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RESEARCH ARTICLE

Assessment of potentially toxic pollutants and urban livability in a typical resource-based city, China

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Abstract

Toxic pollutants are affecting the environment on a global scale. To quantify the extent of the elemental pollution in Peixian, a typical Chinese city, we collected 332 soil samples from agricultural, residential, woodland, and hydrological environments. Using multivariate statistical and geostatistical analyses, the results indicate that contaminants including chromium (Cr), zinc (Zn), copper (Cu), lead (Pb), cadmium (Cd), and arsenic (As) may share common sources such as commercial activities, coal mining activities, water transportation, power generation, and livestock manure. The presence of mercury (Hg) in the southern part of the study area, however, is almost entirely attributed to nearby mining activities. The value of contamination index was the highest in hydrological environments. Health exposure risk assessments of the elements were also investigated. With the exception of Pb, the potentially toxic elements in the study area do not pose a severe non-carcinogenic health risk. At the levels observed in our study, however, Pb may pose a non-carcinogenic risk to children. Based on these results, the area's livability is assessed. The urban livability analysis shows that the livability level is higher in the western part of the study area than it is in the eastern part.

Keywords Toxic elemental pollutants · Pollution index · Health risk · Urban livability · Land use · Resource-based city

Introduction

Due to the long half-lives and non-biodegradability of potentially toxic elements, these pollutants accumulate in the environment and can eventually make their way into the human body through the contamination of drinking water and food crops. Toxic elemental pollutants have become a global problem, disturbing the chemical balance of the environment and becoming a threat to the health of animals and human beings (Madrid et al. 2002; Rai et al. 2019). For instance, chronic exposure to cadmium (Cd) can cause lung cancer, bone fractions, proliferative prostatic lesions, and kidney dysfunction. The chronic effects of lead (Pb) include enzyme inhibition, as well as nervous, skeletal, circulatory, and immune system damage (Pareja Carrera et al. 2014; Żukowska and Biziuk 2008). Generally, potentially toxic elements are poisonous to humans, and high doses and/or long-term exposure may result in morbidity and potentially death (Rai et al. 2019).

The primary sources of these potentially toxic elements are mining, land use changes, and industrialization, especially in developing countries with high populations, such as India and China (Habitat 2004). Peixian City is a typical natural resource-rich city with an estimated 2.37 billion tons of coal available (Lu et al. 2019). In the last few decades, mining activities have significantly impacted the environment. Of all of the mining and manufacturing byproducts, toxic elemental pollution is the most concerning and must be considered in urban planning going forward (Li et al. 2015).

To prevent future soil pollution and to remediate existing toxic elemental contamination, we must identify the exposure risks in different land use cases and create awareness for this issue, specifically as it applies to urban planning. However,

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few studies address the spatial distribution of potentially toxic elements and the resulting health risk and livability impacts in a resource-based city. Therefore, this work aims to (1) assess and compare the potentially toxic elemental pollution in different land use cases and identify the potential sources of those potentially toxic elements, and (2) analyze the urban livability in the study area of Peixian City.

Materials and methods

Study area

Peixian City (116°41′–117°09′E, 34°28′–34°59'N, area of approximately 1576 km^2) is characterized by a temperate monsoon climate with a mean temperature of 14.2 °C. The average annual precipitation is approximately 776 mm, nearly two-thirds of which falls between June and September. Peixian City is coal rich, and the extent of the coal is estimated at approximately 2.37 billion tons. There are eight coal mines, including Longgu Mine, Longdong Mine, Sanhejian Mine, Yaoqiao Mine, Xuzhuang Mine, Zhangshuanglou Mine, Kongzhuang Mine, and Peicheng Mine. Since 1977, over 230 million tons of raw coal has been mined in Peixian City (Liu et al. 2018). Mining is vital to the economic growth in the northern and central parts of Peixian City. However, emissions from mining and mineral processing, such as potentially toxic elements and dust, have drastically affected local communities by way of increased environmental pollution and fewer employment opportunities (Vatalis and Kaliampakos 2006; Yang and Ho 2019). Moreover, aluminum and photovoltaic power manufacturing plants in the southeast have also inflicted serious environmental damage.

