Soil quality assessment of coal gangue piles under different ecological restoration pattern in Yunnan-Guizhou Mountainous area

Tao Lanchu1, He chengzhong1*, Tu chunlin1, Liu zhennan1, Li Bo2
1 Kunming Natural Resources Comprehensive Investigation Center, China Geological Survey, Kunming Yunnan, 65000, China
2 College of Resources and Environment, Yunnan Agricultural University, Kunming 650201, China
* Corresponding author: hechengzhong@mail.cgs.gov.cn

Abstract: The paper aimed at the problem of soil quality and heavy metal pollution of coal gangue piles in Yunnan-Guizhou mountainous area, the soil quality and heavy metal pollution of copper, zinc, iron, manganese and other heavy metals in coal gangue piles at different ecological restoration pattern were determined, and the soil quality and pollution risk degree were evaluated. Results showed that soil pH value of the survey sites ranged from 3.04 to 8.11, soil organic matter content ranged from 48.58 g·kg⁻¹ to 202.29 g·kg⁻¹, soil total nitrogen content ranged from 0.66 g·kg⁻¹ to 2.04 g·kg⁻¹, soil available nitrogen content ranged from 5.25 mg·kg⁻¹ to 33.25 mg·kg⁻¹, soil total phosphorus content ranged from 0.61 g·kg⁻¹ to 2.56 g·kg⁻¹, soil available phosphorus content ranged from 0.46 mg·kg⁻¹ to 102.41 mg·kg⁻¹, soil total potassium content ranged from 9.44 g·kg⁻¹ to 33.25 g·kg⁻¹, and soil available potassium content ranged from 3.25 mg·kg⁻¹ to 149.63 mg·kg⁻¹; soil total copper content of the survey sites ranged from 66.76 mg·kg⁻¹ to 225.83 mg·kg⁻¹, soil total zinc content of the survey sites ranged from 115.15 mg·kg⁻¹ to 368.48 mg·kg⁻¹, soil total iron content of the survey sites ranged from 22.57 g·kg⁻¹ to 64.17 g·kg⁻¹, and soil total manganese content of the survey sites ranged from 223.79 mg·kg⁻¹ to 1898.57 mg·kg⁻¹. These results implied that the coal gangue piles were barren, nutrition and water retention need to be improved in the process of restoration, and the risk of soil copper and zinc pollution in these coal gangue piles were low.

1. Introduction
It is difficult to change the pattern of coal as the main energy source in China in the short term. However, coal resources will damage and pollute the ecological environment of mining areas in the process of mining and utilization [1]. The discharge and storage of coal gangue piles is a common and typical pollution damage form. The discharge and accumulation of coal gangue not only directly encroaches on the land resources, but also indirectly pollutes the surrounding soil environment and damages the surface vegetation, thus causing social conflicts.

Coal gangue piles contains heavy metal elements such as copper, zinc, iron, manganese and lead, which will lead to heavy metal pollution of surrounding soil under long-term accumulation, weathering and leaching. However, the problem of soil heavy metal pollution has the characteristics of accumulation and concealment [2-5]. Therefore, it will cause greater harm to human beings, animals and plants.
Fuyuan County and Panzhou city in Yunnan-Guizhou mountainous area are important coal production bases in Southwest China, which are rich in coal resources [6]. The large and long-term storage of coal gangue piles seriously threatens the surrounding ecological environment. It has become the main ecological environment problem in Yunnan-Guizhou mountainous area, and seriously restricts the ecological civilization construction and green development of the mining area [7].

The paper aimed at the problem of soil quality and heavy metal pollution of coal gangue piles in Yunnan-Guizhou mountainous area, the soil quality and heavy metal pollution of copper, zinc, iron, manganese and other heavy metals in coal gangue piles at different ecological restoration pattern were determined, and the soil quality and pollution risk degree were evaluated, it not only has important theoretical significance in deepening the study of ecological restoration and heavy metal pollution mechanism and environmental behavior of coal gangue, but also has important practical significance for ecological restoration of coal gangue piles and precise prevention and control of soil heavy metal pollution in Yunnan-Guizhou mountain area.

2. Experimental materials and methods

2.1. Sampling point setting
5 coal gangue piles in Yingshang town and Mohong town of Fuyuan county, Huopu town and Hongguo town of Panzhou city were investigated from July 4 to 5, 2020, and 17 topsoil samples (0-20cm) were collected according to the ecological restoration pattern (9 survey sites in Fuyuan county and 8 survey sites in Panzhou city) (Table 1), and the characteristics of soil nutrients and heavy metal pollution in coal gangue files under different ecological restoration conditions were analyzed.

