Pol. J. Environ. Stud. Vol. 35, No. 5 (2026), 5879-5890
DOI: *10.15244/pjoes/210393* ONLINE PUBLICATION DATE: 2025-11-17

Original Research

Sources and Pollution Evaluation of Heavy Metals in Urban Green Space Soil of Suzhou City, Anhui Province, China

Ling Wang, Jiying Xu*, Chen Cheng

School of Resources and Civil Engineering, Suzhou University, Suzhou, 234000, Anhui, China

Received: 13 June 2025
Accepted: 07 September 2025

Abstract

To investigate the heavy metal pollution in the soil of different parks in Suzhou city, surface soil samples were collected from 37 sampling points in 6 parks in Suzhou city. Pollution characteristics analysis, ecological risk assessment, and source analysis were conducted for the elements Hg, Cd, Cu, Pb, Cr, and Zn in these samples. The results showed that the order of the excess rate of heavy metals at the sampling points was Cd>Hg>Pb>Cu>Zn>Cr. According to the analysis of the Nemerow Comprehensive Pollution Index and geoaccumulation index, it was found that Cd and Hg were the most serious pollutants. These two elements were the most important contributing factors to potential ecological risks. Pollution Load Index analysis indicated that all parks exhibited moderate pollution. Among them, Chengnan Park shows the lowest pollution level, while Xuefeng Park demonstrates the highest pollution level. Principal component analysis revealed that three sources were apportioned, which were parent material and agricultural activities (32.705%), transportation (29.162%), and mining and coal-burning activities (19.189%). The research results can provide a basis for the improvement of urban green spaces and the treatment of heavy metals in Suzhou City.

Keywords: urban green land soil, heavy metal pollution, ecological assessment, Suzhou City, source analysis

Introduction

Urban green spaces are a crucial component of the urban ecosystem, playing a significant role in improving the urban ecological environment and enhancing the aesthetic appeal of cities [1]. Urban soil serves as the medium for the growth of urban green plants and the supplier of nutrients, while also acting as both a source and sink for urban pollutants [2]. The quality of urban soil influences the ecological effectiveness of urban green spaces and the quality of urban landscapes [3]. The heavy metal pollution of urban green land soil is more hidden than that of water and air pollution. Even if the heavy metal pollution in the soil used for green space construction is serious, these pollutants will rarely enter the food chain directly, which makes it difficult for the pollution of urban green space soil to attract enough attention [4]. However, when the accumulation of heavy metals in the soil reaches a certain threshold, it can cause significant

*e-mail: jiyingxu1986@163.com
Tel.: +86-158-0557-4977
0000-0001-6709-3262

© 2026 This article is licensed under a Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0)

harm to the ecological environment. Previous research and ecological risk assessments on heavy metals in Suzhou City's soils have mainly focused on areas such as riverbank soils [5], soils along main urban roads [6], farmland soils [7], agricultural soils in coal mining areas [8], and river sediments [9], with less attention given to the soils of urban park green spaces. As part of the ecosystem, heavy metal pollution in urban green space soils can contaminate groundwater and the atmosphere through cyclical processes, thereby affecting human health [10]. The heavy metal content in urban green space soils is an indicator for evaluating the quality of the urban green space soil ecosystem and an important factor influencing the urban ecological environment. This study takes the soil of urban park green spaces in Suzhou City as the research object, conducts an analysis of the content of heavy metals in the soil, evaluates the potential ecological risks, and analyzes the sources of pollution, thereby providing a theoretical basis and reasonable suggestions for urban greening management and residents' health. The aim of this research is thus to provide a foundation for improving urban green spaces and managing heavy metal pollution in Suzhou City.

Study Area

Suzhou City is situated in northeastern Anhui Province (longitude 116°09'-118°10'E, latitude 33°18'-34°38'N), characterized by flat terrain and fertile soils. As a prominent grain and cotton production base in China, it also forms a vital part of the Huainan-Huaibei Coalfield, one of the country's key coal mining regions. The urban greening efforts in Suzhou City have developed rapidly, with green spaces expanding year by year. In 2015, Suzhou was recognized as a National Garden City. Currently, the green coverage rate in the city's built-up areas has reached 45.44%. The primary natural background soils in Suzhou City are fluvo-aquic soil and lime concretion black soils [11]. Due to the accelerating urbanization process, the physical and chemical properties of urban soils have significantly deviated from their original state. Park soil pH levels have commonly increased, trending alkaline. Park soils are typically formed by backfilling with a mixture of transplanted soils (purchased topsoil), locally disturbed soil (construction waste, fragments of original soil), and amended materials (such as peat, compost, and wood chips).

The study selected six parks constructed during different time periods, located in various areas of Suzhou City (Fig. 1). The distribution of sampling points is presented in Table 1. To avoid the effects of root enrichment of woody plants, litter input, and canopy interception of atmospheric deposition on soil heavy metals, all soil samples were collected from underneath turf [12].

Materials and Methods

Sample Collection and Testing

Based on the green space utilization status of the study area, GPS positioning was used to locate 37 sampling points. In strict compliance with HJ/T 166-2004, soil samples were collected using bamboo scrapers

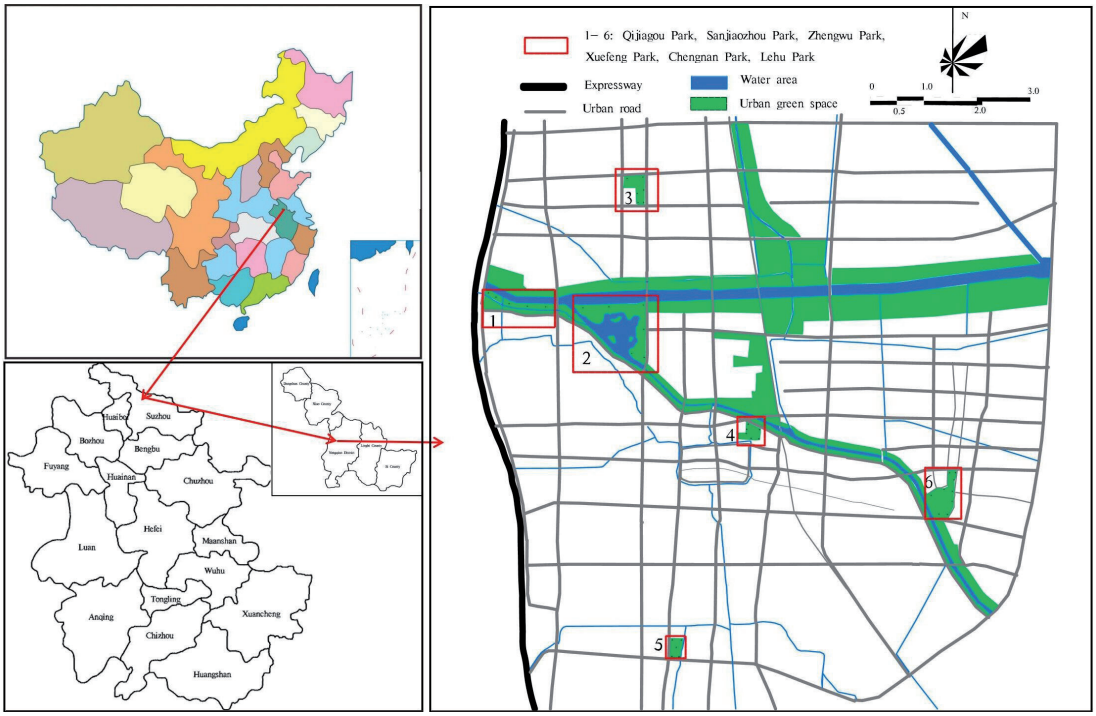

Fig. 1. Location of the study area with sampling sites.

