Distribution Characterization Study of the Heavy Metals for a Mining Area of East Tianshan Mountain in Xinjiang Based on the Kriging Interpolation Method

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Abstract. In order to understand the impact of mining development on the environment, a metal mine at east Tianshan Mountain in Xinjiang province was used as the object of study. The heavy metal content data were obtained from field sampling and indoor measurements, and the data were compared with the heavy metal background values, applying the geostatistic method and Kriging spatial interpolation theory to map the heavy metal distribution in the study area. The results show that the overall heavy metal contamination in the mining area is serious, with significant accumulation of As, Cd and Cr, which is a threat to local human and animal health. And there are obvious correlations and synergies between the distribution of these heavy metals, mostly showing positive correlations, which should be taken into more account in the subsequent environmental rehabilitation of the mine site.

Keywords. Ming area, east Tianshan Mountain, heavy metals, Kriging interpolation.

1. Introduction

The environment is closely related to human activities and there has always been concern about environmental pollution [1]. Mining can cause surface excavation of the original area, causing damage to the local environment [2-3]. Although there are various subsequent measures to restore the environment, long-standing and persistent problems of hidden environmental pollution still exist, especially the heavy metal pollution. Due to the non-degradable nature of heavy metals and the biological enrichment of heavy metals, failure to adopt an effective approach to areas contaminated with heavy metals can ultimately lead to incalculable losses and damage to human health. Therefore, it is important to understand the distribution characteristics of heavy metals in mining areas, which is the basic information for evaluating the environment of mining areas and also provides a basic reference.
for the formulation of corresponding policies. Xinjiang is rich in mineral resources, abundant in water and grass, mineral exploitation and livestock husbandry are important sources of economic income, and the environment pollution will have a direct impact on its economic development [4-5].

The distribution characteristics of heavy metals in mining areas are often characterized by methods such as index of geoaccumulation [6-7], single factor index, Nemero composite index [8-10] and the potential ecological risk index [11], which are basically based on point or small area studies, but rarely involve the distribution of heavy metal contamination in a large area of a mining site and its surrounding environment. Point data are not conducive to the understanding of the overall state of the study area, and the entire facet distribution of the study area can be characterized by point data through geostatistical methods and Kriging spatial interpolation theory [12-13]. The distribution maps of heavy metal pollutants are visually clear and clearly expressed, and this theoretical approach in a large number of literature studies [14-15] have shown its effectiveness, scientific and accurate.

Using the geostatistical method and Kriging spatial interpolation theory, it is possible to ensure the accuracy of the results and at the same time minimize the consumption of human and material resources due to the field survey. However, there are still some difficulties in the actual research, especially for the non-GIS professionals to determine the appropriate model and complete the mapping within the study area when there are many parameters for spatial interpolation. Based on the Spatial Analysis Module of the ArcGIS software, this paper selects the Ordinary Kriging interpolation method to map the distribution of heavy metals (As, Cd, Cu, Ni, Pb, Zn, Cr) in the mining area. By comparing the results with the background values of heavy metals in the study area, we can obtain the degree of heavy metal pollution caused by mining, analyze the spatial distribution characteristics of heavy metal pollutants, and provide strong theoretical support for the subsequent environmental restoration of the mine.

2. Overview of the Study Area
The study area (figure 1) 85°54′28.83″~85°28′31.89″E, 43°1′21.47″~43°34′1.72″N, with a total area of 1276.034km², is located within the East Tianshan Mountains of Xinjiang, China. With an altitude of 2457~5165m (data from Geospatial Data Cloud [16]), an annual maximum temperature of 16℃ and a minimum temperature of -30℃, and a prevailing easterly wind all year round, it is a typical high altitude and cold alpine region [17]. The surface undulates greatly, and the surface cover changes significantly with altitude, from alpine meadows to snow and ice cover, with a lot of bare ground distributed between. Underground ice and perennial permafrost are abundant, and there exists rock glaciers in the study area.

