The Risk Characteristics of Heavy Metals in Urban Soil

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The risk characteristics of heavy metals in urban soil

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Abstract: With the rapid development of China's industrial economy, heavy metals and other pollutants continue to accumulate in the environment, which has created serious threats for the ecological environment and human health. To comprehensively evaluate the ecological risks from heavy metals in the soil in Nanjing, China, as well as the status of the risks to human health, this study randomly collected 50 surface soil samples, and the contents of Al, Ca, Fe, Mg, Mn, Ni, Ti, Cd, Cr, Cu, Pb and Zn in the samples were determined, combined with the ecological risk index and the USEPA health risk assessment model for a comprehensive risk assessment of soil heavy metals in Nanjing. The results show that there has been heavy metal enrichment of Mn, Pb, Zn and other heavy metals in the research area in Nanjing city, and the variation coefficients of Pb and Cu are distinctly large; that is, the distribution of Pb and Cu in the research area shows a great fluctuation. These elements are all slightly polluting, among which the Cu heavy metal pollution degree is different, and Pb element pollution is the most serious. Children are at a high risk of exposure in various ways, among which Pb and Cu elements have a high risk of causing non-carcinogenic issues. Overall, Pb and Cu in Nanjing are important risk elements that should be monitored and controlled. The results of the correlation analysis showed that the content changes of Pb, Zn and Cu; Ni, Ti and Fe; and Zn and Pb had extremely significant correlations, indicating that they may have the same source; while Ti and Ca, Ti and Cu, and Pb and Zn showed opposite changes, indicating that their concentrations were inversely related. The results of the principal component analysis showed that industrial sources in Nanjing contributed the most heavy metals, reaching 34.4%. The second largest source was from parent material and fertilizer, which contributed 32.3% and 19.6%, respectively. The sources with the lowest contributions were from weathering and deposition, which reached 13.7%.
Keywords: Nanjing city, soil, heavy metals, ecological risk, health risk

1. Introduction

Heavy metal pollution has had a large impact on a global scale. With the development of China's industrialization process, serious heavy metal pollution problems have emerged in the soil in urban areas. For example, smelters emit heavy metals through the combustion of fossil fuels and industrial emissions. The dust produced by smelters pollutes the surrounding soil with heavy metals [1]. In China, light and heavy metal pollution in soil accounts for 13.12% and 10.82% of the pollution, respectively, indicating that the problem of heavy metal pollution is not positive [2]. Heavy metal pollution is closely related to people's daily lives. Heavy metal elements in the soil may be mixed in dust and enter the human body through breathing, thus causing diseases, or they may discharge into the water, thereby polluting the water supply, which, in the case of humans, can lead to excessive levels of heavy metals in drinking water. In animals and plants, heavy metals can lead directly to death[3]. In addition, if crops are planted on land contaminated with heavy metals, heavy metal elements will also enter the human body through grain [4]. For example, if rice is planted in soils contaminated with lead and cadmium, there will also be a certain amount of heavy metals in the rice [5]. In addition, heavy metals have a long half-life and are not easy to degrade. Trace amounts of heavy metals can also cause harm to the human body, and serious cases may lead to the destruction of the central nervous system in the human body [6]. Soil heavy metals are a serious threat to the urban ecological environment and the health of urban residents; however from the view of large cities such as Nanjing, research on soil heavy metals has obvious deficiencies. (1) Sampling studies and their test data are many years old and were conducted when the economy of Nanjing was rapidly developing and its city population was rapidly increasing; therefore, new data on the heavy metals in the urban soil in Nanjing are urgently needed. (2) Research studies on the risk of heavy metals in urban soils have generally only considered ecological risk or human health risk assessments separately; thus, there is a lack of studies using both evaluation systems.

Based on this, in this study, we collected soil samples in Nanjing to detect the heavy metal composition of the soil and to analyse the degree of heavy metal pollution in the city soil. Nanjing, the capital city of Jiangsu Province in China, is located in the Yangtze River Basin, has rich natural resources and is a well-known area for fish and rice in China. It has a dense population, a large resident population and a large number of universities. The study of the heavy metal content in the soil of Nanjing is not only beneficial to local residents but also plays a warning role regarding the control of heavy metal pollution. By detecting the corresponding data for Al, Ca, Fe, Mg, Mn, Ni, Ti, Cd, Cr, Cu, Pb and Zn (among which, the five elements: Cd, Cr, Cu, Pb and Zn, are used for the calculation of the single factor index and geoaccumulation index), the ecological and health risks are evaluated based on these data. Soil heavy metals are particularly important to the environment and to human health. This study aims to analyse the ecological pollution of heavy metals in urban environments to evaluate the health risks. We hope this research can establish ecological risks of heavy metals and health risk evaluation systems, providing a theoretical basis for the prevention and control of heavy metal pollution in urban environments.