Table 1. Distribution of soil sampling sites.

Sampling Parks	Site	Amount of Sample	Establishment Year	Main Plants of the Park
Lehu Park	117.03°E, 33.64°N	9	2019	*Ginkgo biloba, Sapium sebiferum, Taxodium distichum*
Sanjiaozhou Park	116.96°E, 33.67°N	6	2007	*Salix Babylonica, Malus. Spectabilis, Cerasus lannesiana, Ginkgo biloba, Malus halliana*
Qijiagou Park	116.94°E, 33.67°N	5	2021	*Sapindus mukorossi, Ginkgo biloba, Salix babylonica*
Xuefeng Park	116.99°E, 33.65°N	6	1951	*Cedrus deodara, Ginkgo biloba, Sophora japonica, Platanus orientalis*
Chengnan Park	116.98°E, 33.61°N	5	2022	*Sapium sebiferum, Ginkgo biloba, Koelreuteria paniculata*
Zhengwu Park	116.97°E,33.69°N	6	2021	*Ginkgo biloba,Lagerstroemia indica, Koelreuteria paniculata, Triadica sebifera, Magnolia grandiflora*

to eliminate tool-induced metal contamination prior to storage in pre-identified polyethylene containers. Soil samples from the 0-15 cm depth were collected using the quartering method. The collected samples were first air-dried naturally, followed by the removal of impurities such as roots. The soil was then ground and passed through a 100-mesh nylon sieve. Finally, the processed samples were stored in pre-labeled polyethylene bags for subsequent analysis.

The experiment was conducted at the Engineering and Technological Research Centre of Coal Exploration, Anhui Province, China. The concentrations of Hg, Cu, Pb, Cr, and Zn in soil samples were determined using X-ray fluorescence Spectrometry (XRF) [13]. To ensure the accuracy of XRF instrument measurements, the instrument should be powered on and preheated for more than one hour before use. A calibration curve is then established using the national standard soil sample of China (GSS-16) and saved to a newly created analytical method. Samples were measured based on this method. The Cd element was analyzed by inductively coupled plasma mass spectrometry (ICP-MS). For ICP-MS detection of Cd, soil samples were first subjected to high-temperature digestion with a mixture of concentrated HNO_3-HF. After digestion, the solutions were cooled to room temperature and volumetrically diluted. All samples were analyzed in three replicates, and the average values were reported as final results. To ensure precision, instrument calibration was performed after every four sample measurements, and quality control was maintained using a national standard soil sample of China (GSS-16). The analytical errors for all elements were controlled within 10%.

Evaluation Method of Soil Heavy Metal Pollution

Nemerow Comprehensive Pollution Index

The Nemerow Comprehensive Pollution Index method is a heavy metal pollution assessment approach based on single-factor pollution index evaluation [14]. This method not only analyzes the average pollution level of various heavy metal elements but also reflects the impact of the most severely contaminated heavy metal on the soil environment [15]. The calculation formulas are as follows:

$$P_i = \frac{C_i}{S_i} \tag{1}$$

$$P_{\mathrm{n}} = \sqrt{\frac{P_{i\max}^2 + P_{iave}^2}{2}} \tag{2}$$

In the formulas (1) and (2), P_i is the single pollution index of heavy metals, C_i is the measured content of heavy metals, and S_i denotes the evaluation standard value of the heavy metal (this study adopts the background values of heavy metal elements in Anhui Province soils). P_n is the Nemerow Comprehensive Pollution Index, P_{imax} refers to the maximum value of P_i, and P_{iave} is the average value of P_i. The classification criteria for soil heavy metal pollution evaluation are detailed in Table 2.

Geoaccumulation Index Method

The pollution of heavy metals in soil is primarily influenced by parent material and human activities [16-18]. However, during the formation of parent rock, changes in environmental conditions, rock weathering, dynamic factors, and geological characteristics can alter the soil background values. The geoaccumulation index (Igeo) method comprehensively accounts for the impacts of both natural geological processes and human activities on soil heavy metal pollution, addressing limitations found in other evaluation methods [19, 20]. Its expression is as follows:

$$I_{geo} = \log_2(C_i / k \times S_i) \tag{3}$$

In the formula (3), Igeo represents the geoaccumulation index of heavy metal element i; C_i denotes the measured content of heavy metal element i; S_i is the background value of the heavy metal element in soil (this study adopts the background values of heavy metal elements in Anhui Province soils); k is the correction coefficient accounting for variations in soil background values due to lithological differences, with k = 1.5.

Methods for the Ecological Risk Index of Soil Heavy Metals

Potential Ecological Risk Index

Potential Ecological Risk Index (RI) is a method used to evaluate the potential impact of heavy metal pollution on the ecological environment, which was proposed by Swedish scientist Hakanson in 1980 [21]. This method links heavy metal content, environmental impact, and ecological hazards, enabling it to characterize the pollution level of individual heavy metal elements as well as reflect the ecological hazards caused by the synergistic effects of multiple elements [22]. The calculation formula is as follows:

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} (T_r^i \times \frac{C^i}{C_f^i}) \quad (4)$$

In formula (4), RI represents the comprehensive ecological risk index. E^i_r is the potential ecological risk index of heavy metal i; T^i_r is the toxic response coefficient of heavy metal i; C_i is the measured concentration of pollutant i in the sample; C^i_f is the background value of pollutant i, where this study adopts the soil background values of Anhui Province as the reference. The toxic response coefficients (T_i^r) for each heavy metal are ranked as follows: Hg = 40 > Cd = 30 > Cu = Pb = 5 > Cr = 2 > Zn = 1 [20]. The evaluation criteria of the potential ecological risk index are shown in Table 2.

Pollution Load Index (PLI) Method

The Pollution Load Index (PLI) method is an approach for assessing soil heavy metal contamination based on elemental background values [23]. This method can reflect the spatial variation of heavy metal pollution and the contribution of individual heavy metals to overall contamination [24, 25]. Its calculation formula is as follows:

$$CF_i = \frac{C_i}{C_{0i}} \quad (5)$$

In the formula (5), CF_i represents the contamination factor of heavy metal i; C_i denotes the measured value of heavy metal i; and C_{0i} signifies the background value of heavy metal i. The background values of heavy metals in this study are based on the soil background values of Anhui Province.