| Area     | Site | Longitude /° | Latitude /° | Ecological restoration pattern | Ecological restoration effect |
|----------|------|--------------|-------------|-------------------------------|------------------------------|
| Fuyuan   | 1    | 104.36266    | 25.46937    | Cover soil, plant crops       | middle                       |
|          | 2    | 104.39232    | 25.48945    | Cover soil, plant fruit trees | best                         |
|          | 3    | 104.42231    | 25.36948    | Cover soil, plant grass       | middle                       |
|          | 4    | 104.27372    | 25.38222    | Cover soil, plant crops       | best                         |
|          | 5    | 104.22546    | 25.44166    | Uncovered soil                | middle                       |
|          | 6    | 104.23230    | 25.46462    | Cover soil, plant trees and grass | worst                  |
|          | 7    | 104.21319    | 25.27889    | Cover soil, plant grass       | middle                       |
|          | 8    | 104.18779    | 25.32039    | Uncovered soil                | worst                        |
|          | 9    | 104.23333    | 25.39922    | Cover soil, plant trees and grass | middle                   |
|          | 1    | 104.45002    | 25.67221    | Cover soil, plant fruit trees | best                         |
|          | 2    | 104.43223    | 25.43271    | Cover soil, plant trees and grass | middle                   |
|          | 3    | 104.41996    | 25.65596    | Cover soil, plant trees and grass | middle                   |
| Panzhou  | 4    | 104.45002    | 25.67221    | Cover soil, plant fruit trees | best                         |
|          | 5    | 104.42005    | 25.65485    | Cover soil, plant grass       | middle                       |
|          | 6    | 104.39700    | 25.70112    | Cover soil, plant grass       | middle                       |
|          | 7    | 104.50398    | 25.70992    | Cover soil, plant grass       | middle                       |
|          | 8    | 104.50403    | 25.71003    | Cover soil, plant trees and grass | worst                  |

2.2. Sample analysis
For the determination of soil nutrient elements, refer to the third edition of soil agrochemical analysis. pH value: water was 1:5, determined by pH meter; the content of soil organic matter was determined by potassium dichromate oxidation method; total nitrogen was determined by semi micro Kjeldahl method; total phosphorus was determined by acid soluble molybdenum antimony anti colorimetry; available phosphorus was determined by double acid molybdenum antimony anti colorimetry; alkali hydrolyzable nitrogen was determined by alkali hydrolysis diffusion method; available potassium was determined by
acetic acid extraction atomic absorption spectrometry; the contents of total copper, total zinc, total iron and total manganese in soil were determined by Flame atomic absorption spectrophotometry after aqua regia digestion.

3. Results

3.1. Soil nutrient status of different coal gangue piles

Table 2 Soil nutrient status of different coal gangue piles

| Area | Site | pH value | Organic matter / g·kg⁻¹ | Total nitrogen / g·kg⁻¹ | Available nitrogen / mg·kg⁻¹ | Total phosphorus / g·kg⁻¹ | Available phosphorus / mg·kg⁻¹ | Total potassium / g·kg⁻¹ | Available potassium / mg·kg⁻¹ |
|------|------|----------|-------------------------|------------------------|-----------------------------|---------------------------|-----------------------------|--------------------------|-----------------------------|
| Fuyuan | 1  | 8.04±0.31 | 87.48±7.48 | 1.46±0.09 | 10.51±1.48 | 0.92±0.07 | 64.01±4.44 | 13.56±0.47 | 95.33±6.33 |
|       | 2  | 8.11±0.53 | 202.29±10.99 | 2.04±0.35 | 14.33±0.95 | 1.10±0.13 | 0.46±0.23 | 10.39±1.55 | 98.79±11.23 |
|       | 3  | 7.39±0.85 | 97.84±8.55 | 1.62±0.11 | 5.25±0.46 | 0.88±0.04 | 0.81±0.11 | 18.95±2.03 | 85.63±13.22 |
|       | 4  | 7.47±0.88 | 177.3±17.22 | 1.78±0.13 | 10.5±0.99 | 0.66±0.03 | 34.49±3.59 | 11.76±1.44 | 81.77±5.21 |
|       | 5  | 6.10±0.47 | 181.18±16.42 | 1.72±0.09 | 15.75±1.32 | 0.69±0.02 | 34.25±3.67 | 14.24±1.15 | 96.12±5.4 |
|       | 6  | 6.98±0.32 | 64.21±5.55 | 0.67±0.08 | 12.25±1.11 | 0.57±0.03 | 8.42±0.78 | 22.5±2.69 | 102.25±8.89 |
|       | 7  | 3.04±0.15 | 228.04±31.48 | 2.66±0.23 | 33.23±2.79 | 0.57±0.04 | 11.06±1.02 | 9.44±1.01 | 3.52±0.41 |
|       | 8  | 5.86±0.43 | 48.58±7.01 | 0.66±0.04 | 22.75±1.89 | 0.91±0.02 | 26.92±2.67 | 12.39±1.45 | 92.95±8.58 |
|       | 9  | 6.21±0.22 | 189.21±15.24 | 1.11±0.08 | 20.99±2.55 | 2.56±0.05 | 102.41±10.89 | 16.65±0.68 | 50.51±4.32 |
|       | 1  | 6.92±0.32 | 290.00±10.37 | 2.52±0.33 | 7.08±6.31 | 1.33±0.01 | 3.22±0.24 | 15.73±1.73 | 114.88±13.22 |
|       | 2  | 8.53±0.44 | 160.31±17.43 | 1.21±0.15 | 17.5±2.11 | 1.08±0.02 | 5.78±0.69 | 17.31±0.98 | 132.52±14.11 |
|       | 3  | 7.74±0.31 | 150.71±12.45 | 2.35±0.27 | 5.25±0.33 | 1.47±0.03 | 9.33±0.88 | 24.09±2.58 | 149.63±12.33 |
| Panzhou | 4  | 8.31±0.72 | 236.83±22.78 | 2.52±0.23 | 7.01±0.68 | 1.14±0.02 | 15.33±2.12 | 19.48±1.47 | 164.54±17.89 |
|       | 5  | 6.76±0.49 | 187.66±15.99 | 1.10±0.10 | 49.22±4.11 | 0.61±0.01 | 14.23±0.89 | 16.57±1.88 | 45.66±4.32 |
|       | 6  | 7.11±0.22 | 97.34±8.78 | 2.34±0.35 | 7.02±0.59 | 0.97±0.03 | 6.76±0.49 | 18.01±1.67 | 91.76±8.56 |
|       | 7  | 6.96±0.12 | 57.55±7.71 | 0.85±0.06 | 14.03±1.19 | 0.87±0.02 | 15.35±1.42 | 35.05±3.69 | 120.1±8.13 |
|       | 8  | 7.53±0.56 | 57.42±2.13 | 1.57±0.24 | 7.00±0.68 | 0.86±0.04 | 64.01±0.78 | 24.86±2.78 | 138.75±20.22 |

