.05%, and 33.33% of the sampling sites, respectively (Figure 2c). In forestland soils, Cd, Pb, and Zn showed "uncontaminated to moderately contaminated" levels in about 3.00% of the sampling sites. Nearly 3.33% of the sampling sites were moderately contaminated by Hg (Figure 2d). In garden land soils, Hg presented as "moderately contaminated" in 1.22% of the sampling sites (Figure 2e). In grassland soils, Pb appeared "uncontaminated to moderately contaminated" in 4.76% of the sampling sites (Figure 2f). In others soils, Hg showed "uncontaminated to moderately contaminated" levels in 9.04% of the sampling sites (Figure 2g).

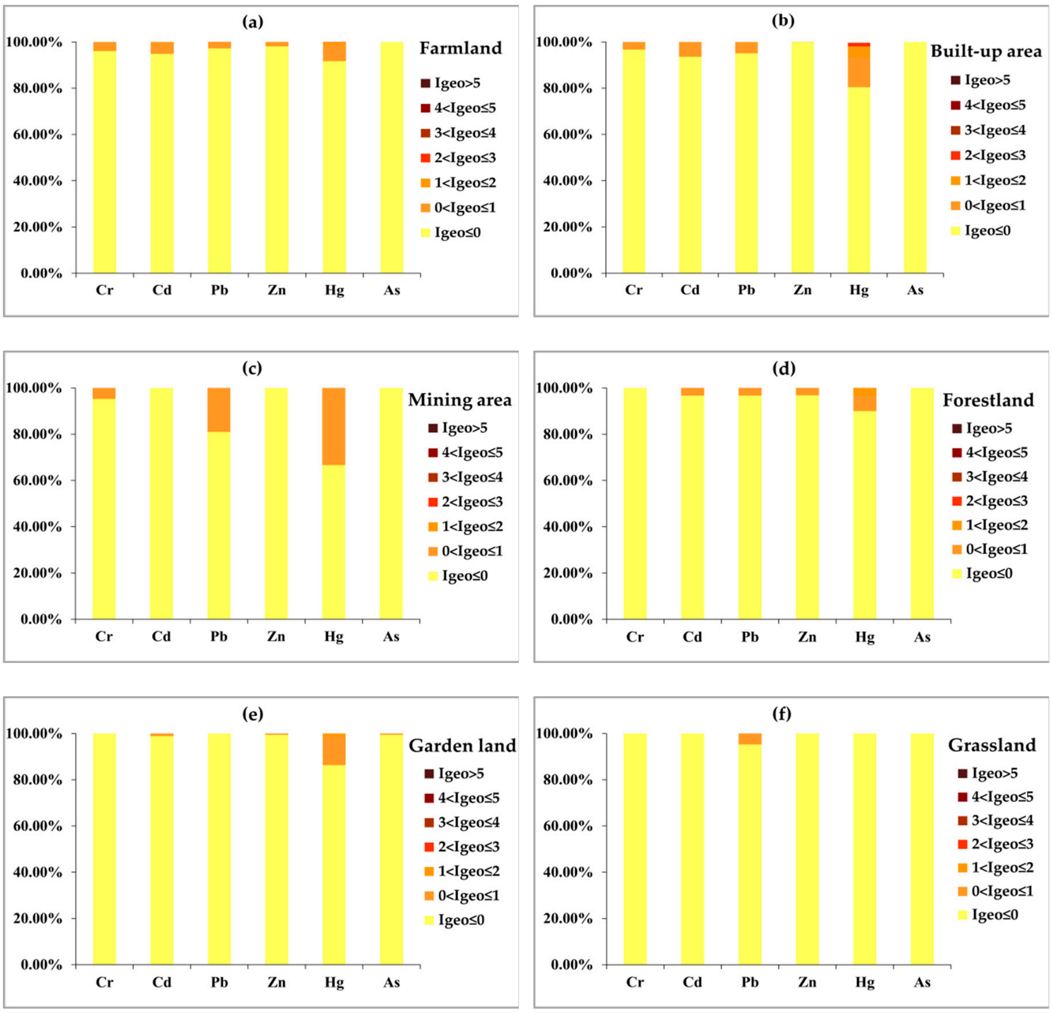


Figure 2. *Cont.*

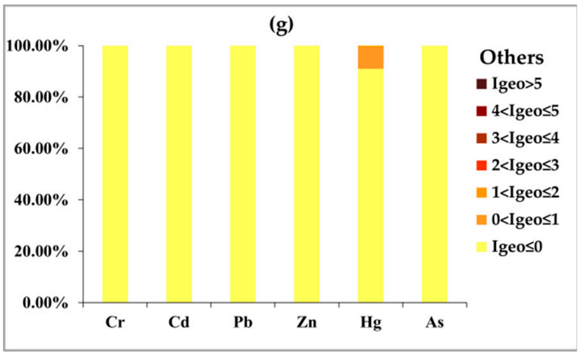
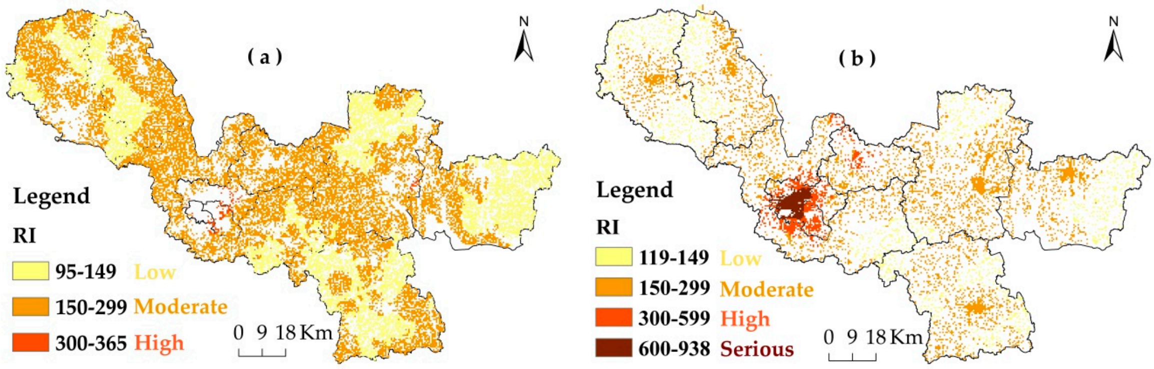


Figure 2. Geoaccumulation indices of soil heavy metals under different land-use types: (**a**) farmland; (**b**) built-up area; (**c**) mining area; (**d**) forestland; (**e**) garden land; (**f**) grassland; and (**g**) others.

3.4. Potential Ecological Risk Assessment of Soil Heavy Metals under Different Land-Use Types

The ecological risk index (RI) distributions of soil heavy metals under different land-use types in Xuzhou are expressed in Figure 3. Meanwhile, each risk level and its corresponding area ratio are shown in Figure 4. The RI values in farmland soils ranged from 95 to 365, showing low, moderate, and high ecological risk levels with approximately 34.86%, 64.52%, and 0.62% of the total farmland area, respectively. As shown in Figure 3a, farmland soils in Yunlong District and Quanshan District were at high ecological risk. For built-up area soils, approximately 22.57%, 63.49%, 9.56%, and 4.38% of the total area were at low, moderate, high, and serious risk levels, respectively, with RI values of 119 to 938. Figure 3b exhibited that built-up area soils in Quanshan District and Gulou District were at serious risk, and that those in Tongshan District and Yunlong District were at high risk. Mining area soils were at low, moderate, and high potential ecological risk levels, with the RI values ranging from 126 to 339, and their corresponding area ratios were 1.15%, 94.83%, and 4.02%, respectively. There was serious risk in mining area soils in Gulou District, which are shown in Figure 3c. Overall, the RI values of forestland, garden land, and grassland soils ranged from 72 to 283, with low and moderate risk levels. As shown in Figure 3d–f, forestland soils in Tongshan District and Jiawang District, garden land soils in Pizhou City, Feng County, and Tongshan District, and grassland soils in Tongshan District were all at moderate risk. In addition, Figure 3g indicated that the RI values of others soils ranged from 115 to 244 with low and moderate risk levels.