The pollution load value (PLI) at a certain point is:

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times ... \times CF_n} \quad (6)$$

In the formula (6), PLI stands for the Pollution Load Index at a given point; n represents the count of assessment elements.

$$PLI_{zone} = \sqrt[n]{PLI_1 \times PLI_2 \times PLI_3 \times ... \times PLI_n} \quad (7)$$

In the formula (7), PLI_{zone} denotes the Pollution Load Index in the research zone; n indicates the number of sampling points. Based on the assessment methodology of the Pollution Load Index (PLI), the pollution status can be categorized into four distinct grades/levels, with the specific classification criteria detailed in Table 2.

Data Analysis and Processing

In this study, the descriptive statistics of soil heavy metal content were analyzed using Excel and Origin software. Origin software was used to calculate the Nemerow Comprehensive Pollution Index, geoaccumulation index (Igeo), potential ecological risk, pollution load index (PLI), and inter-metal correlation analysis in soil. The principal component analysis for heavy metals was conducted with SPSS statistical software.

Results and Discussion

Descriptive Statistics of Soil Heavy Metal Concentrations

The descriptive statistics of six heavy metal concentrations in the green space soils of the study area are presented in Table 3 and Fig. 2. The results show that the mean concentrations of Cr, Cu, Zn, Cd, Pb, and Hg were 50.96, 22.26, 57.33, 1.84, 27.01, and 0.10 mg/kg, respectively.

The median values of all elements were lower than their respective mean values, indicating the presence of significant outliers in the dataset [26, 27]. The coefficient of variation (CV) can represent the fluctuation, dispersion, and degree of anthropogenic influence on soil heavy metal concentrations. A higher value indicates more intensive anthropogenic disturbance [28].

The coefficients of variation (CV) for the six heavy metals in the study area followed this descending order: Hg>Cd>Cu>Zn>Cr>Pb, with Hg and Cd exhibiting the highest variability (124.67% and 102.83%, respectively) and Pb showing the lowest dispersion, only 7.64%. The greatest dispersion degrees of Pb and Cr were observed in Xuefeng Park, whereas Hg showed its highest variability in Qijiagou Park. The content of Hg was the

Table 2. Classification standard of Nemero pollution index (P_n), geo-accumulation index (I_{geo}), risk index (RI), and pollution load index (PLI).

P_n		Pollution Level	I_{geo}	Pollution Level
$P_n \leq 0.7$		Safety	$I_{geo} \leq 0$	Non-pollution
$0.7 < P_n \leq 1$		Warning level	$0 < I_{geo} \leq 1$	Mild pollution
$1 < P_n \leq 2$		Mild pollution	$1 < I_{geo} \leq 3$	Moderate pollution
$2 < P_n \leq 3$		middle pollution	$3 < I_{geo} \leq 5$	Serious pollution
$P_n > 3$		heavy pollution	$I_{geo} > 5$	Extremely pollution
E^i_r/RI		Risk Level	PLI	Pollution degree
$E^i_r < 40$	RI < 150	Mild ecological risk	PLI ≤ 1	non-pollution
$40 \leq E^i_r < 80$	150 ≤ RI < 300	Moderate ecological risk	1 < PLI ≤ 2	Moderate pollution
$80 \leq E^i_r < 160$	300 ≤ RI<600	Intensity ecological risk	2 ≤ PLI < 3	Serious pollution
$160 \leq E^i_r < 320$	RI ≥ 600	Severe ecological risk	PLI ≥ 3	Extremely pollution
$E^i_r \geq 320$	RI ≥ 600	Extreme ecological risk		

highest in Qijiagou Park. This might be closely related to the fact that the Qijiagou River had not been dredged for many years before the park was built, and the silt accumulation was serious.

The ranking of heavy metal exceedance rates compared to Anhui Province's soil background values was as follows: Cd (100%)>Hg (45.95%)>Pb (32.43%)>Cu (21.62%)>Zn (16.22%)>Cr (0). As shown in Fig. 2, the concentrations of Cr, Cu, Zn, and Pb in Xuefeng Park were significantly higher than those in other sampling areas. The concentration of Cr in Xuefeng Park (located in the old urban area with a long-established history and well-developed surrounding transportation infrastructure) was significantly higher than in other parks. This observation was consistent with the research on heavy metals in urban park soils in Beijing conducted by Xu et al. [29]. The concentrations of Cd at all sampling sites exceeded the background values of Anhui Province, showing a 100% exceedance rate. Existing research indicates that elevated cadmium (Cd) levels are associated with long-term phosphorus fertilizer application [30]. Given that park soils are routinely fertilized to maintain landscape vegetation growth, this agricultural practice likely explains the observed Cd exceedances across sampling sites. The measured concentrations of Cr at all sampling sites did not exceed the background values for Anhui Province. The highest Pb concentrations were recorded in Xuefeng Park, while significantly lower levels were observed in Qijiagou Park compared to other sampling areas. The Zn concentrations exceeded the Anhui provincial background value exclusively at Xuefeng Park, whereas Zhengwu Park and Chengnan Park demonstrated remarkably similar Zn levels – a phenomenon potentially associated with the similar time of establishment of the two parks.

Assessment of Heavy Metal Pollution in Soil

Evaluation using the Nemerow Comprehensive Pollution Index

The heavy metal pollution levels in various parks were assessed with the Nemerow Comprehensive Pollution Index, with the results presented in Fig. 3. As shown in Fig. 3, our analysis reveals that all surveyed parks exhibited heavy pollution based on mean contamination levels. Xuefeng Park demonstrated the highest pollution

Table 3. Descriptive statistics of heavy metal concentrations (mg/kg) (n = 37).

Heavy metal	Range	Mean	Median	Standard Deviation	Coefficient of Variation (%)	Background soil (AnHui) [31]	Over standard rates (%)
Cr	28.48-64.06	50.96	50.15	6.77	13.28	70	0
Cu	6.74-52.60	22.26	20.60	8.44	37.87	26	21.62
Zn	35.9-79.08	57.33	56.26	8.20	14.31	64	16.22
Cd	0.21-9.22	1.84	1.24	1.90	102.83	0.134	100
Pb	24.36-31.92	27.01	26.39	2.06	7.64	27	32.43
Hg	0.01-0.49	0.10	0.04	0.12	124.67	0.048	45.95

