Distribution Characteristics and Pollution Assessment of Hg in Soil around Coal Gangue in Fengfeng Mining Area

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Abstract. In order to understand the present situation and ecological risk of Hg pollution in soil around the gangue hills in Fengfeng mining area. Based on the concentrations of Hg in the soil samples, the pollution status and ecological risks of Hg in the soils were assessed by single contamination index, Nemerow comprehensive pollution index and potential ecological risk index. The results showed that: firstly, the concentrations of Hg were 1.98 mg kg\(^{-1}\) to 65.75 mg kg\(^{-1}\) in the research field, and the concentrations of Hg in 97% of the soil samples exceeded the background value of the soil. Secondly, the average concentration of Hg was higher than the risk screening standard value in China. Thirdly, the comprehensive pollution index of the soil around the coal gangue hills was ES>E>EN>S>WN>3, which belonged to heavy pollution. Lastly, the potential ecological risk index of surface soil at a distance of 0-100m from coal gangue hills and deep soil at a distance of 0-80m from coal gangue hills were greater than 320, which represented extremely high potential ecological risk in the research area.

1. Introduction

Fengfeng mining area is located in Handan City, Hebei Province. It is in the middle latitudes. And the climate type in this region is a warm temperate semi-humid continental monsoon. There is no obvious dominant direction throughout the year, but the northwest wind is dominant in winter. The Fengfeng mining area is rich in coal resources, with raw coal reserves up to 35 billion tons. Due to excessive mining, a large amount of coal gangue piles in the mining area. The present stock of coal gangue is 300 million tons in this mining area[1]. Coal gangue solid waste not only pollutes the nearby atmosphere and water, but also occupies a lot of land, which causes serious damage to the environment[2]. These include heavy metal pollution in the surrounding soil, which affects the growth of surrounding plants and the cultivation and exploitation of crops[3].

This research focused on the analysis of Hg pollution in the surrounding soil of coal gangue in Fengfeng Mining Area. A systematic sampling method was carried out for the surrounding soil. The concentrations of Hg in soil samples were determined by inductively coupled plasma atomic emission spectrometry (ICP-OES). The pollution of Hg was evaluated by a single factor and multi-factor index in the surrounding soil. The ecological risk method was used to evaluate Hg polluted areas. It can provide a reference for soil environment remediation and Hg pollution control in Fengfeng mining area.
2. Materials and methods

2.1. Sample collection
Considering the factors of landform and wind direction, the experiments took the coal gangue hill as the center. The directions of five sampling lines are southeast (ES), northwest (WN), northeast (EN), east (E) and south (S) in this research, of which the upwind is southeast (ES) and downwind is northwest (WN). Each sampling line was designed with 10 sampling points, which are 0m, 20m, 40m, 60m, 80m, 100m, 150m, 200m, 300m and 400m. Two depths of soil were collected at each sampling site, including surface soil (0-20cm) and deep soil (20-40cm). A total of 100 soil samples formed a sampling arrangement centered on the gangue hill from near to far, from dense to sparse. Three parallel sampling points were selected for each sampling point, and soil samples were collected by a multi-point mixed sampling method. A new sample was formed by quartering method and put into the sample bag. The soil samples were air-dried in the room, gravel was removed, and screened through 200 mesh (0.074 mm). 0.200 g soil sample was weighed accurately after pretreatment and digestion. The digestion method was HNO₃-HF-HClO₄. Each digestion batch should include reagent blank, analysis blank and repeated samples to evaluate the accuracy and precision of the analysis. The concentrations of Hg in soil samples were determined by ICP-OES (Optima 8000).

2.2. Pollution assessment methods
Single contamination index method, Nemerow comprehensive pollution index and potential ecological risk index were used to evaluate the pollution status of Hg in soil around Fengfeng mining area.

① Single contamination index method and Nemerow comprehensive pollution index method [4] can be calculated from the following formula.

\[
P_I = \frac{C_i}{C_0}
\]

\[
P_N = \sqrt{\frac{P_{ave}^2 + P_{max}^2}{2}}
\]

Where \(C_i\) is the measured concentration of pollutant \(i\) (mg kg⁻¹); \(C_0\) is the evaluation standard of pollutant \(i\) (mg kg⁻¹); \(P_I\) is the single pollution index of pollutant \(i\); \(P_{ave}\) is the average single pollution index of pollutant \(i\) in the soil; \(P_{max}\) is the largest single pollution index of pollutant \(i\) in the soil; \(P_N\) is the comprehensive pollution index of pollutant \(i\).

