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ASSESSMENT OF HEAVY METAL POLLUTION IN AGRICULTURAL SOIL AROUND A GOLD MINE AREA IN YITONG COUNTY

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ABSTRACT

Heavy metals affect the soil and food adversely, as well as threaten the human health and ecosystem by biologically cumulative effect. Yitong county, an important grain production base with abundance of black soil, has been threatened by a gold mine in fields of the security of food production and environment. For the exploration of the pollution situation, the heavy metal contents in agricultural soil around the gold-mining area have been determined in this work. Firstly, a total of 91 samples were collected by field surveying, and the concentrations of 7 elements (As, Cd, Cr, Cu, Ni, Pb and Zn) in those soil samples were analyzed. After that, geoaccumulation index (Igeo), pollution index (PI) and potential ecological risk (PER) were selected as the evaluation indexes to assess heavy metal pollution. In addition, the varimax normalized rotation was applied to trace the source of pollution. The results indicate that the study area was contaminated on a moderate level.

Index Terms— soil heavy metals, pollution index, potential ecological risk

1. INTRODUCTION

Healthy soil is the basic guarantee for food and ecological security. Industrial pollution and overuse of agricultural chemicals lead to the accumulation of heavy metals in soil, which threatens soil safety seriously [1]. Therefore, the evaluation and treatment of heavy metal pollution are the focus of soil research[2].

The environmental damage caused by mining is one of the most serious environmental problems around the world[3]. Gold mining makes many adverse impacts on environment, such as the damage of vegetation, the instability of riverbed structure, soil erosion, landslide and debris flow[4]. Besides, the heavy metal pollution problems will emerge along with gold mining due to the slag's special physical and chemical character. Thus, it is necessary to explore the influence of gold mining on the safety of local soil.

Black soil is one of the most precious natural resources, and also the most fertile agricultural land on the earth[5], which is abundant in the style area. However, gold mining activities in Yitong seriously threatens the cultivated land security. In order to study the impact of gold mining on soil, environmental pollution has been assessed. The main objectives of this study are as follows: (1) determine the concentration of heavy metal of heavy metals including Arsenic(As), Cadmium(Cd), Chromium(Cr), Cuprum(Cu), Nickel(Ni), Plumbum(Pb) and Zinc (Zn) around gold mining area, (2) trace the source of pollution using varimax normalized rotation, (3) assess the heavy metal pollution by the geoaccumulation index(Igeo), pollution index (PI) and potential ecological risk(PER).

2. MATERIALS AND METHODS

2.1. Study area and sample protocol

This study was carried out in Yitong county, Jilin Province, north-eastern China, which has an area of 2523 km^2 and a population size of 0.48 million. The area of cultivated land is 1296 km^2, accounting for 51.3% of the total area of the county. The annual average temperature and sunshine hours amount to about 5.8 ℃ and 2388.9 h, respectively. And the annual average precipitation is 608.4 mm. The suitable climate and fertile land make Yitong county become a commodity grain base county in China.

A total of 91 samples were collected in study area in May 2019. Locations of the soil sampling sites are shown as Fig.1. After removing dopant from the soil, all soil samples were air dried in laboratory and then sieved through a 0.150mm mesh after grinding.

The concentrations of heavy metals (As, Cd, Cr, Cu, Ni, Pb and Zn) were measured by inductively coupled plasma mass spectrometry (ICP-MS) after pretreatment of heating

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digestion, constant volume and filtration. For quality control national standard soil sample (GBW-07405) were employed during the process. The detection levels of the standard were 90.1-110.3% of the standard reference material levels, and the relative standard deviations (RSDs) were less than 6%.

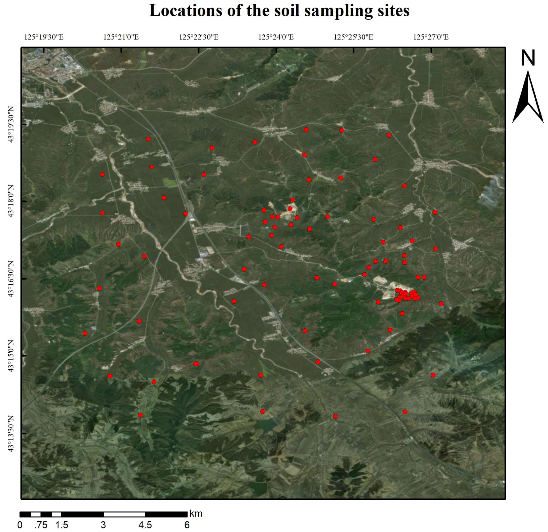

Fig. 1. Locations of the soil sampling sites

2.2. Multivariate statistical analysis

The Pearson correlation coefficient is utilized to measure the intensity of the relationship among heavy metals, which can contribute to tracing the sources of a certain heavy metal. After that, principal component analysis (PCA), one of the mathematical processes, is carried out to transform the spectral characteristics into a linear uncorrelated space using orthogonal decomposition. The varimax normalized rotation, which is used in principal component analysis to maximize the total variance of each factor, was applied to trace the source of the heavy metal pollution.