Sample collection

After dividing the study area into regions 2 km long and 2 km wide, we collected a total of 332 soil or sediment samples from each region in September of 2014 (Fig. 1). We identified the sample sites using GPS devices. Using hand shovels to collect topsoil (0–20 cm) samples, we stored the samples in a cooler at 4 °C, transported them to a laboratory, and then froze them at − 20 °C. Each sample was a mixture of three random subsamples. Prior to analysis, we air dried all samples at room temperature, sieved them through a 2 mm mesh, and then stored them in polyethylene bags at 4 °C. Using a pH meter (Sartorius PB-10, Germany) in water, we determined the soil pH with a water to soil sample ratio of 1:2.5 and measured the soil organic matter (OM) concentration using the potassium dichromate oxidation–ferrous sulfate titrimetric method (Yeomans and Bremner 1988). To determine the concentration of potentially toxic elements such as cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn), mercury (Hg), and arsenic (As), we prepared the samples using a solution of HCl and HNO_3 (3:1) preliminarily and then analyzed them using ICP-Mass Spectrometry.

The laboratory precision of this technique is determined by calculating the relative standard deviation (RSD) of each sample after measuring its contents seven times (Tepanosyan et al. 2018). RSD values of these samples inform the method precision for each element, which is 7.10%, 6.67%, 6.25%, 2.86%, 1.04%, 5.49%, and 3% for Cd, Pb, Cr, Cu, Zn, Hg, and As, respectively. The accuracy for the Cd, Pb, Cr, Cu, Zn, Hg, and As is 6.5%, 7.2%, 5.6%, 7.2%, 4.3%, 3.0%, and 1.15%, respectively. Based on these results, we found that the limit-of-detection (LOD) for Cd, Pb, Cr, Cu, Zn, Hg, and As is 0.01 mg/kg, 0.1 mg/kg, 4.0 mg/kg, 1.0 mg/kg, 0.5 mg/kg, 0.2 μg/kg, and 0.01 mg/kg, respectively.

Soil contamination status assessment

Geo-accumulation index

The geo-accumulation index (I_{geo}) is widely used to quantify the amount of and variation in the potentially toxic element contamination (Muller 1969; Zahra et al. 2014). We calculated the potentially toxic element I_{geo} concentration values for our study area using the equation (Muller 1969):

$$I_{geo} = \log_2(C_n/1.5B_n) \quad (1)$$

where C_n represents the measured concentration of a specific potentially toxic element n in mg/kg, B_n is the geochemical background value of the metal in the local soil parent material in mg/kg (Liao et al. 2011), and the constant 1.5 accounts for potential variation in the background values (Loska et al. 2004). The I_{geo} values are divided into seven classes referring to the Muller's method (Müller 1981).

Contamination index in different land use soils

To provide the assessment of the overall pollution status for a sample, the contamination index (I) of potentially toxic elements was calculated. For example, the contamination index for farmland is calculated using the following equation (He et al. 2019):

$$P_{(Fa)}{}^{i} = \frac{1}{n}\sum_{j=1}^{n}\left(N_{(Fa)}{}^{i}_{j}/N_{(Fa)}\right) \times 100\% \quad (2)$$

$$I_{(Fa)} = P_{(Fa)}{}^{i} \times S_i \quad (3)$$

where $P_{(Fa)}{}^{i}$ is the ratio of sample points with a specific geo-accumulation index I_{geo} found in an agricultural setting to the