2 Research Methods

2.1 Collection and Test

2.1.1 Collection of Soil Samples

On September 10, 2020, we collected soil samples in Nanjing. To avoid accidental error and unstable factor interference, the accumulation of soil samples was conducted as far away as possible from obvious sources of pollution such as waste soil to avoid collecting from newly created sources of pollution; thereby, excluding the surface composition of the soil, eluvial soil and rocks, man-made waste, weeds, and fertilizers , utilizing clean pollution-free tools to collect all soil samples and ensuring that the chemical composition was relatively stable and typical of the soil profile. Sampling depth of the surface soil was 0-20 cm [7]. During the sampling process, the "diagonal point arrangement method" was adopted to place three subsample points at each sampling point, and approximately 200 g of surface soil was collected at each subsample point, which was fully mixed and placed into a self-sealing bag. The geographical location, altitude and surrounding environmental conditions at the sample sites were recorded. The soil samples were transported to the laboratory to be air-dried, crushed, ground, and screened (100 mesh) for later use.

2.1.2 Determination of soil samples

Approximately 100 mg of ground soil sample was placed into a 25 mL polytetrafluoroethylene beaker for a series of digestion processes. The contents of Zn, Pb, Cu, Cr and Ni were measured using an Optima 5300DV inductively coupled plasma emission spectrometer (ICP-A×10S) produced by P×10rkin× 10LM × 10R, USA. The content of Cd was determined by an inductively coupled plasma mass spectrometer × 10LAN9000 (P×10rkin-× 10lm × 10r, Inc., USA). The ICP-A×10S and ICP-MS began to stabilize one hour after ignition and could be tested [8]. The best working conditions and the detection limits for the different elements were determined. To improve the accuracy of the elemental content test, standard material GBW07405 was tested every two samples for calibration.

2.1.3 Planning and Determination of Sampling Points

Nanjing is a typical industrial city with a serious problem of soil heavy metal pollution [9]. In 2019, Nanjing had a permanent population of 8.50 million people, including 7.072 million urban residents, accounting for 83.2 percent of the total urban population. It has a real population of 10,312,200 people. The influence of heavy metal pollution on human health has always been the focus of social problems. To study the main activity area surrounding the heavy metal pollution area, we conducted gradient stationing in urban, suburban, village and town areas using satellite images and field investigations. According to population density and commercial prosperity, we determined 50 soil-sampling sites. The sampling distribution is shown in Figure 1.

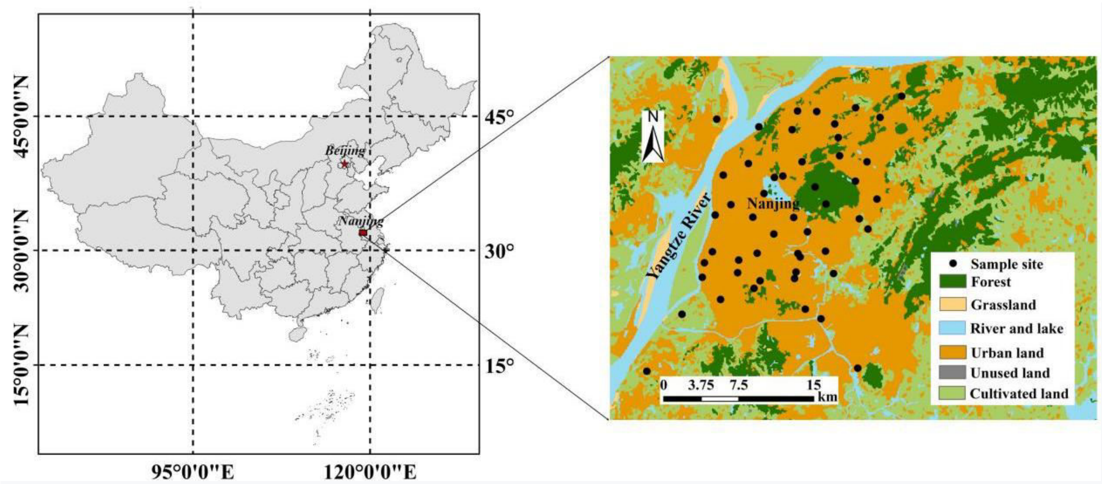

FIG. 1 Distribution of sampling points.

