Pollution evaluation of heavy metals in soil near smelting area by index of geoaccumulation (Igeo)

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Abstract: In order to investigate the heavy metal pollution conditions of soil of smelting area in Zijiang of Chenzhou, Hunan province, 42 samples were studied. The concentrations of heavy metals As, Pb, Cd, Zn and Cu in the soil were determined by using atomic absorption spectrometry (AAS) and atomic fluorescence spectrometry (AFS). Then the potential pollution risks of heavy metal in the soil were evaluated by method of geological acumination index (Igeo). The results indicated that the average concentrations of As, Pb, Cd, Zn and Cu were 187.79, 2074.52, 15.72, 2178.89, 39.69 mg/kg respectively. The geological evaluation of the cumulative index results showed that the contamination degree of 5 heavy metals follow the sequence of Cd > Zn > Pb > As > Cu. The results show that Cd reached extremely pollution degree, Zn reached strong pollution-extremely pollution levels, the pollution of Pb in the soil is classified as strong pollution degree, Cu and As of no pollution according to the results of Igeo based on the background value of heavy metals in the soil of Hunan Province.

1. Introduction

Recently, soil pollution has received increasing attention. Heavy metals are regarded as serious pollutants of soil because of their environmental persistence, toxicity and ability to be incorporated into food chains [1].

Heavy metals in soil may come from agriculture activities, industrialization, mining and smelting activity. Among these, mining and smelting activity is considered as one of the most dangerous anthropogenic activities [2]. Mining operation, grinding, concentrating ores and disposal of tailings, provide obvious sources of contamination in the environment, along with mine and mill wastewater [3]. This will lead to the release and migration of heavy metals thus cause heavy metals pollution of soil near the mining area.

Heavy metals can be migrated from the soil to other ecosystem components, such as groundwater, plants, thus affecting human health through drinking water and food chain, so the evaluation of heavy metal pollution in soil is very important. The index of geaccumulation (Igeo) has been used as a measure of bottom sediment contaminations since 1970s and numerous researchers have employed it to assess the contamination of soils and sediments [4-6]. It not only considers the impact of the background of natural geological process, but also considers the impact of human activities on the heavy metal pollution [7].
This paper studied the heavy metal pollution in soil of Qingjiang lead-zinc mining area in Zixing of Chenzhou, Hunan province. The geological evaluation of the cumulative index is adopted to evaluate the pollution levels of heavy metals As, Pb, Cd, Zn and Cu in the soil. The aim of this study is to assess the level of metal concentrations in soil of smelting mine area and provide a scientific basis for heavy metal pollution control.

2. Materials and methods

2.1. Sample collection and preparation

The geography coordinate of the survey site is longitude 113°17′17.76″E~113°17′36.07″E, latitude 25°45′39.29″N~25°46′1.13″N, located at Qingjiang county, Chenzhou City, Hunan Province. 42 soil samples were collected according to the correlated regulations and standards (GB/T15618-1995). Soil samples were taken every 20 cm from the top soil to a depth of 100 cm. Each sample picked out from a mixture of 3~5 subsamples for 1 kg or so by quarter method. The contents of heavy metals including Cu, As, Zn, Pb and Cd are analyzed by ICP-MS. And Cold Atomic Fluorophotometry is employed to analyze the contents of As.

2.2. The index of geoaccumulation

The geoaccumulation index \( I_{geo} \) is put forward by Muller [8]. The value of the geoaccumulation index is calculated by the following equation:

\[
I_{geo} = \log_2 \left( \frac{C_n}{1.5B_n} \right)
\]

\( C_n \) in the formulas is the measured concentration of the examined heavy metal in the soil, \( B_n \) is the geochemical background concentration of metal ‘\( n \)’, and factor 1.5 is the background matrix correction factor due to lithogenic effects.

| \( I_{geo} \) | Class | Contamination level |
|--------------|-------|---------------------|
| \( \leq 0 \) | 0     | Unpolluted          |
| 0-1          | 1     | Unpolluted to moderately polluted |
| 1-2          | 2     | Moderately polluted |
| 2-3          | 3     | Moderately to strongly polluted |
| 3-4          | 4     | Strongly polluted   |
| 4-5          | 5     | Strongly to extremely polluted |
| \( \geq 5 \) | 6     | Extremely polluted  |

Muller has distinguished seven classes of geoaccumulation index [8]. Table 1 shows Index of geoaccumulation (\( I_{geo} \)) and contamination level.

