Assessment of Heavy Metals and Their Sources in Uncultivated Saline-Alkali Soils of the Xinjiang Junggar Basin (Postprint)

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Abstract

To understand the pollution status of heavy metals in uncultivated saline-alkali soils in the Junggar Basin, Xinjiang, soil samples were collected from uncultivated saline-alkali lands to determine the contents of seven heavy metal elements: mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), arsenic (As), and selenium (Se). Multivariate statistical analysis methods and pollution index evaluation methods were employed in combination with Xinjiang soil background values (Se using the background value of Urumqi) to examine and assess different soil layers (0–20 cm, 20–40 cm) and analyze the sources of heavy metals. The results showed that the average concentrations of the seven heavy metal elements Hg, Cd, Pb, Cr, Ni, As, and Se in the 0–20 cm soil layer in the study area were 0.023, 0.165, 17.999, 62.587, 29.928, 16.325 mg·kg-1 and 0.696 mg·kg-1, respectively; in the 20–40 cm soil layer, the average concentrations were 0.021, 0.148, 17.497, 61.091, 29.995, 17.384 mg·kg-1 and 0.634 mg·kg-1, respectively. Except for Pb, all other elements exceeded the corresponding Xinjiang soil background values to varying degrees. The proportions of non-polluted and lightly polluted sample points for the seven elements in the two soil layers were 66.2%-100% and 74.7%-100%, respectively. The Nemerow comprehensive pollution index evaluation indicated primarily light pollution, with lightly polluted sample points accounting for 78.4% in both soil layers. The sources of Cd, As, and Se were dominated by natural factors, mainly associated with the composition and properties of the soil parent material, with influencing factors including weathering of mountain rocks and seasonal flood transport. The sources of Cr, Pb, and Hg were mainly influenced by anthropogenic factors; heavy metals carried in flue gases from industrial development, transportation, and coal combustion that deposit into the soil are the main causes of elevated background values in natural saline-alkali soils that have not been cultivated or disturbed. The source of Ni may result from the combined effects of anthropogenic and natural factors.

Full Text

Evaluation and Sources of Heavy Metals in Uncultivated Saline-Alkaline Soil in the Junggar Basin, Xinjiang

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Abstract

Uncultivated saline-alkaline soil samples were collected from the Junggar Basin, Xinjiang. Seven heavy metals including Hg, Cd, Pb, Cr, Ni, As, and Se in soil samples were examined. Multivariate statistical analysis and pollution indexes were used in the survey, and the sources of heavy metals in different soil layers (0–20 cm and 20–40 cm depth) were evaluated based on the soil background values of heavy metals in Xinjiang (the soil background values of Se in Urumqi were adopted). The results showed that the average concentrations of Hg, Cd, Pb, Cr, Ni, As, and Se in the 0–20 cm soil layer were 0.023, 0.165, 17.999, 62.587, 29.928, 16.325, and 0.696 mg · kg ^{1}, respectively, and those in the 20–40 cm soil layer were 0.021, 0.148, 17.497, 61.091, 29.995, 17.384, and 0.634 mg · kg ^{1}, respectively. Except for Pb, the contents of other elements were higher than the soil background values of heavy metals in Xinjiang. The evaluation results of the single-factor pollution index of each element in the study area were mainly pollution-free or slight pollution. The proportions of pollution-free and slight pollution of the seven elements in the two soil layers varied from 66.2% to 100% and from 74.7% to 100%, respectively. The Nemerow comprehensive index showed that slight pollution was dominant in the study area, and the proportions of sites with slight pollution in the two soil layers were both 78.4%. The sources of heavy metal elements such as Cd, As, and Se were mainly natural factors, which are mainly related to the composition and properties of soil parent materials. The sources of Cr, Pb, and Hg were mainly affected by human factors. Heavy metals carried by industrial development, transportation, and coal combustion fall into the soil, which is the main reason for the increase of background values of uncultivated and undamaged natural saline-alkaline soil. The source of Ni may be the result of human and natural factors.

Keywords: saline-alkaline soil; soil heavy metal; background value; pollution evaluation; source analysis; Junggar Basin

1 Introduction

Soil heavy metal pollution has become a global environmental issue. Heavy metals enter the soil through atmospheric deposition, irrigation, and fertilizer application, and can harm soil ecosystems and human health through the food chain. With the development of industrialization and urbanization, heavy metal pollution in farmland soils has become increasingly prominent. Previous studies have shown that heavy metal concentrations in soils are influenced by both natural factors and human activities. The Junggar Basin is an important agricultural and pastoral area in Xinjiang, where saline-alkaline soils are widely distributed. However, research on heavy metal pollution in uncultivated saline-alkaline soils in this region is limited. This study aims to evaluate the pollution status and sources of heavy metals in uncultivated saline-alkaline soils in the Junggar Basin, providing a scientific basis for soil environmental protection and sustainable land use.