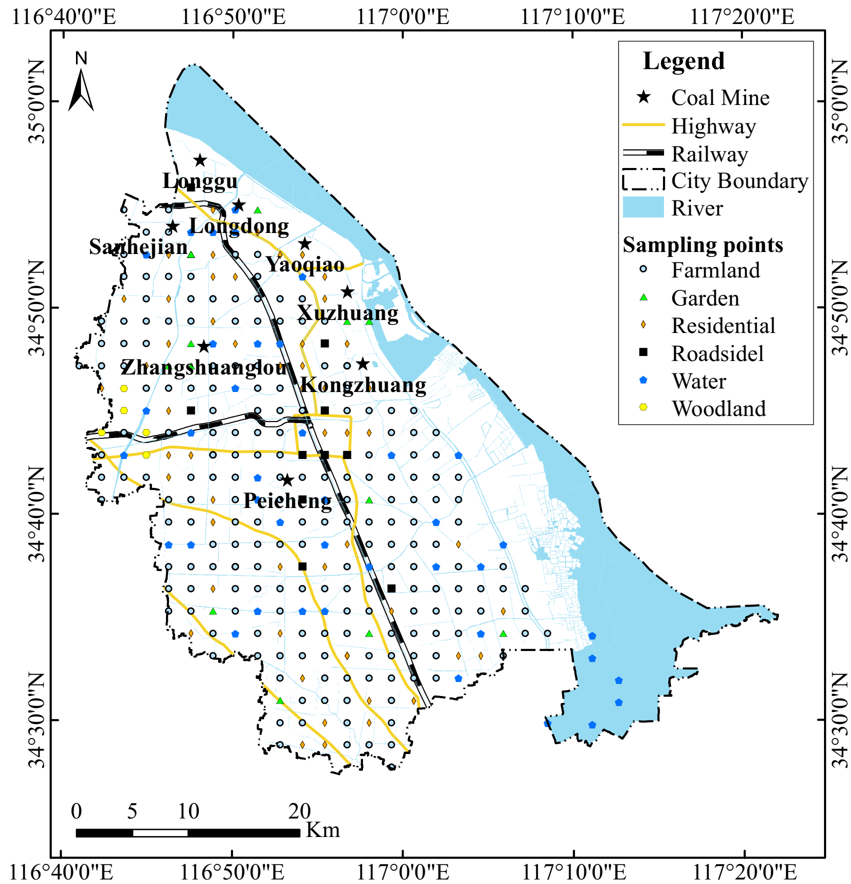


Fig. 1 Sampling locations in our study area

total number of samples collected in an agricultural environment, n is the number of potentially toxic elements, $N_{(Fa)}{}_j^i$ is the number of farmland sample points with contamination level i of metal j, $I_{(Fa)}$ is the comprehensive contamination risk of the potentially toxic elements in an agricultural setting, and S_i represents the toxicity coefficient of the different contamination classes, where Class 0, Class 1, Class 2, Class 3, Class 4, Class 5, and Class 6 are 1, 2, 3, 4, 5, 6, and 7, respectively.

The comprehensive contamination risk indices of the potentially toxic elements in residential, roadside, garden, woodland, and water environments are $I_{(Re)}$, $I_{(Ro)}$, $I_{(Ga)}$, $I_{(Wo)}$, and $I_{(Wa)}$, respectively. A higher I value is associated with heavier toxicity, while a lower I value represents a lesser degree of toxicity.

Statistical analysis

Multivariate statistical analysis

Shapiro-Wilk normality tests were used to check the normality of potentially toxic elements distribution. The results (Table S1) indicated the samples obtained in this study are not normally distributed data. Therefore, Kendall's tau-b correlation was selected to calculate correlations among potentially toxic elements due to its wide applicability. And we used principle component analysis (PCA) to further reduce the data dimensionality and to look for the source of the contamination (Dos Santos et al. 2017; Han et al. 2016). Additionally, we used hierarchical cluster analysis (HCA) to emphasize the heterogeneity between groups of toxic elements, as well as the homogeneity within them, which allowed us to examine the strength of the correlation between the potentially toxic element concentrations and the soil properties. The various statistical methods were performed for a 99% confidence interval (significance $P < 0.01$).

Geostatistical analysis

Kriging spatial interpolation is widely used to refine spatial models by interpolating new values based on existing model data; it is especially valuable in geostatistical analyses because the linear unbiased estimator minimizes model variance (Tavares et al. 2008). After plotting our data in ArcGIS (Version 10.2), we used the kriging spatial interpolation method to infer additional data points in the spatial distribution trend of different potentially toxic elements.

Health exposure risk assessment

Using the method proposed by the US Risk Assessment Information System (RAIS), we determined the human health exposure to potentially toxic elements for both children and adults. In this study, we estimated the average daily intake (*ADI*) (mg/(kg day)) using the following equation:

$$ADI = \frac{C \times EF \times ED \times IngR \times RBA}{AT \times BW} \times 10^{-6} \quad (4)$$

where the different elements of Eq. 4 are defined in Table S2. We calculated the non-carcinogenic risk of a specific single metal hazard quotient (*HQ*) and the multi-elemental hazard index (*HI*) for children and adults with the following equations:

$$HQ_i = ADI_i / RfD_i \quad (5)$$

$$HI = \sum_{i=1}^{n} HQ_i \quad (6)$$

If *HQ* and *HI* are greater than 1, then it is likely that the contamination due to potentially toxic elements will cause adverse health effects; if they have values less than 1, the risk of significant non-carcinogenic effects for those exposed is minimal (Gray 1990).

Analysis of the livability

We determined the livability level (*LL*) by calculating the sum of the I_{geo} and *HQ* values for only those potentially toxic elements with I_{geo} or *HQ* values greater than 1. Then, we divided the *LL* values into four levels (livable, relatively livable, unlivable, and extremely livable) in ArcGiS (Version 2.0) using kriging interpolation.