2.2.1 Principal component analysis

The factor analysis program in IBM SPSS Statistics 26 software was used to conduct principal component analysis on the original data after standardized processing. The purpose of principal component analysis is to describe the relationship between a variety of indicators or factors with a small number of factors. [10]

2.2.2 Evaluation of soil heavy metal pollution

The geoaccumulation index, single factor pollution index and Nemerow pollution index were used to comprehensively evaluate the degree of heavy metal pollution in the soil in Nanjing. German scientist Muller[11] proposed the geoaccumulation index method in 1969. He utilized the measured heavy metal content in the geochemical background value as the parameter. The heavy metals in the soil were classified into different levels according to the calculated ground accumulation index. The formula is as follows:

$$I_{geo} = log_2 \frac{C_i}{k \times B_i}$$

where I_{geo} is the cumulative index of the ground, Ci is the content of heavy metals in the measured soil samples, and Bi is the geochemical background value. K is the correction factor, usually 1.5. According to I_{geo}, there are seven levels of pollution (Table 1).

Table 1 Classification of cumulative index pollution

I_{geo}	Pollution degree	Pollution level
≤0	0	No pollution
0~1	1	Light pollution
1~2	2	Moderate pollution
2~3	3	Moderate pollution - high pollution
3~4	4	Strong pollution
4~5	5	Heavy pollution - extremely high pollution
>5	6	extremely high pollution

The single factor pollution index method directly reflects the cumulative degree of pollution of a certain heavy metal in the soil [12]. The formula is as follows:

$$P_i = C_i / S_i$$

where P_i is the single factor pollution index of an element in the soil, C_i is the measured concentration of an element, and S_i is the evaluation standard of a heavy metal element. In this paper, the Nanjing soil background value is selected as the evaluation standard [13]. The Nemerow pollution index method can reflect the average pollution degree and environmental quality of heavy metals in the soil [14] to evaluate the impact of pollutants on the soil. The formula is:

$$P = \sqrt{\frac{(\bar{P_i})^2 + (P_{imax})^2}{2}}$$

where P is the Nemerow pollution index of soil heavy metal elements, $\bar{P_i}$ is the average value of the single factor pollution index of an element, and P_{imax} is the maximum value of the single factor pollution index of an element. The ratings are as follows (Table 2).

Table 2 Soil heavy metal pollution classification standards

Hierarchy	I	II	III	IV	V
Single factor pollution index (P_i)	$P_i \le 0.7$	$0.7 < P_i \le 1$	$1 < P_i \le 2$	$2 < P_i \le 3$	$P_i \ge 3$
Nemerow pollution index (P)	$P \le 0.7$	$0.7 < P \le 1$	$1 < P \le 2$	$2 < P \le 3$	$P \ge 3$
Pollution levels	Clean (Safety)	Clean (Warning)	Light pollution	Moderate pollution	Heavy pollution

2.2.3 Potential ecological risk index

In this study, the Hakanson potential ecological risk index method [15] was adopted to evaluate the risk degree of heavy metals in the soil in Nanjing. This method combines ecology, biochemistry and other aspects to evaluate the potential ecological risk from heavy metals. The formula is as follows:

$$C_f^i = \frac{C^i}{C_n^i}$$

$$E_r^i = T_r^i \times C_f^i$$

$$RI = \sum_{i=1}^{m} E_r^i$$

where C_f^i is the pollution coefficient of a single heavy metal; C^i is the content of heavy metals in the samples measured experimentally; and C_n^i is the reference ratio of heavy metal pollutant i. In this study, the Nanjing soil background value [10] was used as the reference ratio, T_r^i is the corresponding toxicity coefficient of pollutant i, and the toxicity coefficient of each heavy metal is Cd=30, Cu=Ni=Pb=5, Cr=2, and Ti=Zn=Mn = 1[16~17].

E_r^i is the potential ecological risk index of a single heavy metal element i, and RI is the comprehensive potential ecological risk index of various heavy metals in the study area. The Hakanson method delineates the scope of RI and determines the specific pollution levels as follows (Table 3).

Table 3 Potential ecological risk levels using the Hakanson method

The degree of risk	Minor ecological risk	Medium ecological risk	Strong ecological risk	Very strong ecological risk	Extremely strong ecological risk
E_r^i	E_r^i<40	40≤E_r^i<80	80≤E_r^i<160	160≤E_r^i<320	E_r^i≥320
RI	*RI* <150	150≤*RI* <300	300≤*RI* <600	*RI*≥600	

2.3 Health risk assessment methods

Yushan Wang et al.[18], based on the USEPA health risk assessment model[19], utilized formulas and parameters based on soil particles ingested via the mouth, skin contact and breathing, using the three aspects of soil particles, to calculate for three groups of people (adult men, adult women and children) the exposure pathways and exposure levels of a single heavy metal in the soil particles. Then, the non-carcinogenic risk of individual heavy metals was calculated, analysed and evaluated.

