The spatial distribution of soil heavy metals and ecological restoration of Datong Abandoned Coal Mine in Huainan City

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Abstract. Based on laboratory analysis of soil samples collected from abandoned coal mine in Datong area, content of heavy metals in the soils was monitored and the soils were evaluated for heavy metal pollution. The spatial distribution of heavy metals was study with means of Kriging method by under ArcGIS environment in the abandoned coal mine in Huainan area. The results show: (1) the content of 5 types of heavy metals (Hg, Cd, Cr, Pb, Cu) were all higher than Huainan area background value of soil elements, among of these heavy metals, the enrichment of Cd was higher and polluted quite seriously; the enrichment of Hg, Cr, Pb and Cu was lower, and polluted lightly comparatively. (2) The coal mine waste rock pile and abandoned chemical plant were the main pollution sources. (3) The heavy metal concentrations and space distribution were mainly affected coal mine waste rock pile, and abandoned chemical plant. (4) Positive correlation between concentrations of most heavy metals was significant, and there is a certain relationship between concentrations of heavy metals and organic matter, nitrogen, available phosphorus. On the basis of the above research, some countermeasures were put forward for ecological restoration in Datong abandoned coal mine.

1.Introduction
Studies on ecological restoration of abandoned land mainly focus on soil improvement (mainly including soil improvement, soil chemical improvement, organic matter improvement, plant improvement, microbial improvement) and comprehensive land management. Compared with foreign countries, there was a big gap in the application of new technologies and new concepts related to the management of abandoned coal mines [1]. Ecological restoration of abandoned coal mine is a complex coordinated project. In China, ecological, engineering, economic, environmental, soil science, hydrology and other multidisciplinary theories and technical methods should be adopted to effectively carry out ecological restoration of abandoned coal mine [2]. Some predecessors discussed the ecological restoration methods and models in the subsidence area of Huainan coal mine and put forward the countermeasures [3]. Predecessors of Datong abandoned mining area put forward ecological restoration methods from the perspective of plant allocation and ecological planning, but there was no specific diagnosis of soil environmental problems. Based on the investigation of regional soil environment, this study based on GIS and other technologies analyzed the characteristics of heavy metal pollution and
spatial distribution in the soil layer, reveal the ecological problems in abandoned mining areas, and provide scientific basis for the effective restoration of abandoned mining areas in cities.

2. Situation of the study area

Datong Mine was built in 1903 and put into operation in 1911 in Huainan City. After the closure of the pit, the settlement area was repaired and was being gradually developed into a wetland park for eco-tourism (Figure 1). The mine was shut down in 1978. The resource exhausted mining area forms a large area of "urban wasteland". Huainan Datong wetland is the result of the reconstruction and restoration of the subsidence area of Huainan Datong coal mine, including the abandoned coal gangue yard (slope), the abandoned machinery well, the abandoned chemical plant filter and the waste water well. The area is only about 4.38km². Compared with the two ecological zones of Laolongyan and Dongshan Mountain in Huainan City, there were some problems such as poor soil and water environment quality and poor vegetation growth, and there was still a big gap between the ecological restoration effect of Datong wet area and the urban environment construction target.

![Figure 1](image1.png)

Figure 1. The study area and distribution of sample locations

3. Data source processing and research methods

3.1. Sample collection, processing and content determination

The 42 representative sampling points in the study area were selected for sampling, and the sampling distribution points were shown in figure 1. The samples were divided into three zones: north, middle and south. At least 4 samples were taken from each zone. The sampling area was surrounded by the background sample area, and the surrounding spots were convenient for the base investigation of the investigation recovery area. The sample preparation process was as follows: removing stones, wood chips, animal and plant residues and other foreign bodies from the samples, mixing them evenly, then air drying the soil samples naturally, drying them in an 80°C oven for 24h, grinding them with agate mortar, and passing through a 200-mesh nylon sieve. The 0.5g soil samples were accurately weighed and digested with nitric acid - hydrofluoric acid - hydrochloric acid by microwave. The
contents of Pb, Cd, Cr and Cu were determined by atomic absorption spectrophotometer and Hg were determined by atomic fluorescence spectrometer. The contents of ammonia nitrogen, available phosphorus and organic matter in soil were determined by NaCl extraction - uv spectrophotometry, molybdenum-antimony colorimetric method and potassium dichromate volumetric method.

3.2. Calculation of soil heavy metal pollution index

Single factor index and homogeneous multi-factor index were used to evaluate the pollution status of sampling points:[4]:

\[ I_i = \frac{C_i}{S_i} \quad (1) \]

\[ I = \frac{1}{n} \sum_{i=1}^{n} I_i = \frac{1}{n} \sum_{i=1}^{n} \frac{C_i}{S_i} \quad (2) \]

In equations (1) and (2), \( I_i \) is the environmental quality index of the pollutant, \( C_i \) is the concentration of the pollutant in the environment, \( S_i \) is the evaluation standard of the pollutant in the environment (using the background value), \( I \) is the environmental quality index, and \( n \) is the number of factors participating in the evaluation.