Results and discussion

Analysis of potentially toxic element concentrations

Based on our analyses, the potentially toxic element concentrations in topsoil correlate with different land use patterns, vehicular traffic, human activities, and pollution histories (Table 1) (Argyraki et al. 2018; Lee et al. 2006). Woodland and garden samples were the least contaminated, while the total concentration levels of seven potentially toxic elements ($\sum metals$) were higher in water and roadside sample soils. Potentially toxic element occurrence in soil can be a byproduct of both natural processes (e.g., erosion, atmospheric deposition, and weathering) and anthropogenic activities (e.g., sewage discharge and agricultural/industrial runoff) (Mondal et al. 2018). For example, a serious concern in Peixian City is the presence of contaminated water runoff due to underground mining activities (Yang et al. 2017). Vehicle emissions from both normal traffic and the transportation of coal contribute to the high levels of potentially toxic elements in roadside soils (Liu et al. 2018). The high concentrations of potentially toxic elements in farmland soils have been attributed to the application of agrochemicals, fertilizers, long-term sewage irrigation, and atmospheric deposition (Hou et al. 2014). Our data show that the woodland soils are mostly uncontaminated by these elements; this observation is in line with our understanding that one of the best remedies for toxic elemental pollution is arboreal or vegetation reforestation because the presence of vegetation can alter soil properties and enhance the adsorption capacity of potentially toxic elements (Xiao et al. 2016).

Most of the potentially toxic element concentrations (except Cu and As) do not exceed the soil national second standards (China 1995; State Environmental Protection Agency of China S 1995). However, Hg, Cd, and Cu pollutant concentrations exceeded the mean elemental concentrations

Table 1 Descriptive statistics of soil properties and potentially toxic element concentrations in different land use cases

Characters	Units	Farmland ($n = 206$)	Residential ($n = 56$)	Roadside ($n = 10$)	Garden ($n = 15$)	Woodland (n = 5)	Water ($n = 40$)	All samples ($n = 332$)
pH		8.2 ± 0.18	8.21 ± 0.13	8.26 ± 0.14	8.25 ± 0.14	8.41 ± 0.13	8.18 ± 0.17	8.21 ± 0.17
OM	%	1.55 ± 0.53	1.50 ± 0.40	1.63 ± 0.45	1.34 ± 0.59	1.05 ± 0.16	1.66 ± 0.54	1.54 ± 0.51
Cd	mg/kg	0.16 ± 0.05	0.15 ± 0.04	0.17 ± 0.04	0.15 ± 0.06	0.11 ± 0.01	0.17 ± 0.06	0.16 ± 0.05
Pb	mg/kg	21.05 ± 4.12	20.90 ± 4.40	22.17 ± 4.85	20.10 ± 4.47	16.82 ± 0.85	21.97 ± 4.52	21.07 ± 4.25
Cr	mg/kg	67.87 ± 9.24	66.33 ± 6.75	66.65 ± 6.98	65.77 ± 8.36	62.18 ± 1.78	72.48 ± 19.97	67.97 ± 10.79
Cu	mg/kg	23.14 ± 6.19	22.60 ± 5.35	25.21 ± 6.47	23.32 ± 6.98	16.8 ± 1.14	33.55 ± 44.83	24.33 ± 16.99
Zn	mg/kg	67.16 ± 14.51	65.75 ± 13.21	70.54 ± 17.8	64.24 ± 20.21	48.58 ± 2.61	71.35 ± 16.59	67.14 ± 14.99
Hg	mg/kg	0.03 ± 0.01	0.04 ± 0.03	0.03 ± 0.01	0.03 ± 0.02	0.02 ± 0.01	0.04 ± 0.01	0.03 ± 0.02
As	mg/kg	10.45 ± 2.95	10.08 ± 2.78	11.23 ± 3.01	10.06 ± 3.17	7.85 ± 0.76	11.78 ± 4.29	10.52 ± 3.14
$\sum metals$		189.86 ± 37.07	185.85 ± 32.56	196.00 ± 39.16	183.67 ± 43.27	152.36 ± 7.15	211.34 ± 90.27	191.22 ± 50.23

throughout Jiangsu Province by 138%, 86%, and 38%, respectively. Moreover, the highest Hg, Cd, and Cu concentrations exceeded the mean province values by 1400%, 281%, and 358%, respectively. The mean concentration value of these elements throughout Jiangsu Province are shown in Table S3.

Hg patterns have more spatial variation (coefficient of variation (CV) value of 66.67%), while other potentially toxic elements (CV values ranging from 15 to 35%) had a more uniform spatial distribution (Zhang et al. 2018).

Pollution status of the examined soils

Using the I_{geo} value to describe the potentially toxic element contamination levels, Peixian City has little to no contamination from Pb, Cr, Cu, Zn, and As ($I_{geo} < 0$) but maybe moderately contaminated by Cd and Hg. I_{geo} levels of Cd range from − 0.5178 to 1.3446 with an average value of 0.2542, and I_{geo} levels of Hg range from − 0.6919 to 3.3219 with an average value of 0.5430. The highest Hg I_{geo} value (3.3219), located in the subsidence area of the Xuzhuang coal mine, indicates high levels of contamination. The coal mining subsidence area is a specific but common system in China; mining activities result in potentially toxic element pollution in the groundwater that eventually makes its way into nearby soils via flooding and rainfall.