3 Results and analysis

3.1 Descriptive statistics of heavy metal content in Nanjing soil

The descriptive statistics of heavy metals in the study area in Nanjing city in this study are shown in Table 4. The results show that the average contents of Cd, Cr, Cu, Mn, Ni, Pb, Ti and Zn were 0.12, 72.39, 36.77, 683.03, 32.64, 32.66, 4648.46, and 109.82 mg/kg, respectively, which were 1.39 times the corresponding soil background values in Nanjing. The average contents of Cu, Mn, Pb and Ti heavy metals in the soil samples were higher than those of the Nanjing soil background values. The over-standard rates of Mn, Pb and Zn were 54.00%, 64.00% and 76.00%, respectively. This indicates that Mn, Pb, Zn and other heavy metals were enriched in the study area in Nanjing.

The coefficient of variation can reflect the difference in variation of soil heavy metal contents at different sampling points, the deviation at different points and their influence on human daily life or industry [20]. As seen in Table 1, the coefficient of variations were ranked as Pb > Cu > Zn > Mn > Cd > Ni > Cr > Ti, among which Ti, Cr, Ni and Cd all had relatively small coefficients of variation, with values between 10% and 20%, indicating that these elements were relatively evenly distributed in the study area [21]. The variation coefficients of Pb and Cu were 67.96% and 59.76%, respectively, indicating that the distribution of Pb and Cu in the study area fluctuated greatly and was subject to great human disturbance.

The above analysis shows that the pollution problem of Cd, Cr, Ni and Ti was not obvious in the study area in Nanjing. The mean value of the heavy metal content of Mn was slightly higher than the mean value, and the coefficient of variation was slightly higher, which requires more attention. The point over-standard rate and variation coefficient of Pb in the soil samples were relatively large and should be given more attention.

Table 4 Descriptive statistics of heavy metal content in soil in Nanjing city

Sample	Cd	Cr	Cu	Mn	Ni	Pb	Ti	Zn
Average/（mg/kg）	0.12	72.39	36.77	683.03	32.64	32.66	4648.46	109.82
Standard deviation/(mg/kg)	0.02	8.50	23.92	202.26	5.43	22.19	454.94	65.63
Maximum/(mg/kg)	0.17	97.49	168.04	1922.79	55.74	152.44	5427.34	466.83
Minimum/(mg/kg)	0.07	48.88	9.78	417.78	20.52	13.01	3110.97	43.12
Coefficient of variation/%	17.06	11.74	65.06	29.61	16.63	67.96	9.79	59.76

Background value of soil in Nanjing/(mg/kg-1)	0.14	83.00	31.00	639.00	40.00	23.00	5175.00	79.00
Point over-standard rate/%	12.00	8.00	50.00	54.00	6.00	64.00	8.00	76.00

3.2 Spatial distribution characteristics of heavy metals in soil

ArcGIS10.0 software was used to perform inverse distance interpolation analysis on the content of all heavy metals (Fig. 2).

According to Fig. 2, Al, Cd and Cr had similar spatial distribution characteristics,: heavy metals were on the high side in the central and western parts of the study area, and the spatial distribution characteristics of Cu, Pb and Zn were similar. The higher concentration was mainly distributed in the middle part of the study area. In general, the concentrations of Al, Cd and Cr were higher than those of Cu, Pb and Zn. The high value areas of heavy metals were mainly distributed in the central and western regions, showing a patch-like distribution and decreasing trend from west to east.

Central China is densely populated, railway stations and subway stations are concentrated, and energy consumption and sewage gas discharge are large, which have led to a high content of heavy metals in the soil in the central and some western regions.