3. Results and discussion

The heavy metals considered of concern in the investigation are As, Pb, Cd, Zn and Cu. To assess the environmental pollution of the soil, the concentrations of above heavy metals were determined. Statistical characteristics of heavy metals content in the samples are given in Table 2.
### Table 2. The concentrations of heavy metals in samples.

| Samples | As (mg/kg) | Pb (mg/kg) | Cd (mg/kg) | Zn (mg/kg) | Cu (mg/kg) |
|---------|------------|------------|------------|------------|------------|
| 1       | 64.24      | 399.58     | 5.73       | 738.08     | 19.59      |
| 2       | 71.87      | 1019.23    | 5.38       | 816.18     | 27.77      |
| 3       | 750.10     | 1532.42    | 38.37      | 3105.00    | 50.88      |
| 4       | 73.21      | 542.83     | 4.24       | 610.06     | 22.03      |
| 5       | 81.38      | 416.84     | 8.25       | 843.78     | 19.00      |
| 6       | 66.84      | 421.92     | 8.69       | 945.41     | 26.67      |
| 7       | 306.08     | 851.93     | 53.50      | 2761.18    | 36.97      |
| 8       | 40.59      | 331.22     | 6.05       | 528.30     | 23.66      |
| 9       | 32.38      | 295.84     | 7.69       | 621.90     | 23.43      |
| 10      | 1375.41    | 1769.45    | 113.40     | 2928.50    | 203.39     |
| 11      | 63.33      | 115.13     | 1.89       | 133.83     | 22.80      |
| 12      | 50.71      | 40.66      | 0.64       | 95.09      | 22.18      |
| 13      | 49.50      | 58.54      | 1.35       | 144.64     | 25.59      |
| 14      | 70.33      | 302.00     | 4.31       | 451.35     | 30.29      |
| 15      | 745.72     | 8794.18    | 84.60      | 12743.07   | 105.18     |
| 16      | 431.87     | 10501.53   | 52.63      | 7670.18    | 78.65      |
| 17      | 459.22     | 8609.23    | 34.22      | 4003.80    | 59.41      |
| 18      | 352.06     | 7701.51    | 31.14      | 3446.44    | 48.93      |
| 19      | 52.36      | 337.02     | 6.21       | 564.55     | 37.64      |
| 20      | 40.41      | 229.60     | 4.18       | 547.13     | 18.10      |
| 21      | 753.06     | 3837.55    | 85.44      | 6303.06    | 111.76     |
| 22      | 478.90     | 16651.57   | 6.36       | 3131.40    | 102.87     |
| 23      | 39.58      | 693.76     | 3.13       | 510.44     | 21.96      |
| 24      | 38.71      | 923.39     | 3.42       | 591.02     | 24.24      |
| 25      | 45.75      | 285.86     | 3.84       | 380.49     | 26.16      |
| 26      | 54.74      | 138.66     | 3.84       | 184.89     | 23.66      |
| 27      | 286.30     | 6224.85    | 7.60       | 2199.32    | 65.90      |
| 28      | 370.39     | 12221.02   | 24.47      | 4345.99    | 104.46     |
| 29      | 39.12      | 225.30     | 23.98      | 1328.05    | 26.26      |
| 30      | 30.31      | 66.13      | 14.42      | 999.27     | 22.67      |
| 31      | 34.46      | 63.56      | 0.85       | 90.89      | 16.93      |
| 32      | 45.97      | 57.09      | 0.46       | 92.25      | 16.50      |
| 33      | 42.98      | 61.88      | 0.13       | 72.01      | 17.56      |
| 34      | 47.59      | 45.76      | 1.21       | 93.19      | 21.59      |
| 35      | 36.96      | 79.13      | 0.67       | 124.13     | 22.35      |
| 36      | 46.16      | 89.85      | 1.45       | 82.72      | 20.02      |
| 37      | 35.84      | 73.06      | 0.45       | 92.44      | 19.26      |
| 38      | 58.62      | 71.91      | 0.45       | 92.81      | 23.78      |
| 39      | 57.03      | 314.75     | 0.41       | 210.93     | 12.34      |
| 40      | 46.82      | 236.17     | 1.37       | 185.46     | 21.11      |
| 41      | 60.86      | 248.78     | 2.43       | 172.08     | 20.99      |
| 42      | 59.41      | 249.33     | 1.57       | 178.17     | 22.54      |
| Average | 187.79     | 2074.52    | 15.72      | 2178.89    | 39.69      |
| Background | 27.95 | 89.20 | 0.60 | 103.16 | 17.89 |
Table 2 shows that the concentration of heavy metals in the soil ranges as follows: Cd (0.13-113.40 mg/kg), Cu (12.34-203.39 mg/kg), As (30.31-1375.41 mg/kg), Pb (40.66-16651.57 mg/kg), Zn (72.01-29282.50 mg/kg). The mean concentrations of Cd, Cu, As, Pb, Zn in soil were 15.72, 39.69, 187.79, 2074.52, 2178.89 mg/kg, respectively. It can be found that the average concentrations of heavy metals in soil are much higher than the background concentration of heavy metals in Hunan province.

