

Status and risk assessment of heavy metal pollution in farmland soil in the southern suburbs of Jiaozuo City

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ABSTRACT

A farmland in the southern suburb of Jiaozuo City was selected as the research area, 36 surface soil samples were collected, and the contents of heavy metals (Cd, Cr, Zn, Ni, Cu, Pb and As) in soil were determined. The ecological risk of heavy metals in soil was assessed by single factor pollution index method, Nemerow comprehensive pollution index method and potential ecological risk index method. The results showed that the average contents of Cd, Cr, Zn, Ni, Cu, Pb and As in the soil were 1.25, 62.96, 79.00, 28.91, 22.60, 11.02 and 42.25mg/kg, respectively. Cd and As in soil exceeded the standard, and the exceedance rate was 92.75% and 83.5%. The single factor pollution index was Cd>As>Cr>Zn>Cu>Ni>Pb from large to small, and Cd reached the moderate pollution level. The results of Nemerow comprehensive pollution index showed that Cd reached the level of severe pollution, and As was the level of severe pollution. The evaluation results of potential ecological risk index showed that Cd was at the moderate risk level, As was at the slight risk level, and other heavy metals were at the slight risk level. The comprehensive potential ecological risk index RI value was 13.87-266.80, which was at the slight to moderate risk level. Cd and As were the main risk sources of soil heavy metals, and their contribution rates to the comprehensive potential ecological risk index were 79% and 18%, respectively.

KEYWORDS

Farmland soil; Heavy metal content; Risk assessment.

1. INTRODUCTION

Soil is the most important ecosystem component in human survival and development, and it is also an important resource for people to carry out agricultural production activities. Soil security is the fundamental guarantee for national food security and human health^[1]. With the acceleration of industrialization and urbanization, the problem of soil pollution has become increasingly prominent^[2, 3]. After entering the soil, heavy metals can exist for a long time and accumulate continuously, and migrate and accumulate through plants into the food chain, causing harm to human health^[4]. According to the National Soil Pollution Survey Communique jointly issued by the Ministry of Environmental Protection and the Ministry of Land and Resources in 2014, the excess rate of heavy metal pollution in farmland soil has reached 19.4%, with cadmium (Cd) as the main pollutant, while the latest soil pollution report analysis in China's major grain producing areas shows that the excess rate of heavy metal has reached 21.49%^[5, 6]. Therefore, it is of great practical significance to evaluate soil heavy metal pollution and its health risk.

Jiaozuo is located in the northwest of Henan Province, near the Taihang Mountain in the north and the Yellow River in the south. It is a famous coal resource city and an important grain production

core area in China. In this study, farmland soil in the southern suburbs of Jiaozuo was taken as the research object, and the status of heavy metal pollution was analyzed through field investigation and laboratory sample analysis. On this basis, the single factor index method, Nemerow comprehensive pollution index method and potential ecological risk index method were used to evaluate the potential ecological risk of heavy metals in this area, in order to provide scientific basis for regional environmental pollution prevention and residents' health assessment.

2. MATERIALS AND METHODS

2.1. Overview of the study area

Jiaozuo is located in the northwest of Henan Province, south of Taihang Mountain, east of Xinxiang, west of Jiyuan, south of the Yellow River and Luoyang, Zhengzhou, north of Taihang Mountain and Shanxi Province, the geographical coordinates of 35°10'-35°21' north, 113°4' -113°26' east diameter, the total area of about 4071.1 square kilometers. Jiaozuo is located in the warm temperate continental monsoon climate, with an average annual temperature of 15.2°C and an average annual precipitation of 544 mm. The land area of Jiaozuo is 407,100 hectares, and the agricultural land area of the city is 269,000 hectares, among which the cultivated land area is 192,700 hectares, accounting for 48.17% of the total land area of Jiaozuo. The study area is located in a farmland in the southern suburb of Jiaozuo, Henan Province.