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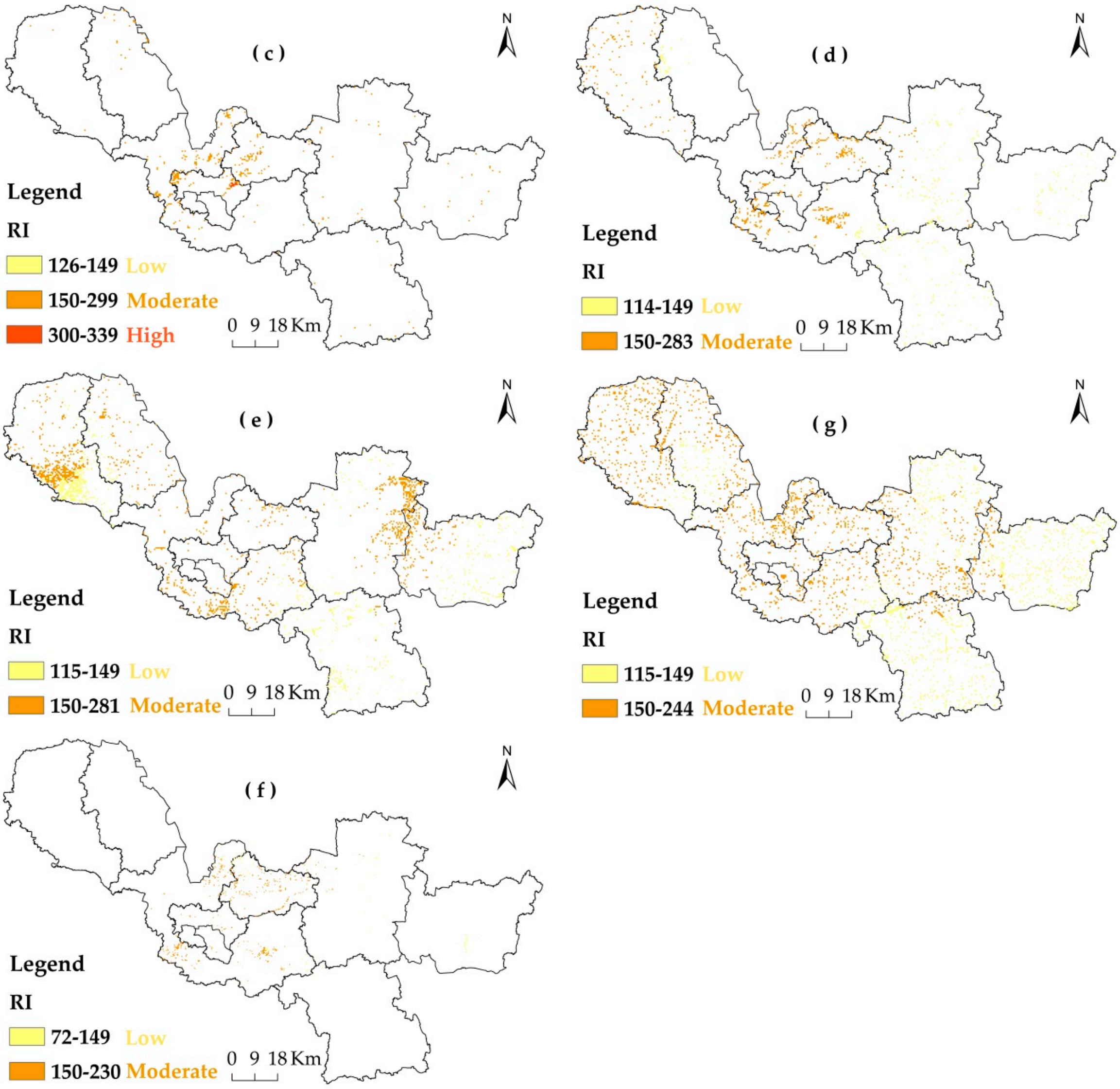

Figure 3. Potential ecological risk indices of soil heavy metal under different land-use types: (**a**) farmland; (**b**) built-up area; (**c**) mining area; (**d**) forestland; (**e**) garden land; (**f**) grassland; and (**g**) others.

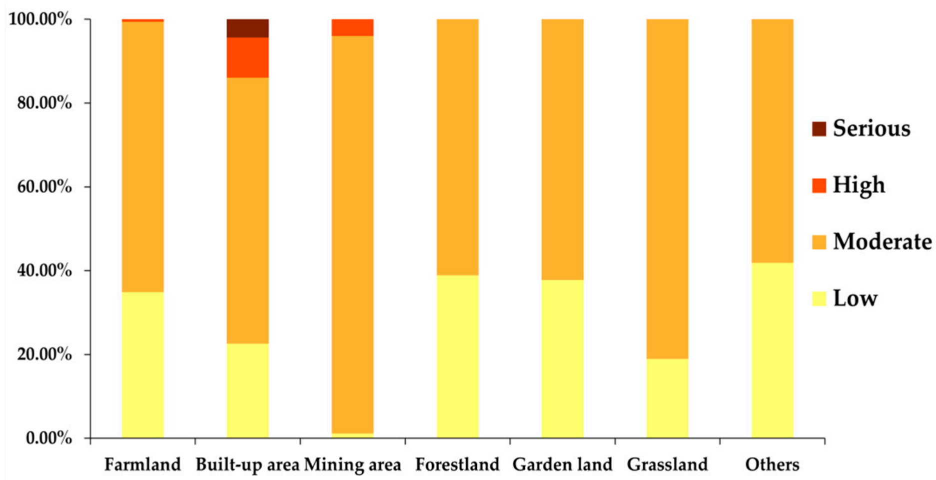

Figure 4. Potential ecological risk levels of soil heavy metals under different land-use types.