Soil pH value of the survey sites ranged from 3.04 to 8.11, and the content of soil organic matter ranged from 48.58 g·kg⁻¹ to 202.29 g·kg⁻¹. The organic matter content of some survey sites was higher, which may be related to the addition of a large amount of organic fertilizer in the restoration process of these survey sites.

Soil total nitrogen content ranged from 0.66 g·kg⁻¹ to 2.04 g·kg⁻¹, soil available nitrogen content ranged from 5.25 mg·kg⁻¹ to 33.25 mg·kg⁻¹, soil total potassium content ranged from 9.44 g·kg⁻¹ to 33.25 g·kg⁻¹, and soil available potassium content ranged from 3.25 mg·kg⁻¹ to 149.63 mg·kg⁻¹, all of which were relatively low, which may be due to the poor water retention of coal gangue piles and the serious loss of nitrogen and potassium.

Soil total phosphorus content ranged from 0.61 g·kg⁻¹ to 2.56 g·kg⁻¹, soil available phosphorus content ranged from 0.46 mg·kg⁻¹ to 102.41 mg·kg⁻¹, the contents of total phosphorus and available phosphorus of coal gangue under different ecological restoration pattern were significantly different. The contents of total phosphorus and available phosphorus in coal gangue piles with best ecological restoration effect were significantly higher than those with middle ecological restoration effect and those without ecological restoration. This showed that the coal gangue piles was poor in nutrients, therefore, it is necessary to improve soil nutrition and increase water holding capacity in the process of ecological restoration of coal gangue piles (Table 1).
3.2. Soil heavy metal content of different gangue files

Soil total copper content of the survey sites ranged from 66.76 mg·kg\(^{-1}\) to 225.83 mg·kg\(^{-1}\) (Figure 1); Soil total zinc content of the survey sites ranged from 115.15 mg·kg\(^{-1}\) to 368.48 mg·kg\(^{-1}\) (Figure 2); Soil total iron content of the survey sites ranged from 22.57 g·kg\(^{-1}\) to 64.17 g·kg\(^{-1}\) (Figure 3); Soil total manganese content of the survey sites ranged from 223.79 mg·kg\(^{-1}\) to 1898.57 mg·kg\(^{-1}\) (Figure 4).

Except for Fuyuan No.7 survey site, Panzhou No.7 survey and Panzhou No.8 survey, soil total copper content of other survey sites exceeded the limit value of screening value (soil total copper content < 100 mg·kg\(^{-1}\)) in the standard for soil environmental quality control and control of soil pollution risk of agricultural land (GB15618-2018); except for Panzhou No.1 survey site, soil total zinc content of other survey sites did not exceed the the limit value of screening value (soil total zinc content < 250 mg·kg\(^{-1}\)) in the standard for soil environmental quality control and control of soil pollution risk of agricultural land (GB15618-2018).

4. Conclusion
(1) The organic matter content of some survey sites was higher, which may be related to the addition of a large amount of organic fertilizer in the restoration process of these survey sites.

(2) Soil total nitrogen content, soil available nitrogen content, soil total potassium content and soil available potassium content were relatively low, which may be due to the poor water retention of coal gangue and the serious loss of nitrogen and potassium.

(3) The content of total phosphorus and available phosphorus in the coal gangue piles after ecological restoration were high, and the content of total phosphorus and available phosphorus in the coal gangue piles without ecological restoration were very low, which indicated that the coal gangue pile were barren, and nutrition and water retention need to be improved in the process of restoration.
The content of total copper and total zinc in a small number of coal gangue piles exceeded the limit value of the screening value of "soil environmental quality agricultural land soil pollution risk control standard", and the risk of soil copper and zinc pollution in these coal gangue piles were low.

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