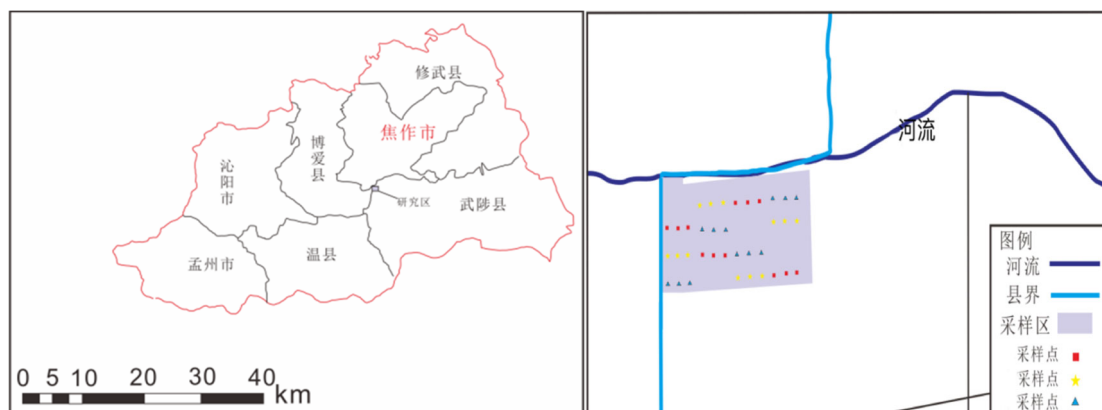


Figure 1. Location of study area and distribution of sampling points

2.2. Sample collection and processing

The farmland in the sampling area was divided into 12 zones with 3 sampling points in each zone, totaling 36 sampling points. The distribution of sampling points is shown in Figure 1. Each soil sampling point selected 1m² square sampling cell, each cell collected four vertex and center depth of about 0-20 surface soil, remove the surface humus and rocks, mixed evenly, take about 1 kg of soil, put it into a ziplock bag, number and record the sampling point information. After the samples are brought back to the laboratory, the debris, roots, and fallen leaves in the soil samples are removed, and the soil is placed in the indoor ventilated place to air dry naturally, during which direct sunlight and external pollution should be avoided. The air-dried soil samples were ground repeatedly and passed through 60 mesh and 100 mesh nylon screens successively. The screened soil samples were bagged and labeled to be measured.

2.3. Sample analysis and determination

The content of heavy metals in soil was determined according to the relevant national standard methods, and the soil samples were digested by HCL-HNO₃-HF-HCLO₄, and then analyzed by inductively coupled plasma emission spectrometer (ICP-OES).

The reagents used in the experiment were all of excellent purity. All soil samples were extracted and analyzed in parallel twice, and the results were averaged.

2.4. Heavy metal pollution assessment methods

2.4.1. Single factor pollution index method

Single factor index method (P_i) refers to the ratio of the measured value of the pollutant in the environmental medium to the standard value of the risk control of the pollutant, which can directly reflect the pollution degree of a pollution factor, and is one of the methods widely used in the world. The calculation formula is:

$$P_i = C_i/S_i. \quad (1)$$

In Formula 1, P_i is the single factor pollution index of heavy metal i in soil, C_i is the actual measured value of heavy metal i , S_i is the standard value of heavy metal i in soil. In this paper, soil Environmental Quality - Standard for the Control of Agricultural Land Soil Pollution Risk (Trial) (GB15618-2018) is selected as the reference standard. According to the pollution grade and pollution status can be determined, the pollution grade classification standard[7] is shown in Table 1.

2.4.2. Nemerow comprehensive pollution index method

Nemerow comprehensive pollution index method can comprehensively reflect the average pollution degree of heavy metal elements in soil. This method takes into account the highest value and average value of single-factor pollution assessment, and highlights the impact of high concentration of pollutants in soil on soil environmental quality. The grading evaluation criteria^[8] are shown in Table 1. The formula of Nemerow comprehensive pollution index method is as follows:

$$P_c = \sqrt{\frac{(\bar{P}_i)^2 + (P_{imax})^2}{2}}. \quad (2)$$

Where: P_c to sum up is the soil heavy metal comprehensive pollution index; \bar{P}_i is the average value of the single factor pollution index of heavy metal elements; P_{imax} is the maximum single-factor pollution index of different kinds of heavy metal elements.