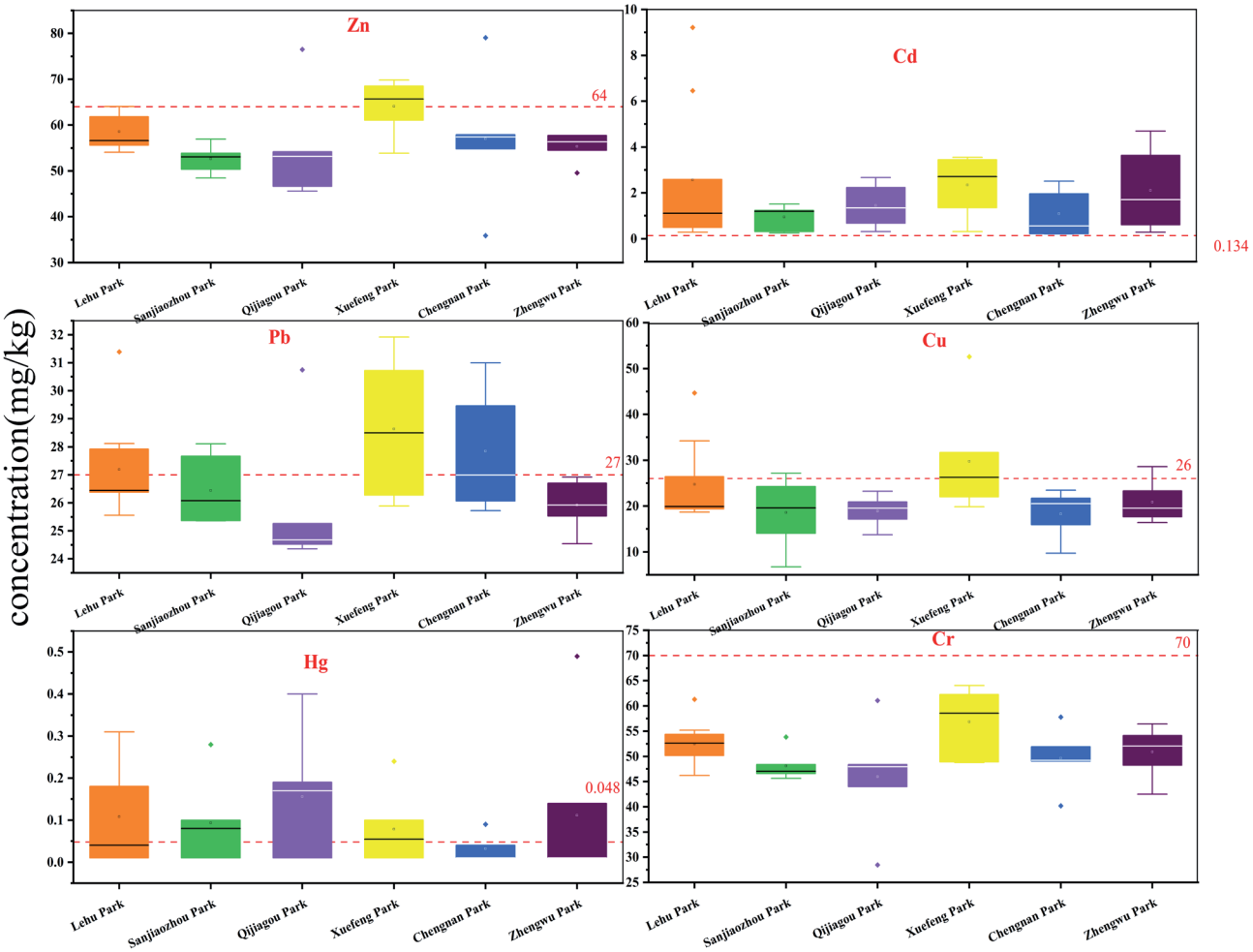

Fig. 2. Box plot showing the concentrations of heavy metals from different parks of Suzhou.
-------- Background values of soil in Anhui Province

intensity, followed by Zhengwu Park, while Lehu Park, Sanjiaozhou Park, and Qijiagou Park showed comparable contamination magnitudes. Chengnan Park registered the lowest pollution level. Notably, outliers in Lehu Park significantly elevated its comprehensive pollution index (Pn). The Nemerow index amplified the weight of maximally contaminated elements. As evidenced in Fig. 2, critical exceedances of Hg and Cd elevated the integrated pollution classification of all parks to "heavy" status, underscoring these metals' dominant contribution to regional ecological risks. While the Nemerow index effectively flags high-risk contaminants, it may disproportionately amplify the impact of individual pollutants. Therefore, a multidimensional assessment incorporating the subsequent geoaccumulation index (Igeo) and potential ecological risk index (RI) is essential for comprehensive evaluation.

Geoaccumulation Index Evaluation

The results shown in Fig. 4 were obtained by evaluating the cumulative index of all sampling points. the geo-accumulation indices of Cr, Zn, and Pb in all samples were all less than 0, indicating a non-pollution level. Cd contamination was the most severe, with all sampling sites being contaminated. Among them, the percentages of sites reaching the extremely contaminated, seriously contaminated, moderately contaminated, and mildly contaminated levels are 8.1%, 32.4%, 35.1%, and 24.3%, respectively. For Hg, 27% and 16.2% of sampling sites reached moderately contaminated and mildly contaminated levels, respectively. Regarding Cu, 5.4% of sites exhibited mild contamination, while the remaining 94.6% showed no detectable contamination.

Ecological Risk Assessment of Heavy Metals in Soil

Potential Ecological Risk Index Assessment

The analysis of the potential ecological risk index bubble diagram (Fig. 5) indicates that certain heavy elements in various parks of Suzhou City have reached moderate to severe pollution levels. The E_i^r values follow this descending order: Cd>Hg>Pb>Cu>Cr>Zn.

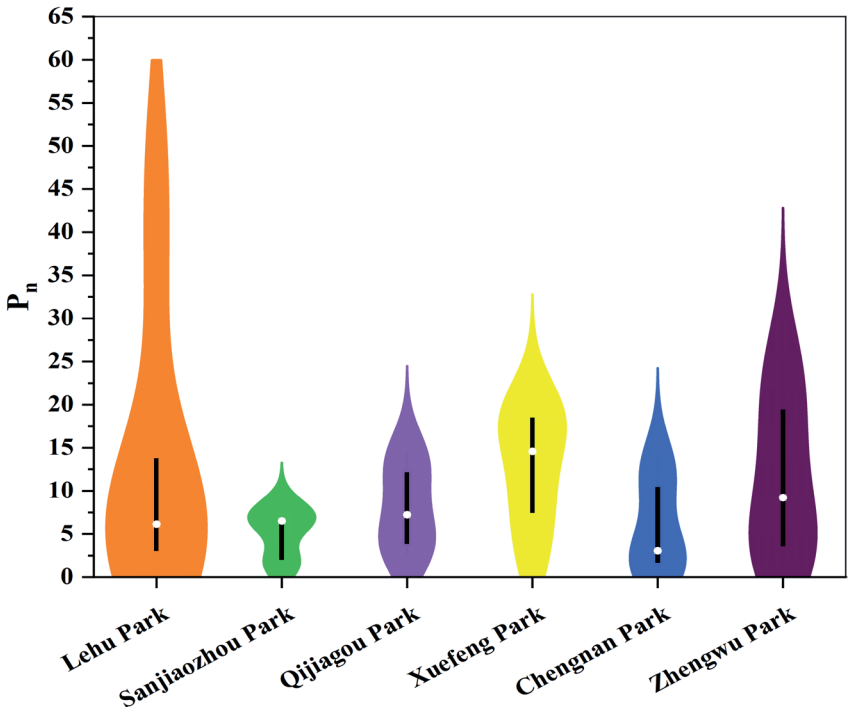

Fig. 3. Histogram of pollution levels of different parks based on Pn.