2 Materials and Methods

2.1 Study Area and Sampling The Junggar Basin is located in northern Xinjiang, with a typical temperate arid climate. The study area is characterized by saline-alkaline soils with pH values of 8–9. A total of 83 sampling sites were selected across the basin. At each site, soil samples were collected from two depths: 0–20 cm and 20–40 cm. The sampling locations were recorded using GPS. A total of 166 soil samples were collected and analyzed.

[Figure 1: see original paper] The study area and distribution of soil sampling sites

2.2 Sample Analysis Soil samples were air-dried, ground, and sieved through a 100-mesh nylon screen. Heavy metal concentrations (Hg, Cd, Pb, Cr, Ni, As, Se) were determined using standard methods. Hg and As were measured by atomic fluorescence spectrometry, Cd and Pb by graphite furnace atomic absorption spectrometry, Cr and Ni by flame atomic absorption spectrometry, and Se by hydride generation atomic fluorescence spectrometry. Quality control was performed using certified reference materials and duplicate samples.

2.3 Pollution Evaluation Methods The single-factor pollution index (P) and Nemerow comprehensive pollution index (P) were used to evaluate soil heavy metal pollution. The single-factor pollution index was calculated as:

$P = C / S$

where C is the measured concentration of heavy metal i, and S is the background value of heavy metal i. The evaluation criteria were: P 1 (pollution-free), 1 < P 2 (slight pollution), 2 < P 3 (moderate pollution), and P 3 (heavy pollution).

The Nemerow comprehensive pollution index was calculated as:

$P = \sqrt{[(P^2 + P^2) / 2]}$

where P is the average single-factor pollution index and P is the maximum single-factor pollution index.

2.4 Statistical Analysis Multivariate statistical analysis including correlation analysis and principal component analysis (PCA) was performed to identify sources of heavy metals. SPSS software was used for statistical analysis.

3 Results and Discussion

3.1 Heavy Metal Concentrations in Soil The statistical description of heavy metal concentrations in the two soil layers is shown in Table 1. The average concentrations of Hg, Cd, Pb, Cr, Ni, As, and Se in the 0–20 cm soil layer were 0.023 ± 0.008, 0.165 ± 0.153, 17.999 ± 4.122, 62.587 ± 15.189, 29.928 ± 13.660, 16.325 ± 10.368, and 0.358 ± 0.392 mg · kg ¹, respectively. In the 20–40 cm soil layer, the average concentrations were 0.021 ± 0.010, 0.148 ± 0.075, 17.497 ± 3.729, 61.091 ± 14.997, 29.995 ± 14.398, 17.384 ± 17.750, and 0.323 ± 0.426 mg · kg ¹, respectively. No significant differences were observed between the two layers ($P > 0.05$).

Table 1 Heavy metal concentrations in different soil layers (mg · kg ¹)

Depth (cm)	Hg	Cd	Pb	Cr	Ni	As	Se
0–20	0.023±0.008a	0.165±0.153a	17.999±4.122a	62.587±15.189a	29.928±13.660a	16.325±10.368a	0.358±0.392a
20–40	0.021±0.010a	0.148±0.075a	17.497±3.729a	61.091±14.997a	29.995±14.398a	17.384±17.750a	0.323±0.426a

Note: Different letters indicate significant differences between layers ($P < 0.05$).

Compared with the background values of heavy metals in Xinjiang soils, except for Pb, all other elements showed concentrations higher than the background values, indicating accumulation in the surface soil.

3.2 Pollution Assessment The single-factor pollution index results showed that the study area was mainly pollution-free or slightly polluted (Table 2). The proportions of pollution-free and slight pollution sites for the seven elements ranged from 66.2% to 100% in the 0-20 cm layer and from 74.7% to 100% in the 20–40 cm layer. Cd showed the highest proportion of slight pollution, reaching 33.8% in the 0–20 cm layer.

Table 2 Statistical description of single-factor pollution index (P)

Element	0–20 cm	20–40 cm
	n	Mean
Hg	83	1.35

Element	0–20 cm	20–40 cm
Cd	83	1.38
Pb	83	0.93
Cr	83	1.27
Ni	83	1.13
As	83	1.46
Se	83	1.79

The Nemerow comprehensive pollution index indicated that slight pollution was dominant in the study area, with 78.4% of sites showing slight pollution in both soil layers. The average comprehensive index was 1.46 for the 0–20 cm layer and 1.55 for the 20–40 cm layer.

3.3 Correlation Analysis Correlation analysis revealed significant relationships among heavy metals (Tables 3 and 4). In the 0–20 cm layer, strong positive correlations were observed between Cd and Se ($r = 0.960$, $P < 0.01$), and between Cr and Ni ($r = 0.886$, $P < 0.01$). Similar correlation patterns were found in the 20–40 cm layer.