2.3. Index of geoaccumulation

Geoaccumulation index considers both the influences of natural geological processes and human activities on heavy metal pollution[6]. Thus, the geoaccumulation index can not only reflect the natural change characteristics of heavy metal distribution, but also judge the impact of human's activities. The Index of geoaccumulation is defined as equation (1):

$$Igeo = \log_2(C_n / 1.5B_n) \tag{1}$$

where C_n represents the detected concentration of heavy metal (mg/kg), and B_n is the reference values. In this study, the background content in Chinese soil (CNEMC,1990) was chosen as the reference values(mg/kg).

As shown in Table 1, the geoaccumulation index can be divided into seven levels.

Table 1. Pollution levels of Igeo

Level	Pollution state
Level0(Igeo<0)	Practically unpolluted
Level1(0≤Igeo<1)	Unpolluted to moderately polluted
Level2(1≤Igeo<2)	Moderately polluted
Level3(2≤Igeo<3)	Moderately to strongly polluted
Level4(3≤Igeo<4)	Strongly polluted
Level5(4≤Igeo<5)	Strongly to extremely polluted
Level6(Igeo≥5)	Extremely polluted

2.4. Pollution evaluation of heavy metals

The single pollution index (PI) and the integrated Nemerow pollution index (PI_N) were applied for the assessment of the soil pollution[7]. PI is expressed as follows:

$$PI = \frac{C_n}{B_n} \tag{2}$$

$$PI_N = \sqrt{\frac{MaxPI^2 + AvePI^2}{2}} \tag{3}$$

$MaxPI^2$ and $AvePI^2$ are the maximum and average value of PI values, respectively.

PI_N takes the average pollution status of carious pollutions and the most serious pollution status into account and is more suitable to describe the single heavy metal pollution. According to the contamination status, PI_N can be classified to five degrees as shown in Table 2.

Table 2. Pollution levels of PI_N

Level	Pollution state
Level0($PI_N \leq 0.7$)	Safety
Level1($0.7 < PI_N < 1$)	Warning
Level2($1 < PI_N \leq 2$)	Light pollution
Level3($2 < PI_N \leq 3$)	Moderately pollution
Level4($PI_N > 3$)	Heavy polluted

2.5. Potential ecological risk index

Potential ecological risk index (PER) consists of multi-element coordination, toxicity level, pollution concentration and environmental sensitivity, and is widespread used in environmental risk assessment. PER is calculated by equation (4)-(6):

$$C_j = C_n / B_n \tag{4}$$

$$E_j = T_n * C_j \tag{5}$$

$$PER = \sum_{i=1}^{n} E_j \tag{6}$$

where the toxic response factors (T_n) for As, Cd, Cr, Cu, Ni, Pb and Zn set to 10,30,2,5,6,5 and 1, respectively[8]. Table 3 shows the pollution levels classified by E_j and PER.

Table 3. Pollution levels of E_j and PER

Level	Pollution state

E_j <40 *or* PER<150	Low risk
40≤E_j < 80 *or* 150≤PER < 300	Moderate risk
80≤E_j < 160 *or* 300≤PER < 600	Considerable risk
160≤E_j < 320 *or* PER≥600	High risk
E_j ≥320	Very high risk

3. RESULTS AND DISCUSSION

3.1. Spatial distribution of heavy metals

The descriptive statistics of heavy metal concentrations are listed in Table 4. In this study, the mean concentrations of As, Cd, Cr, Cu, Ni, Pb and Zn were 43.30mg/kg, 0.11mg/kg, 50.61mg/kg, 15.61mg/kg, 24.98mg/kg, 11.73mg/kg and 57.53mg/kg, respectively. Compared with the background content (11.2mg/kg, 0.097mg/kg, 61.0mg/kg, 22.6mg/kg, 26.9mg/kg, 26.0mg/kg and 74.2mg/kg, respectively) and National soil quality standard (40mg/kg, 0.3mg/kg, 150mg/kg, 50mg/kg, 60mg/kg, 70mg/kg and 200mg/kg, respectively), the mean concentration of As greatly exceeds the background value and national standard, and Cd is slightly higher than that. The mean concentrations of other heavy metals are far below the background values. These results reveal that the gold mining is mainly reason for the pollutions of As and Cd.

To study the distribution of As more intuitively, a kriging interpolation map based on 91 samples is shown in Fig.2. The map shows that the concentration of As showed a decreases trend with the increasement of distance from the gold mine and the area around the gold mining was polluted considerably.