Among the six heavy metals investigated in this study, only Cd and Hg posed significant ecological risks, a finding consistent with previous research by other scholars [32]. The remaining elements all exhibited mild ecological risk levels. The ecological risk of Cd displayed an ascending order across parks: Sanjiaozhou Park<Chengnan Park<Qijiagou Park<Zhengwu Park<Xuefeng Park<Lehu Park. Conversely, Hg exhibited a different risk progression: Chengnan Park<Xuefeng Park<Sanjiaozhou Park<Lehu Park<Zhengwu Park<Qijiagou Park. Comprehensive analysis revealed that Cd and Hg dominated the ecological risk profile, contributing predominantly to the Risk Index (RI) values, which makes the comprehensive potential risks of different parks reach extremely high ecological risks.

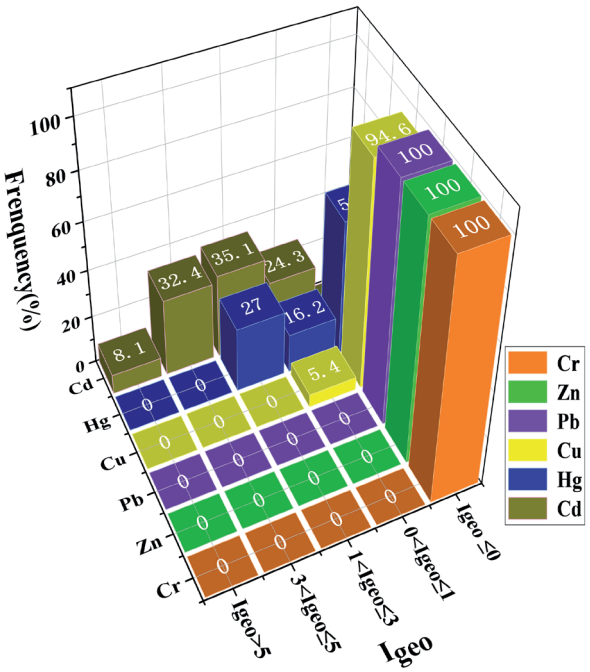

Fig. 4. The frequency percentage for the assessment results of the geoaccumulation index.

Pollution Load Index Assessment

According to preliminary test data and Fig. 6, all parks showed slight pollution conditions. Evaluation of PLIzone values revealed moderate pollution levels across most of the study area. From the position of the PLI value in the box plot of Fig. 6, it can be found that most of the PLI values in Chengnan Park exceed 1.0; the relatively low mean and median values indicate the presence of abnormally low outliers in the dataset. An analysis of the PLI average values across the parks revealed that all parks except Chengnan Park exhibited moderate pollution, with contamination levels decreasing in the following order: Xuefeng Park>Lehu Park>Qijiagou Park>Zhengwu Park>Sanjiaozhou Park. Compared with other parks, Chengnan Park, which was completed in 2022, is located on the southern outer ring of the city. Before its construction, it was farmland, so it was less affected by human activities. This might be the reason for its low level of pollution. Fig. 6 indicates that some sampling sites in both Lehu Park and Xuefeng

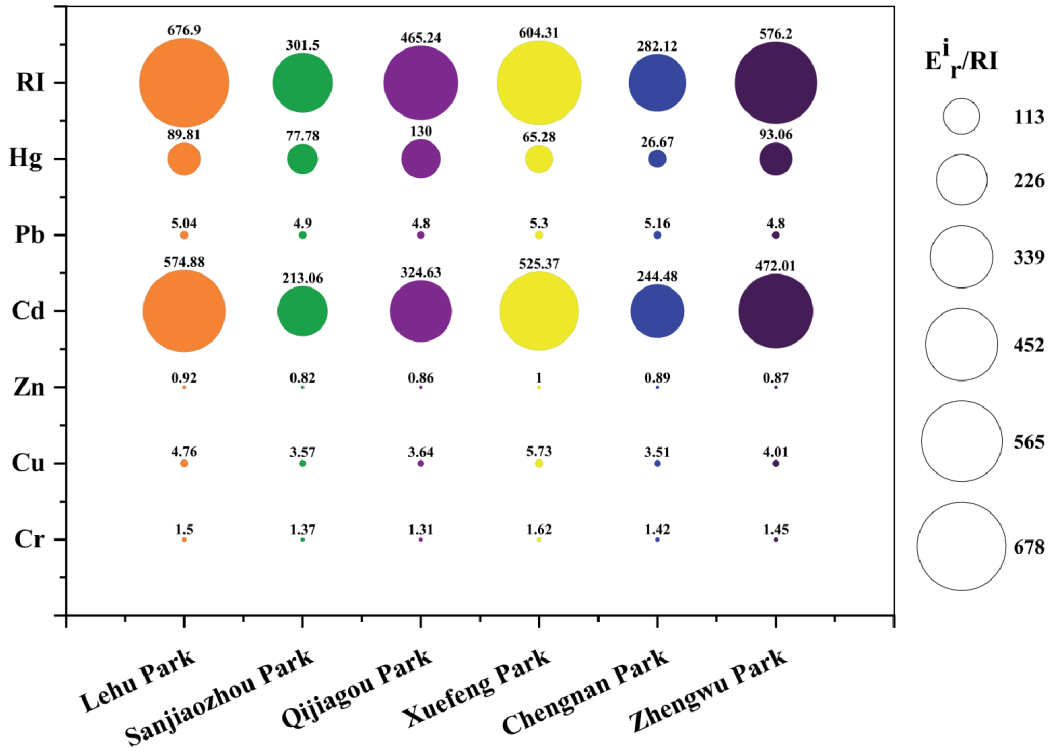

Fig. 5. Bubble diagram of comprehensive potential ecological risk for heavy metals in different parks.

Park had reached severely polluted levels. As shown in Fig. 6, some sampling points in Lehu Park and Xuefeng Park are in a severely polluted state. Among them, the most severe pollution levels observed in Xuefeng Park were likely attributable to multiple factors: its status as the city's oldest park, location in Suzhou's historic urban center, immediate proximity to railway tracks, and the high population density of surrounding areas.