The contamination index (*I*) results vary greatly by land use type. To be specific, the $I_{(Wa)}$ value (146.94) was the highest, followed by $I_{(Ro)}$ (142.86), $I_{(Fa)}$ (136.06), $I_{(Re)}$ (135.71), $I_{(Ga)}$ (133.33), and $I_{(Wo)}$ (108.57). Our results show that that potentially toxic element pollution should be considered a serious threat to aquatic ecosystems in Peixian City. Potentially toxic elements enter these aquatic ecosystems through erosion, atmospheric deposition, and contaminant-rich municipal, domestic, and industrial wastewater (Demirak et al. 2006). Additionally, metals in suspended particulates migrate through the water and settle in sediments; these particulates can persist for long periods of time (Islam et al. 2018). Sediment contamination, which may pose a serious threat to human health through absorption into the food chain, is one of the largest contributors to the contamination of aquatic bodies (Zhang et al. 2017).

Kendall's tau-b correlation, HCA, and PCA analysis

It is important to quantify the relationship between pH and the potentially toxic element concentration because soil pH strongly influences the adsorption and solubility of these elements in soils (Khan et al. 2008; Zhao et al. 2011). The Kendall's tau-b correlation matrix of soil properties and potentially toxic elements, calculated for a 99% confidence level, is presented in Table 2. While previous work yielded a positive correlation between the potentially toxic element concentrations and pH values in the Wunugestushan Mine (Wang et al. 2018), our data showed that the potentially toxic element concentrations and the pH values are negatively correlated, a discrepancy that can be explained by the different pH values in the two study areas. Specifically, 95.7% of the Wunugestushan Mine samples had pH values close to 7.0, while 90.96% of our samples had pH values higher than 8.0, indicating that our soil samples are alkaline, rather than neutral in acidity.

Potentially toxic element concentrations correlated positively with one another, and correlation coefficients are typically high, which indicates that there is a possibility that some of these metals have a common source (Hani and Pazira 2011).

HCA was implemented to datasets to optimize the heterogeneity between groups as well as the homogeneity within them. The 'between groups' method and Squared Euclidean distance similarity measure were adopted, and standardized values of all variables were used by transforming data into Z scores. The HCA results, which involve the formation of three distinct clusters, are shown in the dendrogram in Fig. 2 (a). The first cluster includes Cu, As, Zn, Cr, Pb, OM, and Cd, while the second and third clusters include Hg and pH, respectively.

PCA was implemented to reduce data dimensionality and to find responsible elements of surface sediments contamination. The KMO (0.89) and Bartlett's test ($p < 0.001$) results in PCA showed that it could be used to analyze the dataset. As shown in Fig. 2 (b), the first two components are extracted with eigenvalues > 1 (PC1 = 6.08 and PC2 = 1.27), which explains 81.70% of the total variance. The table of PC loading of each element is presented in Table S4. PC1 alone explains 67.58% of the total variance and showed strong positive loading for As, Cu, Cr, Zn, Pb, and Cd and moderate positive loading for OM. Based on these results, we infer that these metals may have a common source. OM plays an important role in the transport and retention of metals in soils via physical sorption and precipitation (Huang et al. 2017), so it is not surprising that we also observed a positive correlation between the total potentially toxic element content and OM, which matches previously published results for the Wunugestushan Mine soils from north China (Wang et al. 2018). PC2, which explains 14.12% of the total variance, is correlated positively with Hg and negatively with pH. The HCA, PCA, and Kendall's tau-b correlation coefficient results all indicate that the source of the Hg contamination is different from those of the other potentially toxic element. To robustly determine the source of the potentially toxic element contamination, we recommend that additional geostatistical analyses should be performed (Zhou et al. 2014).

Table 2 Kendall's Tau-b correlation matrix for potentially toxic element concentrations and other soil properties

Characters	pH	OM	Cd	Pb	Cr	Cu	Zn	Hg	As
pH	1.000								
OM	− 0.370**	1.000							
Cd	− 0.263**	0.693**	1.000						
Pb	− 0.285**	0.560**	0.597**	1.000					
Cr	− 0.207**	0.332**	0.358**	0.558**	1.000				
Cu	− 0.192**	0.479**	0.571**	0.659**	0.497**	1.000			
Zn	− 0.296**	0.569**	0.649**	0.760**	0.571**	0.752**	1.000		
Hg	− 0.263**	0.524**	0.459**	0.396**	0.201**	0.370**	0.417**	1.000	
As	− 0.170**	0.341**	0.457**	0.643**	0.609**	0.680**	0.708**	0.237**	1.000