② Potential ecological risk index [5] can be calculated from the following formula.

\[
EI = T_i \times P_I
\]

Where \(P_I\) is the single-factor pollution index of pollutant elements in the soil; \(T_i\) is the biological toxicity response factor of different heavy metals, and the toxicity coefficient of Hg pollutants is 40. The pollution classification is presented in Table 1.

| Classification | The single contamination index method \(PI\) | Nemerow Comprehensive Pollution Index Method \(PN\) | Pollution level | Single heavy metal ecological risk index \(EI\) | Ecological risk Degree level |
|---------------|--------------------------------|--------------------------------|----------------|----------------|-------------------------|
| I             | \(PI \leq 0.7\) | \(PN \leq 0.7\) | Clean | \(EI \leq 40\) | Slight |
| II            | \(0.7 < PI \leq 1.0\) | \(0.7 < PN \leq 1.0\) | Still clean | \(40 \leq EI < 80\) | Medium |
| III           | \(1.0 < PI \leq 2.0\) | \(1.0 < PN \leq 2.0\) | Light pollution | \(80 \leq EI < 160\) | Strong |
3. Results

3.1. The content of Hg in the soil

Descriptive statistics of the basic parameters and heavy metal concentrations in the soils are presented in Table 2. The pH of soil was 8.09~10.2 in this study area, with an average of 9.4. Therefore, the soil showed weak alkaline. According to the average values of sampling results at different points, the average concentrations of Hg in surface soil were 14.95, 21.03, 30.29, 33.08 and 22.12 mg kg\(^{-1}\), respectively. The average concentrations of mercury in deep soil were 13.21, 18.45, 26.50, 30.90 and 19.53 mg kg\(^{-1}\), respectively. The concentrations of Hg in 97% of the soil samples exceeded the background value (2.01 mg kg\(^{-1}\)). In general, the average concentrations of Hg in all directions exceeded the risk screening standard (3.4 mg kg\(^{-1}\)) of "Soil environmental quality agricultural land soil pollution risk control standard (Trial) (GB 15618-2018)", which were 4.40, 6.19, 8.91, 9.73, 6.51 times of the standard value; 3.89, 5.43, 7.79, 9.09, 5.74 times of the standard value respectively. It indicates that the soil has been seriously polluted in this region by Hg.

### Table 2 Descriptive analysis of Hg in the soil

| Soil layer | Direction | Maximum value | Minimum value | Average value | Standard deviation | Coefficient of Variation | Background value | Standard value | Coal gangue samples |
|------------|-----------|---------------|---------------|---------------|--------------------|------------------------|-----------------|----------------|---------------------|
| Surface soil | WN       | 42.25         | 1.98          | 14.95         | 15.24              | 0.98                   |                 |                |                     |
|             | EN       | 51.13         | 1.97          | 21.03         | 18.37              | 1.14                   |                 |                |                     |
|             | E        | 57.38         | 2.13          | 30.29         | 22.16              | 1.37                   | 2.01            | 3.40            | 21.63               |
|             | ES       | 65.75         | 2.38          | 33.08         | 23.81              | 1.39                   |                 |                |                     |
|             | S        | 47.25         | 1.98          | 22.12         | 17.77              | 1.25                   |                 |                |                     |
| Deep soil   | WN       | 40.36         | 2.14          | 13.21         | 14.21              | 0.93                   |                 |                |                     |
|             | EN       | 49.56         | 2.06          | 18.45         | 17.40              | 1.06                   |                 |                |                     |
|             | E        | 55.20         | 2.24          | 26.50         | 20.63              | 1.28                   | 2.01            | 3.40            | 21.63               |
|             | ES       | 64.03         | 2.18          | 30.90         | 23.33              | 1.32                   |                 |                |                     |
|             | S        | 46.10         | 2.08          | 19.53         | 16.81              | 1.16                   |                 |                |                     |

Notes: The Background value data are the measured values of soil samples collected far away from the coal gangue hill.

3.2. Evaluation of soil Hg content pollution index

Substituting the measured data of Hg in soil into formulas (1) and (2), the results of single factor index and comprehensive pollution index are shown in Table 3.

