Spatial Distribution characteristics and Ecological risk Assessment of heavy Metal As, Ba in soil of a Chemical Slag Field in Sichuan Province

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Abstract. 45 boreholes were determined according to the situation of an industrial slag field in Sichuan Province. According to 10~20cm stratification as soil sampling, the content and characteristic distribution of heavy metal elements, such as barium (Ba), arsenic (AS) in soil, were determined, and the spatial distribution characteristics of As, Ba were studied by Geostatistics method. The pollution and ecological risk of As, Ba in the industrial slag site were analyzed by using the single factor index method, the Nemerow index method and the potential risk index evaluation. The results show that barium is the main pollution factor of waste residue, with an average value of 127576μg/L, which is mainly distributed in the range of 2.908~2667000 μg/L. The mean value of arsenic was 8.72 mg/kg, respectively.

1. Introduction
The enrichment characteristics and spatial distribution of Cr, Hg and As in the soil of the chemical slag field are studied in this paper, which was based on the heavy metal distribution of the soil in a chemical residue field in Zigong City, Sichuan Province. The evaluation of the main heavy metal components in the slag site was completed by using the single factor evaluation method and the Nemerow comprehensive index evaluation method, which could provide reference for soil environmental protection, soil pollution control, soil environmental risk early warning and rational utilization of soil resources in the accumulation area of chemical slag yard.

2. Materials and methods
The geographical coordinates of the regional center are longitude 104°45′47.71″E, latitude 29°23′33.68″ N, and the area is about 55200 m². It was established in 1938 and is mainly formed by the open-air accumulation of production waste from a chlor-alkali chemical co., Ltd.

The layout points are mainly in accordance with the “Technical Guidelines for Environmental Investigation of the Site” (HJ 25.1 -2014), “the Technical Guidelines for Environmental Monitoring of the Site” (HJ 25.2 -2014), the Beijing “Site Environmental Assessment Guide” (DB11/ T 656-2009), and the related technical standards.

According to the grid point method, one drilling point was arranged per 1600 m², and 44 drilling points were arranged in total. The sampling depth begins with the contact surface of slag soil and the surface layer of undisturbed soil. The sampling depth of the surface layer is 0 ~20 cm, and the depth distance of the other sample is 0.5m, until the bedrock. Sample determination includes on - site rapid
detection and indoor testing. The main equipment used for rapid field detection are XRF (NOV-X system, USA), portable pH meter (PHBJ-260), turbidity meter (GDYS-101SZ), portable conductivity meter (DDBJ-350), palm dissolved oxygen meter (JPB-607) and so on.

3. Method

3.1. Single Factor Pollution Index Method

The single factor pollution index method is the method to evaluate the degree of soil pollution by a single factor, which is currently one of the most widely used evaluation methods at home and abroad [1-3]. The formula is:

\[ p_i = \frac{c_i}{S_i} \]  

\( p_i \) is the environmental quality index of the \( i \) kind of soil pollutants. \( c \) is the measured value of type \( i \) soil pollutants, mg/kg; \( S \) is the evaluation standard value of the \( i \) kind of soil pollutants, mg/kg. The larger the value of \( p_i \), the more serious the soil pollution. Soil pollution can be divided into four grades: Unpolluted \( (p_i \leq 1) \), slightly polluted \( (1 < p_i \leq 2) \), moderate pollution \( (2 < p_i \leq 3) \) and heavily polluted \( (3 \leq p_i) \).

3.2. Nemerow comprehensive index method

Nemerow [4-7] comprehensive index method is used to evaluate soil pollution, and its calculation formula is as follows (2):

\[ P_N = \sqrt{\frac{(C_i/S_i)_{\text{max}}^2 + (C_i/S_i)_{\text{ave}}^2}{2}} \]  

In the formula, \( P_N \) is the comprehensive pollution index; \( (C_i/S_i)_{\text{max}} \) is the maximum Pollution Index for each pollutant; \( (C_i/S_i)_{\text{ave}} \) is the arithmetic mean of the pollution index in each pollutant. Soil heavy metal pollution was classified into 5 grades according to the method, as shown in Table 1.

| Table1 | Heavy metal pollution levels in soil |
|--------|-----------------------------------|
| Pollution level | Safe | Warning Limit | Light pollution | Medium pollution | Heavy pollution |
| \( P_N \) | \( P_N \leq 0.7 \) | \( 0.7 < P_N \leq 0.7 \) | \( 1.0 < P_N \leq 2.0 \) | \( 2.0 < P_N \leq 3.0 \) | \( P_N > 3.0 \) |
| Evaluation methodology | Cleaning | Partial cleaning | The soil began to be polluted | The soil is moderately polluted | The soil has been polluted quite seriously |

4. Analysis of results

The spatial distribution of three heavy metals in 6 layers of soil in the study area is shown in Fig. 3-14 by software of ArcGIS10.1. In the spatial distribution map of element content, the area is identified by yellow and above yellow color areas, which is used to identify the excess area of the element in different layers of soil.