In general, the soils of all of the land types were mainly at a moderate risk level in Xuzhou. There were some high ecological risks in farmland in Yunlong District and Quanshan District, the built-up area in Tongshan District and Yunlong District, and the mining area in Gulou District, which related to approximately 0.62%, 9.56%, and 4.02% of their corresponding total area. Moreover, about 4.37% of the built-up area distributed in Gulou District and Quanshan District was at a serious risk level.

3.5. Correlation Analysis between Heavy Metal Concentration and Organic Carbon Content in Soils

Soil organic carbon plays an important role in the migration, accumulation, and bioavailability of heavy metals by affecting their forms [46]. According to the above analysis, Cr, Pb, and Hg were the main metals causing ecological risk to all kinds of lands, due to their high concentrations. Hence, a correlation analysis between these three metal concentrations and organic carbon contents was obtained in this paper. The results are shown in Table 4. The contents of soil organic carbon ranged from 0.3 to 5.2 g/kg. Soil organic carbon presented significant positive correlations with the Cr, Pb, and Hg concentrations in the farmland, built-up area, forestland, and other soils ($p < 0.01$). In grassland soils, Cr and Hg were significantly positive correlated with their corresponding organic carbon, with $p < 0.05$ and $p < 0.01$, respectively. A significantly positive correlation of $p < 0.01$ was found between organic carbon and Hg in mining area soils. However, Cr and Pb had poor correlations with their corresponding organic carbon.

Table 4. Correlation coefficients between heavy metal concentrations and organic carbon contents in soils under different land-use types.

Land-Use Type	Farmland (n = 1642)			Built-Up Area (n = 608)		
Heavy Metal	Cr	Pb	Hg	Cr	Pb	Hg
Coefficient	0.505 **	0.456 **	0.357 **	0.338 **	0.636 **	0.521 **
Land-Use Type	**Garden land (n = 168)**			**Forestland (n = 60)**		
Heavy Metal	Cr	Pb	Hg	Cr	Pb	Hg
Coefficient	0.362 **	0.658 **	0.552 **	0.345 **	0.640 **	0.526 **
Land-Use Type	**Grassland (n = 21)**			**MiningArea (n = 21)**		
Heavy Metal	Cr	Pb	Hg	Cr	Pb	Hg
Coefficient	0.436 *	0.100	0.858 **	−0.077	0.280	0.558 **
Land-Use Type	**Others (n = 177)**					
Heavy Metal	Cr	Pb	Hg			
Coefficient	0.349 **	0.440 **	0.374 **			

** $p < 0.01$ (two-tailed), * $p < 0.05$ (two-tailed).

4. Conclusions

In general, the mean concentrations of Cr, Cd, Pb, Zn, Hg, and As in Xuzhou were less than the environmental quality standard for soils in China, but the mean concentrations of Cr, Hg, and Pb exceeded their corresponding background values of Xuzhou. In farmland, built-up area, and garden land soils, there were some sampling sites at which the concentrations of six heavy metals were higher than their corresponding background values. In the mining area, forestland, grassland, and other soils, the Cd concentration of all the sampling sites was lower than that of their corresponding background values. Farmland in Yunlong District and Quanshan District, the built-up area in Tongshan District and Yunlong District, and the mining area in Gulou District were at high ecological risk levels. The built-up area in Gulou District and Quanshan District were at serious ecological risk levels. The soil organic carbon showed significant positive correlations with the Cr, Pb, and Hg concentrations in farmland, the built-up area, forestland, garden land, and other soils. Cr and Hg were significantly positively correlated with corresponding organic carbon in grassland soils. A significant positive correlation was found between organic carbon and Hg in mining area soils, but Cr and Pb had poor correlations with corresponding organic carbon.

According to the study, we argue that more attention should be paid to the heavy metal pollution of farmland, built-up area, and mining area soils in Xuzhou. Cr, Hg, and Pb should be controlled to reduce further pollution in some contaminated regions. We will explore the sources of these contaminated metals in the future.

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