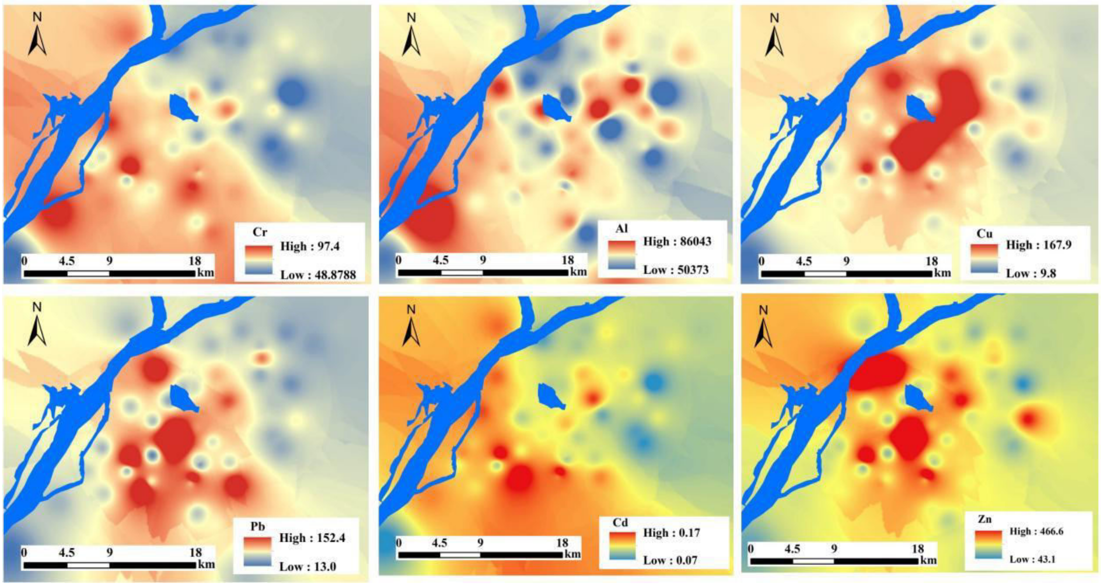

FIG. 2 Spatial distribution of heavy metals in soils in Nanjing.

3.3 Principal component analysis

The factor analysis program in IBM SPSS Statistics 26 software was used to conduct principal component analysis after the standardized processing of the original data. The purpose of principal component analysis is to explain the phenomena in terms of major factors. In principal component analysis, correlation analysis of the original variables is required [22]. As shown in Table 5, the correlation coefficient matrix among 12 variables was calculated, and Pearson correlation among elements was analysed.

3.3.1 Correlation analysis

The results showed (Table 5) that at the 0.01 level (double tailed), the contents of Cd, Cr, Fe, Ni and Al; Cu, Mg, Pb, Zn and Ca; Cr, Fe, Ni and Cd; Fe, Ni, Ti and Cr; Pb, Zn and Cu; Ni, Ti and Fe; and Zn and Pb showed a significant c orrelation, indicating that each of these elements within the same grouping has the same tendency to change as the other elements in the same grouping and that they may have the same source. Ti and Ca; Ti and Cu; and Pb and Zn show opposite changes, indicating that their concentrations are inversely related. At the 0.05 level (double tailed), the contents of Ni and Mn; Pb, Ti, Zn and Cd; and Al, Ni, Cd and Ti are significantly correlated, and they may have come from the same source.

Table 5 Correlation of heavy metal elements

	Al	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Ti	Zn
Al	1	-0.006	0.475**	0.461**	0.099	0.655**	-0.004	-0.015	0.431**	-0.115	0.310*	0.002
Ca		1	0.21	0.032	0.427**	-0.061	0.621**	-0.042	-0.081	0.465**	-0.652**	0.493**
Cd			1	0.699**	0.258	0.770**	0.041	0.061	0.528**	0.348*	0.286*	0.315*
Cr				1	0.139	0.721**	0.054	0.109	0.683**	0.214	0.489**	0.216
Cu					1	0.21	0.029	0.097	0.274	0.827**	-0.438**	0.869**
Fe						1	-0.034	0.037	0.527**	0.135	0.537**	0.149
Mg							1	-0.084	-0.077	-0.014	-0.238	0.022
Mn								1	0.292*	0.116	0.168	0.098
Ni									1	0.221	0.298*	0.26
Pb										1	-0.454**	0.915**
Ti											1	-0.468**
Zn												1

Note: "**." indicates a significant correlation at the level of 0.01 (double tailed). "*." indicates a significant correlation at the level of 0.05 (double tailed).

3.3.2 Principal component analysis

According to the results of the principal component analysis, four effective principal factors were extracted, which were Al, Ca, Cd and Cr, and their variance contributions accounted for 33%, 28%, 13% and 8% of the total variance, respectively. From the component matrix in Table 6, we can see how much information reflecting an element is extracted by the principal component. The principal component can be expressed as a linear combination of each element:

The first principal component:

$$0.520Z\ Al+0.317Z\ Ca+0.815Z\ Cd+0.764Z\ Cr+0.645Z\ Cu+0.752Z\ F\times 10+0.058Z\ Mg+0.187Z\ Mn+0.707Z\ Ni+0.637Z\ Pb+0.104Z\ Ti+0.664Z\ Zn \quad (1)$$

The second principal component:

$$0.451ZAl-0.689ZCa+0.245ZCd+0.423ZCr-0.601ZCu+0.499ZF\times 10-0.286ZMg+0.073ZMn+0.322ZNi-0.649ZPb+0.909ZTi-0.650ZZn \quad (2)$$

The third principal component:

$$0.277ZAl+0.542ZCa+0.179ZCd+0.121ZCr-0.238ZCu+0.135ZF\times10+0.810ZMg-0.419ZMn-0.163ZNi-0.289ZPb-0.095ZTi-0.243ZZn \quad (3)$$