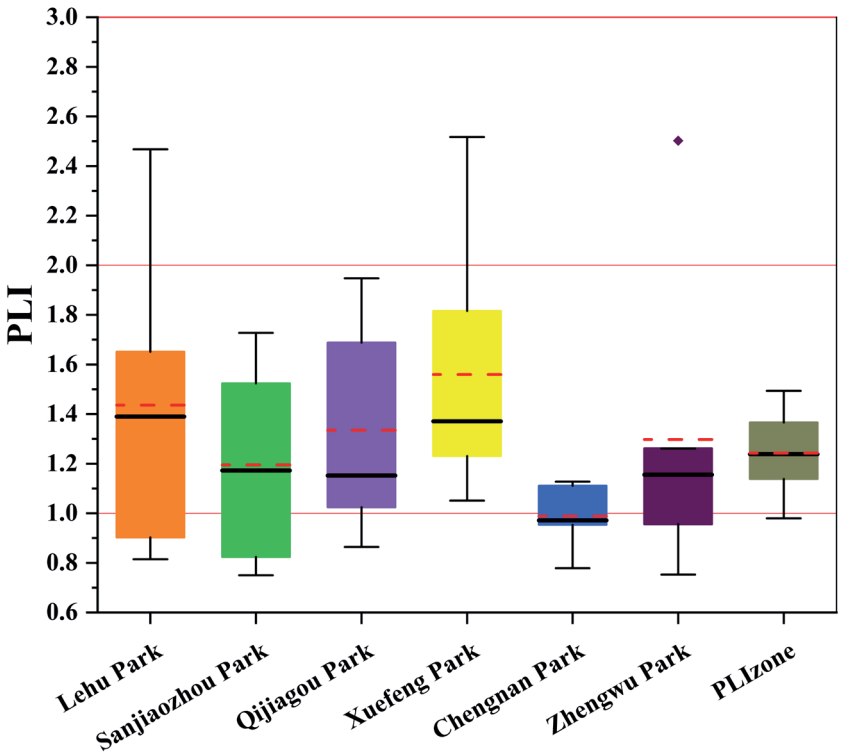

Fig. 6. Box plan of Pollution load index.

Source Apportionment of Soil Heavy Metals

Correlation Analysis of Heavy Metals in Soil

Correlation analysis can be used to explain the sources of heavy metals in soil [33]. The correlation analysis of heavy metal content in different parks in Suzhou City revealed certain correlations among the heavy metals. According to Fig. 7, it can be observed that Pb-Zn, Cu-Cd, and Cu-Cr exhibit significant correlations at the 0.05 level, with correlation coefficients of 0.73, 0.59, and 0.5, respectively. The lack of a significant correlation between Pb and Hg indicates their non-homologous origins.

To more accurately identify the sources of heavy metals, principal component analysis (PCA) was further employed to analyze the origins of heavy metals in the soil.

Principal Component Analysis (PCA) of Soil Heavy Metals

Principal Component Analysis (PCA), a classical multivariate statistical method for identifying natural and anthropogenic sources of soil heavy metals, primarily employs dimensionality reduction techniques to transform multiple correlated variables into a set of comprehensive composite indicators [18]. Principal Component Analysis can elucidate the origins of heavy metals, while Bartlett's test and the Kaiser-Meyer-Olkin (KMO) measure verify the reliability of the results [34]. In this experiment, PCA was performed on the experimental data using SPSS software. The suitability quantity of KMO sampling was 0.518>0.5, and the significance of the Bartlett's sphericity test was 0.000<0.05. This indicated that principal component analysis could be conducted. Three principal factors (eigenvalues >1) were selected as potential heavy metal sources (Table 4). The cumulative contribution rate of these three principal components reached 81.056%, which could basically represent the information contained in the data.

PC1 explained 32.7% of the variance, and the factor loadings of Cu, Cd, and Cr reached 0.891, 0.784, and 0.706, respectively. Correlation analysis revealed strong associations between Cu-Cd and Cu-Cr pairs, a finding further supported by the highly consistent concentration trends of these three elements across different parks in the box plot (Fig. 2). Compared to Cd, Cu and Cr exhibited lower coefficients of variation (CV), indicating comparatively minor anthropogenic influences and likely derivation from parent rock materials in the soil. The similar geochemical behavior of Cu and Cr in basic rocks, coupled with their strong correlation and highly consistent spatial distribution across parks, conclusively establishes soil parent material sources as the dominant control over their origins. The co-occurrence of Cd as an impurity in copper-based pesticides explains both the strong Cu-Cd correlation and the agricultural influence on their pollution sources [35]. The coefficient of variation (CV) for Cd reached 100%, with all measured values across sampling sites exceeding the background levels for Anhui Province. This strongly indicates significant anthropogenic influence on Cd contamination. Research has demonstrated that elevated Cd concentrations in soils are linked to prolonged application of phosphate fertilizers [36, 37]. The soil in park green spaces

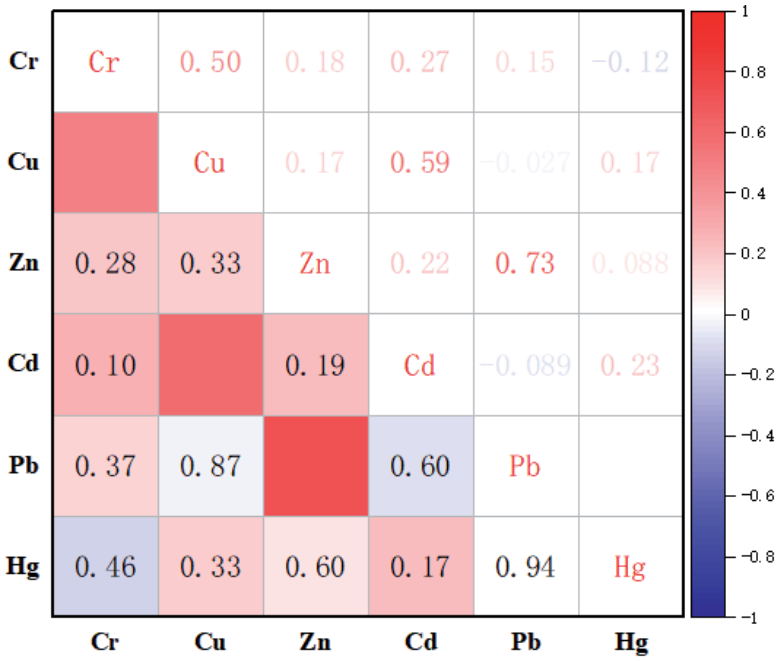

Fig. 7. Correlation analysis results for heavy metals.

Table 4. Rotated component matrix of soil heavy metals in different parks.

Heavy metal	PC1	PC2	PC3
Cr	0.706	0.182	-0.466
Cu	0.891	0.014	0.073
Zn	0.18	0.909	0.095
Pb	-0.076	0.942	-0.06
Hg	0.13	0.057	0.9
Initial Eigenvalues	2.131	1.604	1.128
Variance Contribution rate (%)	32.705	29.162	19.189
Cumulative %	32.705	61.868	81.056

is regularly fertilized, and pesticide application is made to ensure the aesthetic effect of the plant landscape, which may be the reason for the excessive Cd concentration at all sampling points. Sun also found a high correlation between Cu and Cd when studying heavy metals in farmland soils near highways in Suzhou City, and attributed their sources to agricultural sources through factor analysis [28]. Cr concentrations at all sampling sites did not exceed the background values for Anhui Province, with a coefficient of variation (CV) of 13.28%, indicating minimal anthropogenic influence and low migration capacity of Cr, which was consistent with the research of Zhang et al. [38]. Therefore, PC1 represents the combined influence of soil parent material and agricultural activities.