**represents significant correlation at the 0.01 level

Spatial distribution of potentially toxic elements

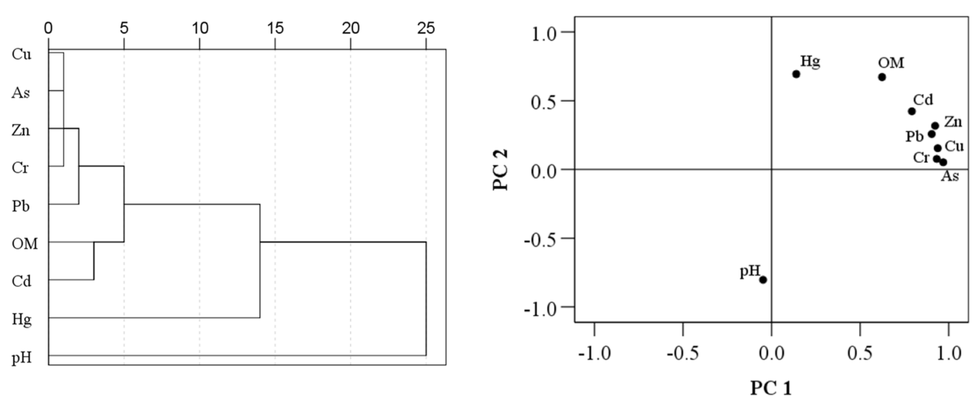
Fig 3 shows the spatial distribution patterns of the potentially toxic element concentrations. Because Cr, Zn, Cu, Pb, Cd, and As trend with one another and with total potentially toxic element concentrations, we conclude that these potentially toxic elements may have similar natural anthropogenic sources. Conversely, the spatial patterns of Hg indicate that this metal may have a source that is different than those of the other potentially toxic elements. This spatial information provides further confirmation for the results of the HCA, PCA, and Kendall's tau-b coefficient analyses.

The midwest area of Peixian City is characterized by high total potentially toxic element concentrations, which may be caused by its unique geographical location. First, this area is close to the center of the city and is surrounded by shops and restaurants; dense populations and commercial activities can increase the potentially toxic element concentrations (Cao et al. 2014). Second, human mining activities are a well-known source of potentially toxic element pollution (Tang et al. 2013), and the high pollutant concentration region of Peixian City is adjacent to the Kongzhuang and Peicheng coal mines. Third, ship emissions can contribute to the potentially toxic element contamination of nearby soil (Cao et al. 2018; Zhuang et al. 2016); the nearby Beijing-Hangzhou grand canal, as a five-level channel, has a significant amount of ship traffic on a daily basis. Fourth, industrial runoff may have contaminated nearby Weishan Lake, which in turn can cause contamination of the soil during flood season. Finally, agricultural byproducts from adjacent farmland, such as livestock manure, which shows high concentrations of Cd and Zn (Cai et al. 2015; Peng et al. 2019), can provide an additional source of potentially toxic element pollution in the topsoil. The highest Hg concentrations occurred in the south part of our study area. The contamination level of Hg appears to be severe because of human mining activities, particularly when human activities involve the transfer of a large amount of Hg from deep geologic stores to earth-surface reservoirs (Engstrom et al. 2014).

Human health risk assessment

Table 3 shows the results of the non-carcinogenic health risk assessment for children and adults, assuming an ingestion

Fig. 2 HCA and PCA of potentially toxic element concentrations and other soil properties. (**a**) Dendrogram derived from hierarchical clustering analysis. (**b**) Loading plot for rotated components produced by PCA



(a) Dendrogram derived from hierarchical clustering analysis

(b) Loading plot for rotated components produced by PCA.

Fig. 3 Spatial distribution of potentially toxic elements (Cd, Pb, Cr, Cu, Zn, Hg, and As) in urban soils