Table 1. Classification standard of soil heavy metal pollution assessment

Rank division	I	II	III	IV	V
Single factor pollution index (P_i)	$P_i < 0.7$	$0.7 \leq P_i < 1$	$1 \leq P_i < 2$	$2 \leq P_i < 3$	$P_i \geq 3$
Nemerow Composite pollution Index (P_c)	$P_c < 0.7$	$0.7 \leq P_c < 1$	$1 \leq P_c < 2$	$2 \leq P_c < 3$	$P_c \geq 3$
Pollution degree	Clean (safe)	Still clean (warning limit)	Light pollution	Moderate pollution	Heavy pollution

2.4.3. Potential ecological risk index method

Potential ecological risk index method is a method proposed by Swedish scholar Hakanson for evaluating soil pollution degree and ecological risk. This evaluation method not only includes the

content level of heavy metals in soil, but also combines the toxic effects of heavy metals with environmental effects^[9, 10]. The calculation formula of this method is as follows:

$$RI = \sum_{i=1}^m E_r^i = \sum_{i=1}^m (T_r^i \times P_i). \quad (3)$$

In the formula, P_i is the single factor pollution index of the i metal, and T_r^i is the toxicity coefficient of the i metal. The size of the toxicity coefficient^[11] is shown in Table 2, E_r^i is the single potential ecological risk index of the i metal, and RI is the comprehensive potential ecological risk index of multiple heavy metals. Individual potential ecological risk coefficient and comprehensive potential ecological risk coefficient are divided into different levels of ecological risk^[12], as shown in Table 3.

Table 2. Toxicity Coefficient of different heavy metal pollutants

Types of heavy metals	Cr	Ni	Cu	Zn	Cd	Pb	As
Toxicity coefficient	2	5	5	1	30	5	10

Table 3. Potential ecological risk level standard

Risk index	Ecological risk degree				
	Slight risk	Medium risk	Medium strong risk	Strong risk	Very strong risk
E_r^i	$E_r^i < 40$	$40 \leq E_r^i < 80$	$80 \leq E_r^i < 160$	$160 \leq E_r^i < 320$	$E_r^i \geq 320$
RI	$RI < 150$	$150 \leq RI < 300$	$300 \leq RI < 600$	$RI \geq 600$	

3. RESULTS AND DISCUSSION

3.1. Heavy metal content in soil

The statistical table of heavy metal content in farmland soil in the study area is shown in Table 4 and Figure 2. The average heavy metal content in farmland soil in the study area is $Zn > Cr > As > Ni > Cu > Pb > Cd$ in descending order, in which the average content of Cd, Cr, Zn, Ni, Cu and As exceeds the soil background value of Henan Province^[13]. Compared with the "Soil Environmental Quality Agricultural land Soil pollution Risk Control Standard" (GB15618-2018), only As and Cd exceed the standard. The content of As was 3.36-77.00mg/kg, and the over-standard rate was 83.5%. The content of Cd was 0.19-2.96mg/kg, and the over-standard rate was 92.75%. From the perspective of coefficient of variation, the coefficient of variation of Cd, Cr, Zn, Ni, Cu, Pb and As 7 heavy metals in surface farmland soil in the study area was 0.56, 0.21, 0.26, 0.22, 0.28, 0.33 and 0.35, respectively, and the degree of variation was as follows: $Cd > As > Pb > Cu > Zn > Ni > Cr$, in which Cd is highly variable^[14], indicating that Cd is obviously influenced by human activities in soil. The remaining elements belong to the moderate variation, the degree of dispersion is low, and the influence of human activities is small. Wheat and corn are mainly planted in the study area all the year round, and human activities are frequent. The application of chemical fertilizers, pesticides and other agricultural production activities may lead to the accumulation of As and Cd in the soil^[15], which is also one of the reasons for the excessive heavy metals in the soil in the study area.