The fourth principal component:

$$-0.189ZAl+0.173ZCa-0.070ZCd+0.080ZCr-0.120ZCu-0.162ZF\times10+0.375ZMg+0.830ZMn+0.220ZNi-0.069ZPb+0.077ZTi-0.087ZZn \quad (4)$$

It can be seen from (1), (2), (3) and (4) that the contents of heavy metal elements Cd, Cr, Fe and Ni in the first principal component contributed greatly, and this pollution may have come from industrial wastewater from mines and smelting. Therefore, the first principal component was determined to be an industrial pollution source. The contents of Ti and Fe in the second principal component contributed greatly, and these elements were labelled characteristic elements of the soil parent material. Therefore, the second principal component was determined to be the source of parent material [10]. Mg and Ca contributed more to the third principal component, which are the main components of common fertilizers, and the third principal component was determined as the source of fertilizers [22]. Mn and Mg contributed more to the fourth principal component, and these two elements represent precipitation and a combination of processes of Fe and Mn in the soil-weathering process [22]. Therefore, the fourth principal component was judged as the weathering and deposition source. The element distribution is regional, and the main heavy metal elements in different regions are different. According to the principal component analysis, the industrial contribution of heavy metals in Nanjing soil was the largest, reaching 34.4%. The parent material and fertilizer sources contributed 32.3% and 19.6%, respectively, and the weathering and deposition sources contributed 13.7%.

Table 6 Component matrix [a]

Element	Composition			
	1	2	3	4
Al	0.52	0.451	0.277	-0.189

Ca	0.317	-0.689	0.542	0.173
Cd	0.815	0.245	0.179	-0.07
Cr	0.764	0.423	0.121	0.08
Cu	0.645	-0.601	-0.238	-0.12
Fe	0.752	0.499	0.135	-0.162
Mg	0.058	-0.286	0.81	0.375
Mn	0.187	0.073	-0.419	0.83
Ni	0.707	0.322	-0.163	0.22
Pb	0.637	-0.649	-0.289	-0.069
Ti	0.104	0.909	-0.095	0.077
Zn	0.664	-0.65	-0.243	-0.087

a. Four components were extracted.

Table 5 Total variance interpretation

	Initial eigenvalue			Sum of squares of the extraction load		
Composition	Total	Percentage of variance	Cumulative %	Total	Percentage of variance	Cumulative %
1	3.995	33.29	33.29	3.995	33.29	33.29
2	3.389	28.242	61.531	3.389	28.242	61.531
3	1.502	12.518	74.049	1.502	12.518	74.049
4	1.014	8.449	82.498	1.014	8.449	82.498
5	0.649	5.406	87.904			
6	0.502	4.18	92.084			
7	0.367	3.061	95.145			
8	0.231	1.927	97.072			
9	0.127	1.057	98.129			
10	0.09	0.747	98.876			
11	0.077	0.643	99.519			
12	0.058	0.481	100			

3.4 Ecological risk assessment of heavy metals in Nanjing soil

The pollution index of each heavy metal was calculated based on the soil background value of Nanjing that was used as the evaluation standard. From the perspective of the single factor pollution index, the average value of the single factor pollution index of Cd was 0.83, which was the lowest among the five heavy metals, representing a clean soil in regard to Cd. The average value of the Cr single factor pollution index was 0.88, indicating light pollution. The average value of the Cu single factor pollution index was 1.19, which represents light pollution. The maximum value was 5.42, far greater than 3, which indicates heavy pollution. The minimum value was 0.32, which was lower than the minimum values of Cd and Cr and indicates no pollution. The average value of the single factor pollution index of Pb was 1.42, which was the highest among the five heavy metals, which indicates light pollution; the maximum value was 6.63, representing heavy pollution, which was also the maximum value of a single factor pollution index of all heavy metals; and the minimum value was 0.56, indicating a clean soil in regard to Pb. There were also differences between Pb heavy metals in different regions in Nanjing. The average value of the Zn single factor pollution index was 1.39, indicating light pollution; the maximum value was 5.91, indicating heavy pollution; and the minimum value was 0.54, indicating a clean level. In terms of the average value of the single factor pollution index, the pollution degree of different heavy metals was ranked as Pb> Zn> Cu> Cr> Cd, indicating that Pb was the most serious heavy metal polluting element in Nanjing. Pb pollution can cause serious harm to the soil, human body, crops and economy. Therefore, Nanjing should give attention to the Pb metal pollution.

According to the Nemerow pollution index of each heavy metal, the pollution index of different heavy metals ranged from 0.9 to 5. The pollution degree of each heavy metal varied greatly in Nanjing, indicating different pollution degrees. The highest pollution level was Pb, its Nemerow pollution index was 4.79, which indicates heavy pollution. The lowest pollution level was Ti, and its Nemerow pollution index was 0.98, which indicates a clean level. Among all heavy metals, Cu, Pb and Zn indicate a heavy polluted; Mn indicates a moderately polluted level; and

Cd, Cr and Ni indicate a mildly polluted level. According to the Nemerow pollution index of each heavy metal, the pollution degree in the Nanjing area was ranked as Pb>Zn>Cu>Mn> Ni>Cd=Cr>Ti.