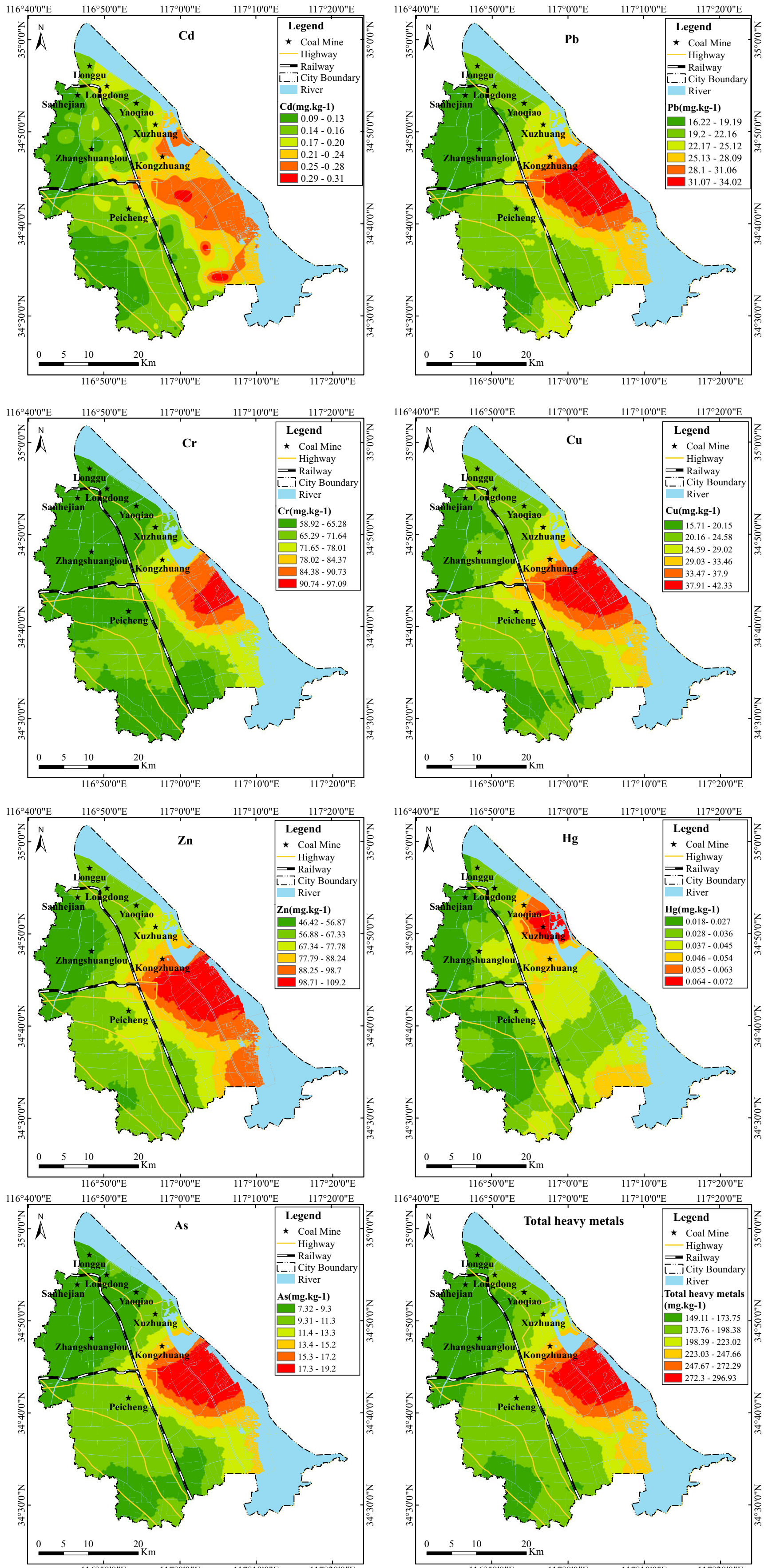


Table 3 Human health risk of the potentially toxic elements in Peixian City soils

Characters	Children			Adults		
	Min	Max	Mean	Min	Max	Mean
Cd-HQ	3.75E − 03	1.36E − 02	6.68E − 03	4.02E − 04	1.46E − 03	7.15E − 04
Pb-HQ	**1.32E + 00**	**3.57E + 00**	**1.92E + 00**	1.42E − 01	3.83E − 01	2.06E − 01
Cr-HQ	4.67E − 04	8.78E −04	5.76E − 04	5.00E − 05	9.41E − 05	6.17E − 05
Cu-HQ	4.57E − 03	1.37E − 02	7.45E − 03	4.90E − 04	1.47E − 03	7.98E − 04
Zn-HQ	1.82E − 03	4.86E − 03	2.86E − 03	1.95E − 04	5.21E − 04	3.07E − 04
Hg-HQ	1.04E − 03	1.68E − 02	2.66E − 03	1.11E − 04	1.80E − 03	2.84E − 04
As-HQ	8.08E − 02	2.68E − 01	1.34E − 01	5.19E − 03	1.73E − 02	8.61E − 03
HI	**1.45E + 00**	**3.71E + 00**	**2.08E + 00**	1.51E − 01	3.92E − 01	2.17E − 01

Bold represents values greater than 1

pathway via contamination of the soil. The non-carcinogenic health risk caused by exposure to these potentially toxic elements is higher for children than it is for adults (Chabukdhara and Nema 2013; Tepanosyan et al. 2018). For the potentially toxic elements in our study area, the *HQ* values were below the safe level of 1, indicating there is no severe non-carcinogenic health risk for adults in this environment. However, Pb may pose a non-carcinogenic risk to children, a conclusion that supports similar findings for certain locations in India (Singh et al. 2018). Chronic exposure to Pb can lead to nervous, circulatory, endocrine, and skeletal diseases, as well as immune system damage (Pareja Carrera et al. 2014). Special measures must be taken to protect children, who are more vulnerable to the Pb pollution in our study area.