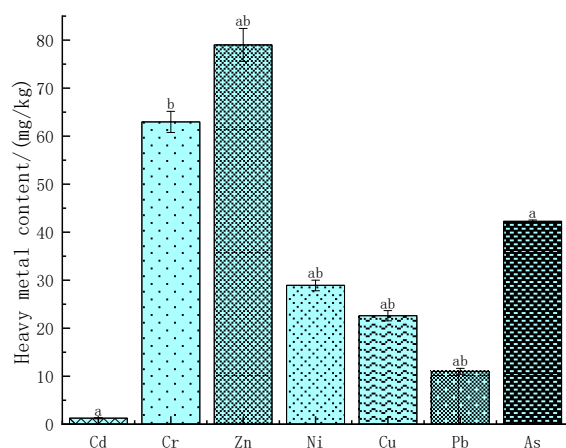


Figure 2. Heavy metal content of farmland soil in test area

Table 4. Heavy metal content of farmland soil in test area

Heavy metal	Radius (mg/kg)	Mean value (mg/kg)	Standard deviation (mg/kg)	Background value (mg/kg)	Coefficient of variation (mg/kg)	Screening value (mg/kg)	Control value (mg/kg)
Cd	0.19-2.96	1.25	0.70	0.09	0.56	0.6	4.0
Cr	31.02-87.63	62.96	13.06	53.60	0.21	250	1300
Zn	29.96-116.03	79.00	20.26	65.10	0.26	300	—
Ni	14.28-40.87	28.91	6.50	24.90	0.22	190	—
Cu	8.70-36.99	22.60	6.30	21.60	0.28	100	—
Pb	3.70-19.13	11.02	3.59	14.40	0.33	170	1000
As	3.36-77.00	42.25	14.96	12.94	0.35	25	100

3.2. Soil heavy metal risk assessment

3.2.1. Nemerow pollution index method

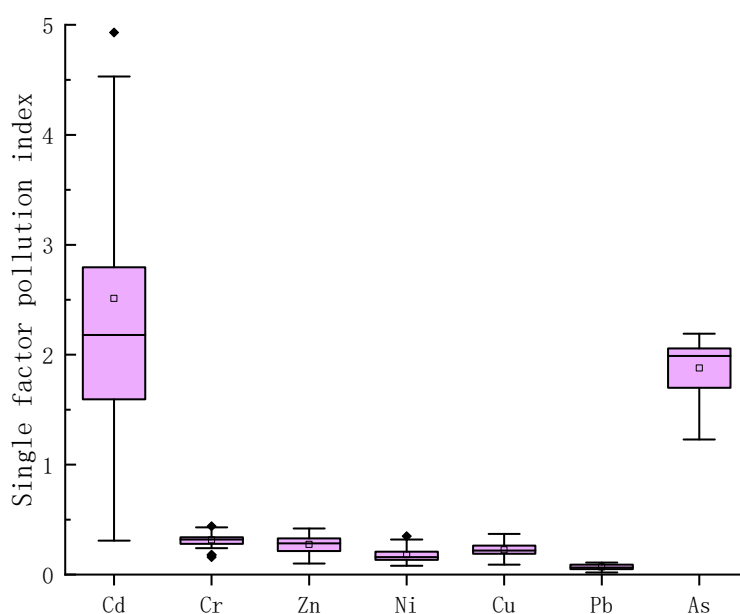


Figure 3. Soil monofactor pollution index in the research area

The results of single factor pollution index showed that Cd (2.51) >As (1.69) >Cr (0.31) >Zn (0.27) >Cu (0.23) >Ni (0.18) >Pb (0.07). Among them, Cd pollution was at a moderate level, with the highest value reaching 7.73. As pollution is at a light level, with a maximum value of 3.08. The mean P_i of the single factor pollution index of the remaining elements Cr, Zn, Ni, Cu and Pb is less than 0.7, which belongs to the clean level. Cd is the main excessive factor of heavy metal pollution in farmland soil in the study area. Nemero comprehensive pollution index evaluation showed the same results, Cd pollution was the most serious, reaching the level of severe pollution, As reached the level of moderate pollution. Zhang Jing et al.^[16] have shown that heavy metals in soil pollution in Jiaozuo are mainly Cd, Hg, Pb and Zn, among which Cd has the highest over-standard rate and the most serious pollution, which should be paid attention to.

Table 6. Pollution degree in the study area

Evaluation index	Cd	Cr	Zn	Ni	Cu	Pb	As
Average single factor index (P_i)	2.51	0.31	0.27	0.18	0.23	0.07	1.69
Maximum factor index	7.73	0.44	0.42	0.35	0.37	0.11	3.08
Nemero Composite pollution Index ($P_{综}$)	5.75	0.38	0.35	0.28	0.31	0.09	2.48
Pollution degree	severe	clean	clean	clean	clean	clean	moderate

3.2.2. Potential ecological risk index method

According to the average value of the potential ecological risk index of a single element, the heavy metal risk of farmland soil in the study area was Cd>As>Cu>Ni>Cr>Pb>Zn from high to low (Table 7). The mean values of Cd and As are 75.42 and 16.90, respectively, which are medium risk and slight risk. The mean values of the other 5 heavy metals are all less than 2, which are slight risk levels.