The mine is an open pit mine located in the main watershed of the Tianshan Mountains. To ensure the integrity of the natural attributes of the study area, the boundaries of the study area were obtained through the ArcGIS Hydrology Extraction Module’s Basin Analysis tool and include two watersheds. To the south of the watershed, there are many small rivers that eventually flow into the Yili River; to the north of the watershed, the rivers converge on Lake X in the northeast of the mining area and eventually flow into the Manas River basin [18]. This area is one of the water sources for production and life in the north and south of Xinjiang, and it is also a water source to ensure the economic development of the oasis in the arid zone and the ecological stability in the cold zone. The mine has an annual output of 5 million tons per year, and consists of a mining area, a processing area, a tailings accumulation area and a living area. Due to the specific location of the mine and the diffusion of heavy metal pollutants by rivers, it is necessary to map the distribution of heavy metals in the study area in order to understand their distribution characteristics.
Figure 1. Geographic location of the study area: (a) shows the location of the study area in China; (b) shows the location of the DEM and sampling sites in the study area; (c) shows an enlarged view of the sampling site portion of the study area.

3. Data and Methods

3.1. Field Sampling and Sample Processing
In the field, surface soil was collected along the highway. One sampling plot was set up for every 100-150 m elevation increase, and there were six sampling areas from I to VI. The area of the sampling area is about 30 m×50 m. The average thickness of the soil is about 40 cm, because the soil in this area is straw-felt soil, the surface layer is rich in organic matter, the development of the deep soil is slow and the degree of weathering is low. Therefore, sampling was mainly done on 20 cm in layer A of the soil. A review of the relevant literature revealed [17] that the heavy metal (As, Cd, Cu, Ni, Pb, Zn, Cr) background values of this area in soil were 11.2, 0.12, 26.70, 26.60, 19.40, 68.80, and 49.30 mg·kg⁻¹, respectively, and 8.76, 0.15, 25.52, 24.50, 17.26, 75.44, 51.44 mg·kg⁻¹ in sediment.

The distribution of sample points is shown in figure 1 (b) and (c), and 39 samples were totally collected. The samples were dried naturally in the laboratory, weeds and stones were removed, after grinding, it has passed 0.154 mm aperture screen. The obtained samples were digested using a nitric acid-perchloric acid-hydrofluoric acid mixture and the heavy metals As, Cd, Cu, Ni, Pb, Zn and Cr were determined by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES, Agilent 7500a, USA).

3.2. K-S Test and Heavy Metals Mapping
SPSS is used to perform K-S test on the measured values of heavy metals to ensure whether they conform to the normal distribution, which is one of the basic premises of applying spatial interpolation. The K-S test [19] is one of the most commonly used methods for normal distribution test, which can be determined by the p-value. Data that conform to the normal distribution can be directly imported into ArcGIS software for spatial interpolation, while data that do not conform to the normal distribution can be converted to conform to the normal distribution before interpolation. If the data are normally distributed, p>0.05, once p<0.05, the observed data are not normally distributed.

The measured values of various heavy metals were examined by K-S, and all the P values (table 1) were greater than 0.05 mg·kg⁻¹ and were normally distributed, which could be used directly for spatial interpolation and mapping the distribution of heavy metals in the study area.
Table 1. Mean values of heavy metal measurements in the study area, background values and results of the K-S test

| Heavy metal | As  | Cd  | Cu  | Ni  | Pb  | Zn  | Cr  |
|-------------|-----|-----|-----|-----|-----|-----|-----|
| Average measured value | 13.55 | 0.15 | 39.24 | 32.96 | 17.82 | 87.43 | 89.49 |
| P-value | 0.07 | 0.09 | 0.06 | 0.20 | 0.20 | 0.09 | 0.20 |
| Soil background value | 11.20 | 0.12 | 26.70 | 26.60 | 19.40 | 68.80 | 49.30 |
| Sediment background value | 8.76 | 0.15 | 25.52 | 24.50 | 17.26 | 75.44 | 51.44 |

Note: Units are all mg·kg⁻¹ (background values from literature [17]).

4. Results and Analysis

4.1. Precision Analysis of Interpolation Results
The heavy metal distribution map of the study area was obtained by Ordinary Kriging interpolation, the predicted values corresponding to the sampling points were extracted, and the errors between the predicted and measured values were obtained using the cross-validation method, and the results are shown in figure 2, (a)–(g) for elements As, Cd, Cu, Ni, Pb, Zn, Cr, in that order.