Urban livability analysis

Urban livability is a multifaceted concept encompassing the natural environment, health and social services, leisure, culture, and more (Badland et al. 2014). Based on our analysis,

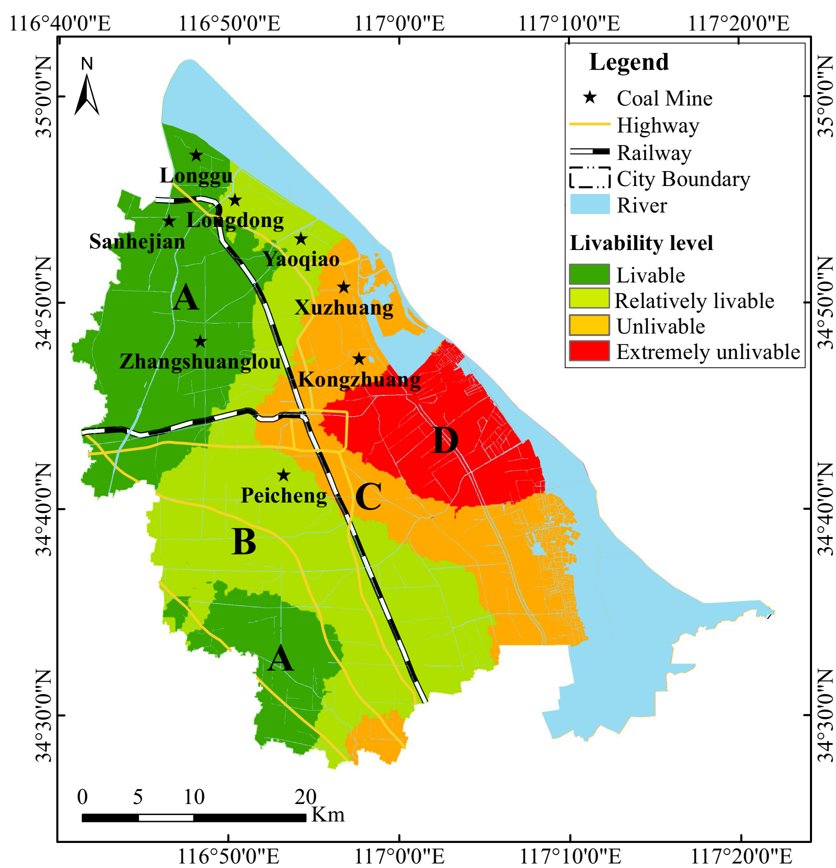


Fig. 4 Distribution of livability values in Peixian City

the livability level is higher in the western part of Peixian City than it is in the eastern part. More specifically, areas A and B have the highest livability values, area C has a more moderate livability value, and area D has the lowest livability value (Fig. 4). In general, 62.5% of our study area is classified as livable.

Because Pb contamination levels are highly correlated with total potentially toxic element concentrations, the Pb level may be a good indicator of the total potentially toxic element concentration in our study area. Additionally, Pb is the only potentially toxic element occurring in high enough concentrations to potentially pose a health risk to children. As a result, the livability results largely track with the spatial distribution trends of Pb. Therefore, urban planners should assess the sources and contamination levels of Pb when making decisions in the future.

Conclusion

This study is the first to characterize and identify the sources of the potentially toxic element pollution in Peixian City. The results show that the combination of Kendall's tau-b correlation analysis, HCA, PCA, and geostatistical analyses can be used to identify potential sources for these potentially toxic elements. Cr, Zn, Cu, Pb, Cd, and As most likely share a common source. Possible sources of contamination could be commercial activities, coal mining activities, water transportation, power generation, or livestock manure. The highest Hg level is most likely due to human mining activities. Of all of the potentially toxic element contaminants we examined, Pb is the only element that poses a non-carcinogenic health risk to children, even if the levels are not high enough to be a risk to the adults in our study area. Urban livability levels in Peixian City are higher in the western part of the city than they are in the eastern part.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The authors of this article did not perform any studies with human or animal participants.

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