### Table 3 the pollution evaluation index of Hg in the soil of the different directions

| Direction | Soil layer | PI | PN |
|-----------|------------|----|----|
|           |            | 0m | 20m| 40m| 60m| 80m| 100m| 150m| 200m| 300m| 400m|    |
| VN        | Surface soil | V  | V  | V  | V  | IV | III| III | II  |   |    | 15.77|
|           | Deep soil   | 20.08 | 18.17 | 12.12 | 5.84 | 2.89 | 1.86 | 1.48 | 1.10 | 1.12 | 1.06 | 14.94|

Notes: The Background value data are the measured values of soil samples collected far away from the coal gangue hill.
With the "Soil environmental quality agricultural land soil pollution risk control standard (Trial)(GB 15618 - 2018)" risk screening value as the standard, the single factor pollution index and Nemerow comprehensive pollution index are evaluated in Table 3. Based on the analysis of single factor average pollution index (PI) of each direction around the coal gangue hill, WN (0~80m), EN (0~100m), E (0~150m), ES(0~150m) and S (0~100m) are greater than 3, 61% of the sampling points in the study area belong to severe pollution. PN in each direction of the surrounding soil was ES > E > EN > S > WN > 3, which caused severe pollution. The regional Hg pollution degree is large, and the pollution index span is large. Due to the mining activities in the mining area, the Hg pollution in this area gradually decreases from the center of coal gangue to the surrounding area. The vicinity of the study area (0~100m) belongs to the heavy pollution area, the main reason for this phenomenon is that the soil Hg in the mining area is often discharged into the air through the atmosphere, and then Hg enters the soil of the mining area by atmospheric rainfall. The collection points near the coal gangue are (0~100m), which is the main reason for the higher Hg pollution than other sampling points.

3.3. Potential ecological risk assessment of soil heavy metals
The potential ecological risk assessment index of Hg was calculated by taking the average value of 10 sampling points from the coal gangue hill in 5 directions, and the potential ecological risk index of heavy metals in different distances was obtained. The potential ecological risk assessment results of soil Hg are shown in Figure 1.

![Figure 1: Potential ecological risk assessment index of Hg in the soil](image-url)
The potential ecological risk indexes of the surface soil near the coal gangue [0~100m) are greater than 320, and the potential ecological risk indexes of deep soil near the coal gangue [0~80m) are greater than 320, 55 % of the sampling sites in the study area represent extremely strong potential ecological risk. It shows that the long-term storage of coal gangue has brought serious Hg pollution to the local soil environment. The potential ecological risk index of deep soil near the coal gangue [80~100m) is greater than 160. There represent very strong potential ecological risk. The potential ecological risk indexes of the surface soil from the coal gangue [100~150m) are greater than 80, and the potential ecological risk indexes of the deep soil near the coal gangue [100~150m) are greater than 80, there represent strong potential ecological risk. The potential ecological risk index of surrounding soil near the coal gangue [150~400m) is greater than 40, and there represent medium potential ecological risk. Therefore, the research of Hg shows a strong potential ecological risk in the whole region, and the prevention and control of Hg pollution in the soil around the gangue hill should be strengthened in the whole region. It is suggested that the solidification / phytoremediation method should be used to restore environments of Fengfeng mining area.

4. Conclusions

(1) The concentrations of Hg in 97% soil samples exceeded the background value. In general, the average concentrations of Hg exceeded the risk screening standard in all directions, which were 4.40, 6.19, 8.91, 9.73 and 6.51 times of the standard value, respectively; 3.89, 5.43, 7.79, 9.09 and 5.74 times of the standard value, respectively. It indicates that the soil has been seriously polluted in this region.

(2) Regional Hg pollution degree is large, pollution index span is large. 61 % of the sampling points belong to severe pollution in the research area. The Hg pollution gradually decreased from the coal gangue center to the surrounding in the study area.

(3) The potential ecological risk indexes of the surface soil near the coal gangue [0~100m) are greater than 320, and the potential ecological risk indexes of deep soil near the coal gangue [0~80m) are greater than 320, 55 % of the sampling sites in the research area represent extremely strong potential ecological risk. The potential ecological risk index of deep soil near the coal gangue [80~100m) is greater than 160, there represent very strong potential ecological risk.

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References
[1] Fan J.S., Meng Z.Q, Li Y.H. (2011)Potential ecological hazards of heavy metals in coal gangue mountain of a mining area. Industrial safety and environmental protection, 37: 11-12.
[2] Yang Q. (2015)Research on Coal Gangue Pollution and Resource Utilization. Rural Economy and Technology., 26: 41-42.
[3] Wang X.Y., Yang J, Guo H.X. (2006)Research on heavy metal pollution of soil caused by coal gangue stacking in mining area. Journal of China Coal Society., 31: 808-812.
[4] Wang L.F., Bai Y.X., Gai S.N. (2011)Single-Factor and Nemerow Multi-Factor Index to Assess Heavy Metals Contamination in Soils on Railway Side of Harbin-Suifenhe Railway in Northeastern China. Applied Mechanics and Materials., 1366: 3033-3036
[5] Lars H. (1980)An ecological risk index for aquatic pollution control. a sedimentological approach. Hakanson Lars., 14: 975-1001.