The variance contribution rate of PC2 was 29.162%, and the factor loadings of Zn and Pb reached 0.909 and 0.942, respectively. Studies have shown that the production of these two elements is closely related to the emissions of vehicle exhaust and the dust generated by tire friction [39]. From the box plot of heavy metal concentration (Fig. 2), the contents of Pb and Zn in Xuefeng Park, where the surrounding road network is dense, were higher than those in other parks. Xuefeng Park, being a long-established urban park, features a higher proportion of woodland patches dominated by large trees. These arboreal patches alter the local microclimate, enhancing their function as a sink for urban particulate matter, thereby leading to increased accumulation of Zn and Pb in the soil. This conclusion was consistent with the research on heavy metal pollution in urban parks in Ningbo conducted by Liu et al. [40]. Xuefeng Park is located in the old urban area, with heavy surrounding traffic flow and the earliest establishment time of the park. Therefore, PC2 mainly represents the source of transportation.

PC3 accounted for 19.189% of the total variance, with Hg demonstrating the highest factor loading (0.9). Among the six heavy metals studied, Hg exhibited the most severe pollution and the highest coefficient of variation. Combined with the geo-accumulation index, 43.2% of the sampling sites were contaminated by Hg, indicating a significant influence from anthropogenic sources. Existing research identifies coal mining as a primary source of Hg contamination, and as Suzhou City is a key region of the Huainan-Huaibei coalfield with extensive mining operations and coal-fired power plants in its vicinity [41]. PC3 was conclusively attributed to mining and coal combustion-related sources.

Conclusions

The coefficient of variation (CV) of Cd and Hg exceeding 100% indicated significant anthropogenic interference. The content of Cd in all sampling points exceeds the background values for Anhui Province. As indicated by calculations of the geoaccumulation index and Nemerow Comprehensive Pollution Index, all sampling points were classified as severely polluted. Combined with the potential ecological risk assessment, it can be further confirmed that Cd posed extremely severe ecological impacts. Based on the geoaccumulation index, Hg contamination was detected in 43.2% of the sampling points. Combined with the Nemero comprehensive pollution index assessment, Hg pollution was classified as severe in all areas except Chengnan Park, where it exhibited moderate contamination. Additionally, significant potential ecological risks associated with Hg were identified at all sampling sites except Chengnan Park. In conclusion, the soil remediation efforts in the urban green spaces of Suzhou City should prioritize addressing the exceedance of Cd and Hg concentrations beyond permissible limits.

According to the correlation analysis, heavy metals in the soils of different park green spaces in Suzhou City originate from three distinct sources. PC1 was identified as the parent material and agricultural activities factor, primarily including Cu, Cd, and Cr. PC2 corresponded to the transportation factor, dominated by Zn and Pb. PC3 represented the mining and coal combustion factor, solely associated with Hg.

Acknowledgments

This research was funded by the open research platform project of Suzhou University (2022ykf12), the Anhui Excellent Young Teacher Training Project (YQYB2024075), the Academic and Technical Leader Reserve Candidate Program (2024XJHB08), the Postdoctoral Researcher of University of Science and Technology of China (No.425098), the scientific research development fund project of Suzhou University (2023fzjj08).

Conflict of Interest

The authors declare no conflict of interest.

References

1. LU Y., FENG H., GAN H.H. Soil fertility characteristics and enzyme activity for urban parks in Guangzhou city. Journal of Soil and Water Conservation. **21** (1), 160, **2007**.
2. CHEN W.F., SUN Q.Y., SONG X.L., DONG Y.X. Distribution and ecological risk assessment of heavy metal elements in soils of green spaces at different urban function areas. Research of Soil and Water Conservation. **26** (3), 148, **2019**.
3. XU H.T., DAI Z.Y., SUN Z.H., LI X.Y., JIE Y.B. Investigating the heavy-metal concentrations in soils from rainwater-harvesting green spaces in Beijing. Landscape and Ecological Engineering. **20** (4), 581, **2024**.
4. LUO S.H., CHEN R.R., HAN J.G., ZHANG W.W., PETROPOULOS E., LIU Y., FENG Y.Z. Urban green space area mitigates the accumulation of heavy metals in urban soils. Chemosphere. **352**, 141266, **2024**.
5. WU J.X., MIN N., YAN F. Study on distribution characteristics of heavy metals on both sides of road under different pipe transport condition. Journal of Baoshan University. **38** (2), 76, **2019**.
6. KAN L.B., XU J.Y., HU C. Environmental Quality Evaluation of Heavy Metals Content in Soils on Both Sides of Main Road in Suzhou City. Henan Science and Technology. (11), 151, **2018.**
7. WANG X.Y., XU. J.Y., ZHAO H.T., DAI H.B., ZHANG H.T., HAN S.X., CHEN C., ZHAO J.Y., WANG L., GAO J.J., WU J.Y. Ecological and health risk assessment of heavy metals in soils of vegetable base in north of Suzhou, Anhui province. Polish Journal of Environmental Studies. **32** (6), 1, **2023**.
8. ZHANG C.L., YUAN X.T. Distribution and evaluation on potential ecological risk of heavy Metals in soil of Suzhou. Journal of Shijiazhuang University. **14** (3), 9, **2012**.
9. YU Y.Q., FENG S.B. Distribution characteristics and pollution evaluation of heavy metals in the bottom mud of Xinbianhe River in Suzhou. Western Resources. (3), 123, **2018**.
10. XU W.F., KANG L.W., HE Z.Q. Determination of heavy metals and their states in the soil of Handan. Journal of Jishou University (Natural Science Edition). **25** (3), 79, **2004**.
11. ZHANG J., PENG W.H., LIN M.L., LIU C.M., CHEN S., WANG X.J., GUI H.R. Environmental geochemical baseline determination and pollution assessment of heavy metals in farmland soil of typical coal-based cities: A case study of Suzhou City in Anhui Province, China. Heliyon. **9** (4), 1, **2023**.
12. LI Y.L., WANG C.Q., YAN C.W., LIU S.W., CHEN X.T., ZENG M.S., DONG Y.H., JIAO R.Z. Heavy metal concentrations and accumulation characteristics of dominant woody plants in iron and lead-zinc tailing areas in Jiangxi, Southeast China. Forests. **14** (4), 846, **2023**.
13. CHENG C., XU Z.M., FENG S.B., WANG L. Distribution, ecological risk and source analysis of heavy metals in farmland soil around chating copper ore in Xuancheng Region of southern China. Polish Journal of Environmental Studies. **32** (2), 1581, **2023**.
14. JIAN R.F., YUE F.J., ZHU Z.Z., LIU X.L., ZHANG L.Y. Temporal and spatial variation of heavy metals in coastal wetlands around the Bobai Sea and analysis of their sourses. China Environmental Science. **43** (11), 6025, **2023**.
15. LIU Y., LIU M.Q., WANG L., YIN A.J., HUANG Z.L., YAO D.D., DAI W., WANG N., WANG H. Evaluation of heavy metal pollution in farmland soil around an abandoned silicon plant in Yunnan. Journal of Agro-Environment Science. **41** (4), 785, **2022**.
16. FORSTNER U., MULLER G. Concentrations of heavy metals and polycyclic aromatic hydrocarbons in river sediments: geochemical background, man's influence and environmental impact. GeoJournal. **5** (5), 417, **1981**.
17. LV J.S., LIU Y., ZHANG Z., DAI J. Factorial kriging and stepwise regression approach to identify environmental factors influencing spatial multi-scale variability of heavy metals in soils. Journal of Hazardous Materials. **261**, 387, **2013**.
18. MARTIN J.A.R., RAMOS-MIRAS J.J., BOLUDA R., GIL C. Spatial relations of heavy metals in arable and greenhouse soils of a mediterranean environment region (Spain). Geoderma. **200**, 180, **2013.**
19. COLAK M. Heavy metal concentrations in sultana-cultivation soils and sultana raisins from Manisa (Turkey). Environmental Earth Sciences. **67** (3), 695, **2012**.
20. BDULLAH M.I.C., SAH A.S.R.M., HARIS H. Geoaccumulation index and enrichment factor of arsenic in surface sediment of Bukit Merah Reservoir, Malaysia. Tropical Life Sciences Research. **31** (3), 109, **2020**.
21. HAKANSON L. An ecological risk index for aquatic pollution control: a sedimentological approach. Water Research. **14** (8), 975, **1980**.
22. NI X.K., FENG X., YU Y., JIANG X.X., LI Z.C., LI H., XIA X. Pollution characteristics and source analysis of heavy metals in soils surrounding a typical solid waste disposal plant. Journal of Agro-Environmental Science. **38** (9), 2146, **2019**.
23. TONLINSON D.L., WILSON J.G., HARRIS C.R., JEFFREY D.W. Promblems in the assessment of heavy-metal levels in estuaries and formation of a pollution index. Helgoland Marine Research. **33**, 566, **1980**.
24. YUAN B., CAO H.L., DU P., REN J., CHEN J., ZHANG H., ZHANG Y.H., LUO H.L. Source-oriented probabilistic health risk assessment of soil potentially toxic elements in a typical mining city. Journal of Hazardous Materials. **443**, 130222, **2023**.
25. HAE J.Y., HYO J.J., KI M.B., DAL R.J., KAN T.W., RYU H.S., HAN J.H., WON J.Y., JUNG H.J., SOON H.H., NA E.H. Organic matter and heavy metal in river sediments of southwestern coastal Korea: spatial distributions, pollution, and ecological risk assessment. Marine Pollution Bulletin. **159**, 11146, **2020**.