Figure 2. Error between predicted and measured values: (a)–(g) for elements As, Cd, Cu, Ni, Pb, Zn, Cr, in that order.

It can be seen from the figure that the heavy metal elements through the kriging interpolation value and the error between the measured value of most concentrated in the range of 1 error, larger errors are very few, individual existence. The error between the predicted value and the real value is very small, which shows that the use of Ordinary Kriging interpolation method is effective, the interpolation results are real and reliable, with great reference significance.

4.2. Characteristics of the Spatial Distribution of Heavy Metals
The spatial analysis module of ArcGIS platform was used to spatially interpolate the measured heavy metals in the study area using Ordinary Kriging interpolation method to obtain the heavy metal
distribution map in the study area, and the results are shown in figure 3. Combined with the background values of heavy metals in the study area (table 1), the distribution characteristics of each heavy metal in the study area were analyzed and compared using the corresponding background values of the corresponding heavy metals as the threshold values.

![Figure 3](image.png)

**Figure 3.** Distribution of heavy metals in the study area: (a)–(f) for heavy metals As, Cd, Cu, Ni, Pb, Zn, Cr, in that order.

As shown in figure 3, the heavy metal contaminated soils plotted by Ordinary Kriging interpolation shows that the heavy metal contents in the study area are higher than the background values, both in the surface soil and in the sediment, indicating that the mining activities in the area do bring some heavy metal contamination to the surrounding environment, with Cr contamination being the most serious, followed by Pb. Cu shows an accumulation trend in the mining area. The other six heavy metals act as pollutants in mining areas and show a cumulative trend in low elevation living areas, meadow grazing areas, tailings areas, and at Lake X. The accumulation of As and Cu showed a positive correlation and a negative correlation with Cu; the accumulation of Zn was not serious in living areas. Each heavy metal pollution should be taken seriously in the subsequent environmental restoration.

As showed an accumulation trend in the living area, tailings area, meadow grazing area and Lake X, with accumulations exceeding 14.37 mg·kg⁻¹, 28.3 per cent above the background value, lower than in normal surface soil in the mining area, but also slightly higher than in the sediment, roughly between 9.12 and 10.19 mg·kg⁻¹; Cd levels ranged from 0.074 to 0.26 mg·kg⁻¹. Between 0.12 mg·kg⁻¹ in surface soil and 0.15 mg·kg⁻¹ in sediment at background values, the metal accumulates mainly in living areas, meadow grazing areas and tailings areas, with cumulative values exceeding the background values, between 0.17 and 0.26 mg·kg⁻¹; Cu accumulates mainly in mining areas and is comparable to background values in other areas; Ni accumulates in tailings areas and lakes. The accumulation of Pb showed an island-like pattern and was lower than the background value except in some meadow grazing areas where it exceeded the background value; Zn mainly accumulated in the tailings area with values ranging from 119.47 to 164.29 mg·kg⁻¹; Cr mainly accumulated in the tailings area, Lake X and meadow grazing areas.

In general, the study area is heavily contaminated with heavy metals, and the accumulation of heavy metals from mining exceeds background values; the accumulation of heavy metals in the mining area is not high due to regular excavation, but diffusion to the surrounding area is evident and is a typical source of contamination.

5. **Conclusion**

Through field sampling and indoor treatment, the spatial interpolation theory was used to interpolate sampling points to create a thematic map of heavy metal pollution distribution in the study area, and
the analysis of heavy metal distribution and distribution characteristics among regions showed that: (1) Heavy metal pollution in the study area as a whole due to mining activities is relatively serious, with most regions exceeding the background level; (2) The mining area is a typical source of pollution relative to other surrounding areas; (3) The study area is heavily contaminated by As, Cd and Cr, which accumulate in the living area, lake area and meadow grazing area and should be paid attention to; (4) The distribution characteristics of each heavy metal have obvious correlation, mainly positive correlation, and there are synergistic effects; (5) Follow-up environmental restoration of the mining area should pay attention to the heavy metals pollution, the interaction between heavy metals should be taken into account in the environmental restoration work so that it makes for a better restoration of the environment.

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