Table 3 Correlation matrix of heavy metals in soil 0–20 cm depth

	Hg	Cd	Pb	Cr	Ni	As	Se
Hg	1						
Cd	-0.013	1					
Pb	0.225*	0.239*	1				
Cr	-0.040	-0.279*	0.635**	1			
Ni	-0.125	0.273*	0.538**	0.886**	1		
As	0.273*	0.355**	0.000	0.031	0.161	1	
Se	-0.038	0.960**	0.082	0.115	0.060	0.337**	1

Note: * indicates $P < 0.05$, ** indicates $P < 0.01$.

Table 4 Correlation matrix of heavy metals in soil 20–40 cm depth

	Hg	Cd	Pb	Cr	Ni	As	Se
Hg	1						
Cd	0.140	1					
Pb	0.204	0.451**	1				
Cr	0.147	0.192	0.829**	1			
Ni	0.120	0.288**	0.869**	0.529**	1		
As	0.288**	0.268*	-0.056	0.091	0.020	1	
Se	0.181	0.829**	0.224*	0.173	0.005	0.173	1

3.4 Source Analysis Principal component analysis (PCA) was performed to identify sources of heavy metals. Three principal components were extracted for both soil layers, explaining 80.21% and 81.46% of the total variance, respectively (Table 5).

Table 5 Eigenvalues and cumulative contribution rates of the correlation matrix among seven elements in different soil layers

Component	0–20 cm			20–40 cm		
	Eigenvalue	Contribution (%)	Cumulative (%)	Eigenvalue	Contribution (%)	Cumulative (%)
F1	2.775	39.642	39.642	3.150	44.997	44.997
F2	1.839	26.277	65.919	1.568	22.402	67.399
F3	1.000	14.288	80.207	0.984	14.058	81.457
F4	0.698	9.978	90.185	0.754	10.766	92.223
F5	0.494	7.063	97.248	0.405	5.781	98.003
F6	0.115	1.640	98.888	0.108	1.539	99.543
F7	0.078	1.111	100.000	0.032	0.457	100.000

The rotated factor matrices (Tables 6 and 7) revealed that: - F1 was dominated by Cd, As, and Se, representing natural sources from soil parent materials - F2 was dominated by Pb and Cr, representing anthropogenic sources such as industrial activities and coal combustion - F3 was dominated by Ni, representing mixed sources

Table 6 Factor matrix of varimax rotation of seven elements in soil 0–20 cm depth

Element	F1	F2	F3
Hg	-0.045	0.691	0.168
Cd	0.944	0.170	0.073
Pb	0.571	0.613	0.012
Cr	0.505	0.658	-0.065
Ni	0.072	-0.163	0.976
As	0.790	-0.524	-0.072
Se	0.819	-0.072	-0.060

Table 7 Factor matrix of varimax rotation of seven elements in soil 20–40 cm depth

Element	F1	F2	F3
Hg	0.474	0.365	0.546
Cd	0.944	-0.016	-0.146

Element	F1	F2	F3
Pb	0.425	0.674	-0.200
Cr	0.484	0.737	0.075
Ni	0.284	0.337	0.752
As	0.876	-0.411	-0.178
Se	0.878	-0.393	-0.147

4 Discussion

The results indicate that heavy metal pollution in uncultivated saline-alkaline soils of the Junggar Basin is generally slight, with most elements showing concentrations slightly above background values. The sources of heavy metals can be categorized into two main groups:

1. **Natural sources**: Cd, As, and Se showed strong correlations and loaded on the same principal component, suggesting their origin from natural soil-forming processes and parent material composition. These elements are typically associated with the geochemical background of the region.
2. **Anthropogenic sources**: Cr, Pb, and Hg showed moderate to high pollution indices and were associated with industrial activities, transportation, and coal combustion. The Junggar Basin has experienced rapid industrial development and increased traffic in recent years, which contributes to atmospheric deposition of these metals onto soils.

Nickel exhibited characteristics of both natural and anthropogenic sources, with moderate pollution indices and mixed factor loadings. This suggests that Ni enrichment may result from both geological background and human activities.

The vertical distribution showed no significant differences between the two soil layers, indicating that heavy metal accumulation is primarily a surface phenomenon in these uncultivated soils. The slight increase in As and Se concentrations in the deeper layer may be related to the mobility of these elements in alkaline soil conditions.

5 Conclusions

(1) The uncultivated saline-alkaline soils in the Junggar Basin showed slight heavy metal pollution, with 78.4% of sampling sites classified as slightly polluted according to the Nemerow comprehensive index. The pollution-free and slight pollution proportions for the seven elements ranged from 66.2%-100% in the 0–20 cm layer and 74.7%-100% in the 20–40 cm layer.

(2) Cd, As, and Se were primarily derived from natural sources related to soil parent materials, while Cr, Pb, and Hg were mainly influenced by anthropogenic activities including industrial development, transportation, and coal combustion. Ni originated from both natural and human sources.

(3) The study provides baseline data for heavy metal concentrations in uncultivated saline-alkaline soils of the Junggar Basin. Continuous monitoring is recommended to track changes in heavy metal accumulation as human activities intensify in the region.

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Note: Figure translations are in progress. See original paper for figures.