4.1. Distribution of Ba in soils at different depths

The spatial distribution of two heavy metals in 6 layers of soil in the study area is shown in Fig. 1-4 by software of ArcGIS10.1. In the spatial distribution map of element content, the area is identified by
yellow and above yellow color areas, which is used to identify the excess area of the element in different layers of soil.

4.1.1. Distribution of Ba in soils at different depths

From figure 1 to figure 4, it can be seen that the average value of Ba is 2909.66 mg/kg and the Ba element mainly distributed in the range of 411.8 ~ 27500 mg/kg. The number of samples exceeding the standard is 75, the rate of exceeding the standard is 34.09%.

Fig. 1 Distribution map of Ba in 0-0.2 m depth of soil

Fig. 2 Distribution map of Ba in 1-1.2 m depth of soil

Fig. 3 Distribution map of Ba in 3-3.2 m depth of soil

Fig. 4 Distribution map of Ba in 4-4.2 m depth of soil
Fig. 5 Distribution map of As in 0-0.2 m depth of soil

Fig. 6 Distribution map of As in 1-1.2 m depth of soil

Fig. 7 Distribution map of As in 3-3.2 m depth of soil

Fig. 8 Distribution map of As in 4-4.2 m depth of soil

5. Assessment of soil pollution

5.1. Single Factor Pollution Index Method

Based on "Site Soil Environmental Assessment Screening Value" (DB50/T723-2016 Chongqing Local Standard), Ba pollution index, as shown in figure 9 and figure 10.

It can be seen from Fig.9, Fig.10, the pollution index is 1 < P < 2 in the range of 0~150 cm, 650 cm ~750 cm, 850 cm ~1000 cm and 1400~1500 cm, there is a slightly pollutes. It is moderately polluted in the range of 250-280 cm, 500-600 cm, 750-800 cm, 1000-1500 cm, 1330-1380 cm, which pollution index is 2 < P < 3.
Fig. 9 Soil pollution index at different depths of 1~800cm

Fig. 10 Soil pollution index at different depths of 800~1600cm

Similarly, the As pollution index at different depths from the surface is shown in figure 12, figure 13.

Fig. 11 Soil pollution index at different depths of 1~800cm

Fig. 12 Soil pollution index at different depths of 800~1600cm

Fig. 9-12 show that the proportion of heavy metal pollution in soil in the study area is Ba > Mn > As. The slight pollution of Ba and Mn accounted for 29.3% respectively. Ba moderate pollution accounted for 16%, Ba severe pollution accounted for 10%.

5.2. Nemerow Integrated Pollution Index Method

Nemerow comprehensive pollution index method was used to evaluate the degree of soil pollution, as shown in Fig.13 and 14.
Figure 13 and 14 shows that 100% of the surface soil sites were contaminated with Ba and 18% with Mn. Among them, 40% of the soil monitoring sites were moderately polluted by Ba. There is little clean soil in the study area.

6. Conclusion
Through the statistical analysis of the soil detection data, the main pollution factors in the soil are Ba As and Mn. The average value of Ba is 2909.66 mg/kg and the Ba element mainly distributed in the range of 411.8 ~ 27500 mg/kg. The number of samples exceeding the standard is 75, the rate of exceeding the standard is 34.09%. The average As in the soil was 8.72 mg/kg, mainly in the range of 1.29-88.43 mg/kg. The number of soil samples was 220, the number of super-standard samples was 2, the over-standard rate was 0.91%, the maximum over-standard multiple was 0.474 times, and the over-standard points were mainly distributed in ZK-35# (Pollution depth 3.0 - 3.6 m). The average value of manganese in soil is 636.41 mg/kg, which is mainly distributed in the range of 119.6 ≤ 9057 mg/kg. The number of over-standard samples was 3, the over-standard rate was 1.36%, and the maximum over-standard multiple was 3.469 times.

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