The calculated Igeo of heavy metals in soil samples are shown in Figure.1.

Figure 1. Percentage of samples in Muller class.

Figure 1 displays sample percentages in Müller classes for As, Pb, Cd, Zn and Cu. As and Cu concentrations fall mainly in classes 0 and 1. For Cd, 59.52% of the samples fall in class 6, 7.15% in class 5, 14.28% in class 4, 7.15% in class 3, 9.52% in class 2 and 2.38% in class 1. For Pb, 28.57% and 21.43% of the samples are included in classes 0 and 2, 14.29% in class 1, 11.90% in class 3, 4.76% in class 4, 2.38% in class 5 and the remaining 16.67% fall in class 6. For Zn, 19.05% of the samples fall in class 0, 16.67% in class 1, 4.76% in class 2, 21.43% in class 3, 11.90% in class 4, 7.14% in class 5 and 19.05% in class 6.

Table 3. The average values of Igeo values for each metal.

| Heavy metals | Igeo value | Pollution level          |
|--------------|------------|--------------------------|
| As           | -0.37557   | unpolluted               |
| Pb           | 3.964368   | strongly polluted        |
| Cd           | 7.033816   | extremely polluted       |
| Zn           | 4.48427    | strongly to extremely polluted |
| Cu           | -0.04501   | unpolluted               |

Table 3 shows the average values of Igeo values for each metal and their pollution level. The results indicate that the soil of the study area can be categorized as follows: unpolluted with Cu and As, strongly polluted with Pb, strongly to extremely polluted with Zn and extremely polluted with Cd. The contamination degree from strong to weak in soil is: Cd > Zn > Pb > As > Cu.

4. Conclusions
The average concentrations of Cd, Cu, As, Pb, Zn in soil were 15.72, 39.69, 187.79, 2074.52, 2178.89 mg/kg respectively. It can be concluded that the average concentrations of heavy metals in soil are much higher than the background concentration of heavy metals in Hunan province.
The geoaccumulation index of heavy metals in the soil decreases as follows: Cd > Zn > Pb > As > Cu. Igeo results reveal that the study area is not contaminated with respect to As and Cu, strongly contaminated with Pb, strongly to extremely contaminated with Zn, and extremely contaminated with Cd.

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