3.3. GIS processing of spatial data

In ArcGIS10.0, using GPS to record latitude and longitude coordinates of each sampling point accurately determine the specific location of the sampling points in the study area, in the property sheet inputting the heavy metal element content of each sample point, using statistical analysis module (Geo-statistical Analyst), the Ordinary Kriging method respectively, for spatial interpolation, the spatial distribution map of heavy metal elements in the soil of abandoned mining area was obtained. The above two interpolation maps were used to calculate the difference value of raster layer and analyze the concentration and distribution of heavy metals in the layer.

4. Result analysis

4.1. Distribution and aggregation of heavy metal pollution in soil

The distribution and concentration of heavy metal elements in Figure 2, the positive value indicated that the content in the deep layer was higher than that in the surface layer, and the negative value indicated that the content in the surface layer was higher than that in the bottom layer. There were positive value for Hg content in waste shaft, waste pile, chemical waste water Wells and filter most area, and there was negative value in a small area (natural environment), and Hg element content was greatly influenced by the underlying original pile of coal gangue, and the original chemical detection of Hg content in the factory by the discharge of wastewater was high. The underlying soil Hg content in high wastewater infiltration was high, the influence of Hg constantly enriched. The content of Cd was higher in the bottom layer. Cr had high bottom content in most areas such as waste well, gangue pile and filter tank. Pb was high in the bottom layer of waste engine well and gangue heap area, and high in the surface layer of natural environment and original chemical plant filter and waste water well, with surface polymerization. The surface soil content of Cu in gangue heap and waste water well was high, and the bottom soil content was high in western natural environment.

The spatial distribution of surface and bottom heavy metals in the above soil shows that the distribution of Hg and Cd elements in the soil of Datong waste mining area was affected by the coal gangue heap (bottom soil) and the effluent from the former chemical plant (top soil), and they were enriched in the bottom soil, causing serious pollution. Element Cr were most affected by the effluent from the original chemical plant, followed by the gangue pile. The content of Pb was the highest in the gangue heap slope and the bottom soil was enriched in the gangue heap. The content of Cu in topsoil was affected by chemical plant, while the bottom soil was affected by gangue pile and chemical plant wastewater. Comparatively speaking, with Hg, Cd and Pb elements, the coal gangue heap had more pollution on the bottom soil content, and the former chemical plant discharge wastewater had more pollution on the top soil.
4.2. Correlation between heavy metal elements and organic matter content in soil

In addition to the significant negative relationship of Cr and Hg, other showed significant positive correlation, such as between Cd and Pb, Cu, Pb and Cu in Datong Mine waste mining area in soil heavy metal elements, and the correlation coefficient between Hg and Pb was the larger, positive correlation significantly. These elements correlation indicated abandoned mining area compound pollution hazards. Most elements in soil at the same time also showed that heavy metals may be associated with derived from coal gangue, chemical wastewater. In terms of the correlation between heavy metal elements and nutrients in soil, most of them are negatively correlated, such as Cu with ammonia nitrogen and organic matter, Pb with ammonia nitrogen, Cr with ammonia nitrogen and organic matter, and Cd with ammonia nitrogen and organic matter. There was a significant positive correlation between Cu and available phosphorus, Cd and available phosphorus, and Hg with ammonia nitrogen and available phosphorus.

5. Ecological restoration approaches

5.1. Screening and planting of native plants suitable for abandoned mining areas

Plants planted in Datong mining area should be able to withstand coal gangue poverty and drought, and plants in sewage environment should be able to compare the ability of pollution tolerance and water purification[5]. At the same time, it is required to be easy to plant, have strong reproduction ability, and be able to expand into the dominant community by artificial planting, thus transforming the harsh environment.

5.2. Reduce soil heavy metal pollution

Heavy metal pollution was serious in Datong abandoned mining area. Heavy metal enrichment plants were used to enrich heavy metal elements in the soil, and the plants are removed periodically to reduce heavy metal pollution and improve soil environmental quality, which was conducive to the succession of regional biological communities and the restoration of ecological environment.

5.3. Strengthen the purification of water and soil environment by constructed wetlands

There were constructed wetlands in the existing abandoned Datong mining area, where heavy metal super-enriched wetland plants were cultivated, and the underwater silt was cleaned regularly to purify the soil and water environment.

Figure 2. The accumulation of heavy metals in the soil
5.4. Improve soil fertility and plant nutrition
The lack of soil nutrients will lead to the restriction of plant growth and development in Datong abandoned mining area. Therefore, organic fertilizer, nitrogen fertilizer, phosphate fertilizer or nitrogen-fixing plants should be widely applied to improve soil nutrient supply and promote plant growth and ecological environment restoration in mining areas.

5.5. Comprehensive control of complex heavy metal pollution
There was a great correlation between heavy metal pollution elements in Datong abandoned mining area, and there was a great potential for compound pollution. Biological and microbial remediation technology, topsoil conversion, ecological engineering and other measures should be taken to reduce heavy metal pollution.

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