According to the average single potential risk index of heavy metals, the potential ecological risks of the eight heavy metals in the Nanjing research area were ranked as Cd>Pb>Cu>Ni> Cr>Zn> Mn>Ti. The average single potential risk indices were 24.86, 7.10, 5.93, 4.08, 1.74, 1.39, 1.07, and 0.90, respectively, indicating slight ecological risk. The Ti single potential ecological risk index was less than 1, indicating the least degree of harm. The average Cd single potential risk index was 24.86, which was the most harmful but it had only a slight ecological risk, indicating that Cd was the most important ecological risk element in the Nanjing research area. In conclusion, the comprehensive potential ecological risk index was 47.07, which is above 40, reaching the level of medium potential ecological risk, which should be given more attention, and measures should be formulated to prevent the further aggravation of heavy metal soil pollution, especially the treatment of Cd heavy metal pollution.

Table 8 Each ecological risk index

	Nemerow pollution index		Single factor pollution index			Individual potential ecological risk index (× 10 ir)	
	Pollution index	hierarchy	Average	Maximum	Minimum value	Risk index	Risk classification
Cd	1.036538764	mild	0.83	1.21	0.53	24.86	slight
Cr	1.034446001	mild	1	1	1	1.74	slight
Cu	3.92367681	severe	1	5	0	5.93	slight
Mn	2.25798651	moderate				1.07	slight
Ni	1.141838431	mild				4.08	slight
Pb	4.792824096	severe	1.42	6.63	0.56	7.1	slight

Ti	0.97641134	clean				0.9	slight
Zn	4.2925241	severe	1.39	5.91	0.54	1.39	slight
comprehensive			0.5			47.08	medium

3.5 Health risk assessment of heavy metals in Nanjing soil

The concentration of heavy metals in 50 soil samples collected in Nanjing in this study was processed according to the USEPA health risk assessment model [15], and the exposure amount of a single heavy metal in the soil particle exposure pathway under the non-carcinogenic risk was obtained, as well as the results of its non-carcinogenic risk (Table 9).

According to the data in Table 9, the exposure amount of a single heavy metal in the exposure pathway of soil particles under three non-carcinogenic risks was analysed. Through the overall analysis of the average exposure amount and the analysis of oral intake exposure amount, except for Cd, the exposure amount was ranked as children > adult female > adult male. Skin contact exposure was analysed, except for Cu element, and the exposure was ranked as children > adult female > adult male. Inhaled soil particle exposure was analysed and ranked as children > adult male > adult female. In conclusion, children are exposed to large amounts of soil particles in various ways. Therefore, attention should be given to the health problems from heavy metals in children.

The mean values of the total non-carcinogenic risk (HI) to adult males, adult females and children were 3.14×10^{-6}, 3.25×10^{-6}, and 6.17×10^{-5}, respectively, which were the acceptable ranges (HI <1[23]). The total mean value (HI) of the risk-exposed population was ranked from low to high as adult males, adult females and children. This is consistent with the research results of Yushan Wang et al. [18]. Among these three groups of exposed people, the HQ average values of the four heavy metal elements selected in this study were ranked from high to low as HQ_{Cu}> HQ_{Pb}> HQ_{Cd}> HQ_{Zn}. Among them, the HI of Pb to adult males and adult females accounted for 54.29% and 55.89%, respectively.

In summary, the aggregate values of the non-carcinogenic risks of Cd, Cu, Pb and Zn in Nanjing are all within their acceptable ranges at present, and the contribution values of Pb and Cu to HI are relatively high. Therefore, the monitoring and control of Pb and Cu should be strengthened.