The comprehensive potential ecological risk index (RI) of heavy metals in farmland soil in the study area was 13.87-266.80, which was at the slight to moderate risk level. Cd and As were the main risk sources of heavy metals in soil, and their contribution rates to the comprehensive potential ecological risk index were 79% and 18%, respectively. The average contribution of the other five heavy metals to the comprehensive potential ecological risk index was only 3%. Based on potential ecological risk assessment, Cd is the main source of heavy metals in the study area, which is consistent with the characteristics of heavy metal pollution in farmland soil^[17]. Xin Jiahui et al.^[18] also showed that Cd was the most important risk source in agricultural areas of the riverfront soil heavy metal pollution risk assessment of the Middle route of the South-to-North Water Transfer Project. Moreover, studies have shown^[19] that Cd in farmland soil has the same source or is affected by the same external factors as Cd in the sediment of surrounding rivers, or the change of Cd content in farmland soil is affected by Cd in the sediment of rivers. Therefore, it is considered that the possible sources of heavy metal pollution in the study area are mainly the heavy metal residues in the irrigation of the surrounding rivers and fertilizers.

Table 7. Er、RI and risk level of heavy metals in farmland soils in the study area

Statistical value	Potential ecological risk index E_r^i							Integrated potential ecological risks / (RI)
	Cd	Cr	Zn	Ni	Cu	Pb	As	
Maximum value	232.00	0.88	0.42	1.74	1.85	0.56	30.80	266.80
Minimum value	9.35	0.31	0.10	0.38	0.44	0.11	1.34	13.87
Mean value	75.42	0.63	0.27	0.90	1.13	0.35	16.90	95.60
Degree of risk	intermediate	slight	slight	slight	slight	slight	slight	slight

4. CONCLUSIONS

(1) From the point of view of heavy metal content, the average content of heavy metal elements in farmland soil in the study area from large to small is: Zn > Cr > As > Ni > Cu > Pb > Cd. From the point of view of the coefficient of variation, the coefficient of variation of heavy metals in soil is Cd > As > Pb > Cu > Zn > Ni > Cr, in which Cd reaches a high degree of variation, indicating that Cd is most obviously affected by human activities in soil in the study area. The remaining elements belong to the moderate variation, the degree of dispersion is low, and the influence of human activities is small. The average contents of Cd, Zn, Ni, Cu, Pb and As in the soil of the study area were higher than the background values of Henan Province, and there was an obvious accumulation phenomenon, in which Cd and As exceeded the standard, and the exceedance rates were 88.89% and 87.5%, respectively.

(2) The evaluation results of single factor pollution index showed that the heavy metal Cd pollution of farmland soil in the study area was at a moderate level, with the highest value reaching 7.73; As pollution was at a light level, with a maximum value of 3.08. The remaining elements Cr, Zn, Ni, Cu and Pb belong to clean levels. From the comprehensive pollution index, Cd reaches the level of heavy pollution, As reaches the level of light pollution, and the remaining elements belong to the clean or still clean level.

(3) The evaluation results of potential ecological risk index method showed that the heavy metal risk of farmland soil in the study area was as follows from high to low: Cd>As>Cu>Ni>Cr>Pb>Zn, RI results showed that Cd and As were the main risk sources of soil heavy metals, which were at medium risk level and slight risk level respectively, and their contribution rates to the comprehensive potential ecological risk index were 79% and 18%, respectively, while the average contribution rates of the other 5 heavy metals to the comprehensive potential ecological risk index were only 3%.

The evaluation results of Nemero comprehensive pollution index method and potential ecological risk index method both show that Cd is the main risk source of heavy metals in farmland soil in the study area. Therefore, we should focus on strengthening the control and prevention of Cd in farmland soil in the study area. As element also has a certain degree of pollution, which should also be paid attention to.

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