Table 4. Descriptive statistics of heavy metal concentrations

	As	Cd	Cr	Cu	Ni	Pb	Zn
Min	1.42	0.01	3.65	0.94	2.84	0.62	6.76
Max	445.5	0.42	106.7	24.81	60.90	16.64	109.1
Mean	43.30	0.11	50.61	15.61	24.98	11.73	57.53
Std.	73.69	0.054	13.34	3.68	7.69	2.53	12.32
C.V	1.70	0.49	0.26	0.23	0.31	0.21	0.21

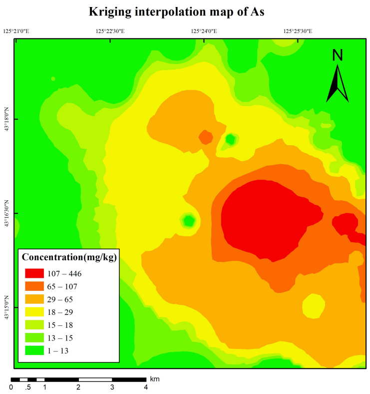

Fig. 2. Kriging interpolation map of As

3.2. Source apportionment

The Pearson correlation coefficient and PCA were applied to trace pollution source. Three principal components (PC) can present 85.171% of the variance (PC1:49.073%, PC2:25.231%, PC3:10.867%). The first principal component is mainly related to Zn, Pb and Cu, which yield values of 0.903, 0.810 and 0.775, respectively. As shown in Table 5, there presents a strong correlation ship among those three heavy metals, which indicates that they may have the same source. However, the concentration of these heavy metals is below the standard. The reason for this may be related to the characteristics of soil parent material.

The second and third principal components are both mainly related to As, which yield values of 0.642 and 0.571, respectively. The main gold mining in Yitong county is arsenical gold ore. With the process of smelting, the corresponding heavy metals moved into the soil and accumulated gradually, which caused serious pollution. Besides, there was not significant correlation between As and other heavy metals, which proves that gold mining only impacts As content.

Table 5. Pearson correlations matrix among the heavy metals

	As	Cd	Cr	Cu	Ni	Pb	Zn
As	1						
Cd	0.461	1					
Cr	-0.02	0.035	1				
Cu	-0.03	0.285	0.434	1			
Ni	0.033	0.083	**0.846**	0.481	1		
Pb	0.361	0.609	0.173	0.545	0.336	1	
Zn	0.404	0.641	0.369	**0.712**	0.431	**0.692**	1

Table 6. Rotated component matrix among the heavy metals

	PC1	PC2	PC3
As	0.387	**0.642**	**0.571**
Cd	0.640	0.581	-0.011
Cr	0.572	-0.683	0.356
Cu	**0.775**	-0.270	-0.434
Ni	0.690	-0.605	-0.268
Pb	**0.810**	0.268	-0.156
Zn	**0.903**	0.199	-0.155
% of variance	49.073	25.231	10.867
Cumulative %	49.073	74.304	85.171

3.3. Pollution assessment of examined soils

In this part, Igeo, PI and PER are introduced to assess the soil heavy metals pollution. The box-plots of these indicators are shown in Fig. 3-5. The mean Igeo of all heavy metals is below 0, which means the soil is in a practically unpolluted state.

According to PI, other metals are in safety state except for As and Cd. Considering both the average and the most serious pollution status, the mean of PI_N shows that the soil is in slight pollution state. PER also indicates that the ecological risk of the soil is low except for the abnormal points around the mining area, which is consistent with PI.

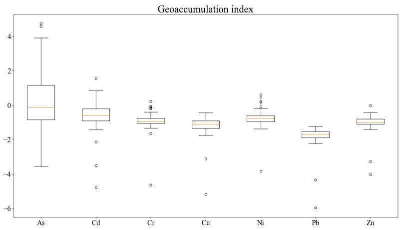

Fig. 3. Box-plots of the geoaccumulation index (Igeo) for heavy metals

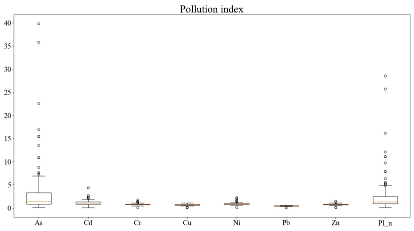

Fig. 4. Box-plots of the pollution index (PI) and integrated Nemerow pollution index (PI_N) for heavy metals

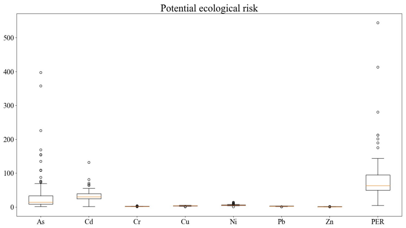

Fig. 5. Box-plots of potential ecological risk index (PER) for heavy metals

In general, the soil environment quality of Yitong county conforms to national standard apart from the gold mining area. Relevant departments should take steps to prevent the spread of the pollution for safeguarding the quality and safety of cultivated land around the mining area.

4. CONCLUSION

This study provides an evaluation of the gold mining activity influencing on soil environmental quality. After the tracing analysis using a variety of indictors, it can be seen that gold mining only impacts the accumulation of As. Meanwhile, the concentration of As showed a decreases trend with the increasement of distance from the gold mine. In general, soil remediation in Yitong county is needed towards the As contamination in the gold mining area. The analysis based on sampling data has the disadvantage of insufficient accuracy. Therefore, hyperspectral remote sensing technologies will be used to achieve high-precision soil quality assessment in the future.

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