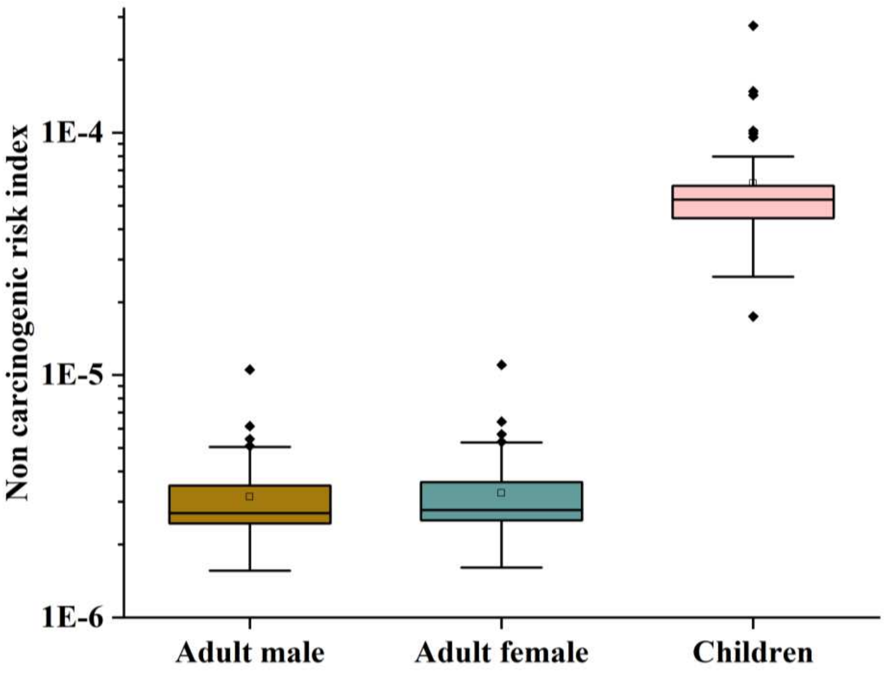

FIG 3 Non-carcinogenic risks (The ordinate is logarithmized).

Table 9 Health risk assessment

	Element / Group	Cd	Cu	Pb	Zn	Total
Exposure via oral ingestion	Adult male	4.0589×10^{-14}	1.2864×10^{-11}	1.1423×10^{-11}	3.8415×10^{-11}	
	Adult women	4.7609×10^{-14}	1.5089×10^{-11}	1.3399×10^{-11}	4.5059×10^{-11}	
	Children	1.3106×10^{-13}	2.8472×10^{-11}	2.5283×10^{-11}	8.5023×10^{-11}	
Exposure via skin contact	Adult male	1.8823×10^{-11}	4.2612×10^{-9}	2.2703×10^{-10}	2.5449×10^{-9}	
	Adult women	1.9988×10^{-11}	4.5250×10^{-9}	2.4109×10^{-10}	2.7025×10^{-9}	
	Children	2.9293×10^{-11}	2.2879×10^{-6}	3.5333×10^{-10}	3.9606×10^{-9}	
Inhaled soil particle volume	Adult male	1.9781×10^{-11}	6.2695×10^{-9}	5.5672×10^{-9}	1.8722×10^{-8}	
	Adult women	1.7923×10^{-11}	5.6807×10^{-9}	5.0444×10^{-9}	1.6963×10^{-8}	
	Children	2.1000×10^{-11}	6.6557×10^{-9}	5.9102×10^{-9}	1.9875×10^{-8}	

Non-carcinogenic risk	Adult male	1.10×10^{-6}	2.64×10^{-7}	1.70×10^{-6}	7.10×10^{-8}	3.14×10^{-6}
	Adult women	1.11×10^{-6}	2.56×10^{-7}	1.82×10^{-6}	6.57×10^{-8}	3.25×10^{-6}
	Children	1.54×10^{-6}	5.74×10^{-5}	2.70×10^{-6}	7.97×10^{-8}	6.17×10^{-5}
	Total	3.75×10^{-6}	5.79×10^{-5}	6.23×10^{-6}	2.16×10^{-7}	6.81×10^{-5}

4 Conclusion

(1) The pollution from Cd, Cr, Ni and Ti was not found in the study area in Nanjing. The mean heavy metal content of Mn was slightly higher than the background value, and the coefficient of variation was slightly higher, which needs more attention. The point over-standard rate and variation coefficient of Pb in soil were relatively large and should be given more attention. The results of principal component analysis showed that the contents of Pb, Zn and Cu; Ni, Ti and Fe; and Zn and Pb were significantly correlated, indicating that they may have the same pollution sources. Ti and Ca, Ti and Cu, and Pb and Zn showed opposite changes, indicating that their concentrations were inversely related.

(2) In terms of the average value of the single factor pollution index, the degree of pollution of different heavy metals was ranked as Pb>Zn>Cu>Cr>Cd, indicating that Pb was the most serious heavy metal polluting element in Nanjing. Therefore, Nanjing should give more attention to the problem of Pb metal pollution.

(3) The USEPA health risk assessment model was used to analyse the exposure amount of individual heavy metals in soil particle exposure pathways in adult males, adult females and children. The results showed that the exposure amount of soil particles in each pathway of heavy metals in children was higher, and the non-carcinogenic risk of Pb and Cu was higher.

(4) The contribution of soil heavy metals from industrial sources in Nanjing was the largest, reaching 34.4%. The parent material and fertilizer sources contributed 32.3% and 19.6%, respectively, and the weathering and deposition sources contributed 13.7%.

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