26. WEI P., SHAO T., WANG R.J., CHEN Z.Y., ZHANG Z.D., XU Z.P., ZHU Y.D., LI D.Z., FU L.J., WANG F.E. A study on heavy metals in the surface soil of the region around the Qinghai Lake in Tibet Plateau: pollution risk evaluation and pollution source analysis. Water. **12** (11), 3277, **2020**.
27. WIELDING L.P. Spatial variability: its documentation, accommodation and implication to soil surveys. In Soil spatial Variability. NIELSEN D.R., BOUMA J., Pudoc Scientific Publishers: Wageningen, Netherlands, 166, **1985**.
28. SUN L.H. Pollution assessment and source approximation of trace elements in the farmland soil near the trafficway. Journal of Environmental Engineering and Landscape Management. **28** (1), 20, **2020**.
29. XU H.T., DAI Z.Y., SUN Z.H., LI X.Y., JIE Y.B. Investigating the heavy-metal concentrations in soils from rainwater-harvesting green spaces in Beijing. Landscape and Ecological Engineering. **20** (4), 581, **2024**.
30. WAN Y.A., LIU J., ZHUANG Z., WANG Q., LI H.F. Heavy metals in agricultural soils: sources, influencing factors, and remediation strategies. Toxics, **12** (1), 63, **2024.**
31. JI W.B., LU Y.Y., YANG M., WANG J., ZHANG X.Y., ZHAO C.Y., XIA B., WU Y.J., YING R.R. Geochemical characteristics of typical karst soil profiles in AnHui province, southeastern China. Agronomy. **13**, 1067, **2023**.
32. LIU Y., HE C.H., NIU X.K., ZHANG D., PAN B. Health risk assessment of soil heavy metals in a small watershed of a mining area in Yunnan. Environmental Science. **43** (2), 936, **2022**.
33. LI W., BU D., SUN J., SHAN Z.Y., LV X.B., XIONG J. Distribution and ecological risk assessment of heavy metal elements in the surface sediments of Bagaxue wetlands in Lhasa. Environmental Chemistry. **40** (1), 195, **2021**.
34. BUX R.K., BATOOL M., SHAH S.M., SOLANGI A.R., SHAIKH A.A., HAIDER S.I., SHAH Z.U. Mapping the spatial distribution of soil heavy metals pollution by principal component analysis and cluster analyses. Water Air Soil Pollution. **234** (6), 330, **2023**.
35. GUO S.Y., CHEN X.Y., WEI W., LI T.S., YIN F., XU L. Risk assessment and source analysis of heavy metal contamination in the soil of the Juanshui River Mouth. Environmental Pollutants and Bioavailability. **35** (1), 2212127, **2023**.
36. GRAY C.W., MCLAREN R.G., ROBERTS A.H.C., CONDRON L.M. The effect of long-term phosphatic fertiliser applications on the amounts and forms of cadmium in soils under pasture in New Zealand. Nutrient Cycling in Agroecosystems. **54**, 267, **1999**.
37. FILZEK P.D.B., SPURGEON D.J., BROLL G., SVENDSEN C., HANKARD P.K., KAMMENGA J.E., DONKER M.H., WEEKS J.M. Pedological characterization of sites along a transect from a primary cadmium/lead/ zinc smelting works. Ecotoxicology. **13** (8), 725, **2004**.
38. ZHANG Z.G., CAI W.Q., HU Y.B., YANG K., ZHENG Y.H., FANG C., MA C.N., TAN Y.N. Ecological risk assessment and influencing factors of heavy-metal leaching from coal-based solid waste fly ash. Frontiers in Chemistry. **10**, 1, **2022**.
39. LIU H.L., ZHAO F.K., YANGL., SHEN L.J., YANG K.F., Li M., CHEN L.D. Study on heavy metal pollution in urban park soil and influencing factors: A case study of Ningbo city. Ecology and Environmental Sciences, 34 (5), 773, 2025.
40. LV J.S., ZHANG Z.L., LI S., LIU Y., SUN Y.Y., DAI B. Assessing spatial distribution, sources, and potential ecological risk of heavy metals in surface sediments of the Nansi Lake, eastern China. Journal of Radioanalytical and Nuclear Chemistry. **299**, 1671, **2014**.
41. ZHANG J., LI X., LIU L.Y., LI Y.R. Characteristics and source analysis of heavy metal pollution in farmland around a coal-fired power plant. Environment Science. **44** (12), 6921, **2023**.