



Influence factor analysis of soil heavy metal based on categorical regression

J. Xu¹ · P. Xiao²

Received: 16 July 2021 / Revised: 20 August 2021 / Accepted: 30 August 2021 / Published online: 13 September 2021
© Islamic Azad University (IAU) 2021

Abstract

Determining the factors that affect the heavy metal components of soil can reveal the source of and to prevent and control heavy metal pollution in soil. After sampling, screening, testing, and other steps, the amounts of various heavy metals in 975 sampling points were obtained. The heavy metal data were associated with eight different environmental factors, and the impact of each factor on the heavy metal components of soil in Xiangzhou District was studied by means of categorical regression. The research result and analysis shows that the way land is used, and industrial production and soil type are the key elements that impact the dispersion of heavy metals in the soil in Xiangzhou District. At the same time, the interaction among factors such as the slope, the traffic distance, the way the land is used, and the soil type can affect the lead, cadmium, and mercury contents of the soil. Analysis and research of the hot spots of heavy metals in the soil found a good spatial correlation between the heavy metal distribution in the soil and some factors, such as soil parent material, industrial activities, and population density. Some hot spots of heavy metal pollution correspond to indicators such as population density and industrial activities. Although categorical regression is less used in heavy metal research, it is an appropriate method to find out factors affecting the heavy metal contents of soil, which can provide a new perspective for future researchers.

Keywords Categorical regression · Factor identification · Heavy metal · Soil

Introduction

The roots of food crops and industrial crops can imbibe the heavy metal components of soil (Tauqeer et al. 2021a, b; Tauqeer et al. 2021a, b; Iftikhar et al. 2021; Turan 2021a, b). These enter the human body by means of the food chain and have a huge negative impact on human physical and mental health (Tauqeer et al. 2021a, b; Tauqeer et al. 2021a, b; Iftikhar et al. 2021; Turan 2021a, b). Analyzing the factors affecting the extent of soil pollution by heavy metal components through technical means can help determine the reason for the heavy metal pollution and also help propose heavy metal control measures (Sucharova et al. 2011). Both

synthetic and natural factors cause deposition of heavy metals in soil far beyond what nature can process. Among the natural factors impact the heavy metal components of soil are parent material (He et al. 2017; Afu et al. 2020; Zinn et al. 2020), topography (Ahn and Lee 2011; Chen et al. 2012; Liu et al. 2016), and soil type (Uchimiya et al. 2010; Tumanyan et al. 2019). Human factors mainly include the waste from industrial production (Zhou et al. 2016; Zhang et al. 2018; Gao and Wang 2018), mining activities (Nawab et al. 2015; Zhu et al. 2018; Qin and Huang 2019), pesticide input and agricultural fertilizer (Rui et al. 2016; NING et al. 2017; Turan et al. 2017, 2018; Turan 2019, 2020; Wang et al. 2020a, b), land use type (Tian et al. 2020a, b; Tian et al. 2020a, b; Sun et al. 2020), and automobile exhaust from traffic activities (Guney et al. 2010; De Silva et al. 2016; Dongping et al. 2019), which contribute a lot to heavy metal emission.

There are many methods for determining the distribution and contents of heavy metal in the soil, for example, statistical analysis, isotope tracer, geographical detector, and geostatistics. The more common applications of statistical analysis methods are principal component analysis, clustering, and correlation analysis through research and discussion of the

Editorial responsibility: J Aravind.

✉ P. Xiao
maikedang@mails.ccnu.edu.cn

¹ Faculty of Resources and Environmental Science, Hubei University, Wuhan 430062, China

² The College of Urban and Environmental Sciences, Central China Normal University, Wuhan 430079, China



internal relationship between elements; classification of the elements with good correlation into the same group; and determination of different categories of influencing factors by using prior knowledge or through investigation (Huo et al. 2012; Shi et al. 2013; Lv 2019). Objective data, such as isotopic proportions of different sources, are used by the isotope tracer technology to find out the source of soil pollutants (Norbu et al. 2017; Sun et al. 2017; Jiang et al. 2019). A geographical detector uses the spatial variability of geographical variables, which calculates the impact environmental variables have on dependent variables (Qiao et al. 2017, 2019; Luo et al. 2019). The key factors that affect the dependent variables can be determined by combining the degree of change in environmental variables.

In fact, ordinal, numerical, and nominal variables all affect heavy metal contents of the soil. Categorical regression (CATREG) can scale these variables. Compared with the methods mentioned earlier, the CATREG analysis used in this study is more advantageous when applied to investigate the sources of the heavy metal contents of soil. For example, Figueiredo et al. used CATREG to analyze the factors that affect the self-evaluation of health by the elderly in Brazil and found that difficulties in dressing, feeding, and seeking medical treatment influence this self-evaluation to a large extent (Figueiredo et al. 2019). Wang et al. used CATREG to analyze the factors affecting the Chinese public's cultural participation and found that major, income level and other factors affect the public's participation in museums (Wang et al. 2020a, b). Lu et al. established a relationship model between landscape types and perception factors by using the CATREG method. The results showed that waterfront space has the best effect on perceptual attention recovery, followed by vegetation space, courtyard space, and square space (Lu and Fu 2019). These studies clearly indicate an effective analysis method to study and analyze the core elements influencing the dispersion of heavy metal contents of the soil. After analyzing the environmental factors that affect heavy metal contents in the soil, the classification method is used to quantitatively analyze each factor's influence on heavy metal contents of the soil, which is one of the few applications of the CATREG method in the traceability analysis of heavy metals in soil. In practical application, this method is particularly effective in identifying factors influencing of soil heavy metals in soil when there are both ordinal, numerical, and nominal variables. Although this method is not widely used in this field, it can provide another perspective and technical support to identify sources responsible for the pollution of soil by heavy metals.

Materials and methods

Research area

The area of Xiangzhou District (Xiangyang City, Hubei Province, China) is 2306 km² and includes 12 townships.

In 2018, the total permanent population of the administrative region reached 1.2 million and the gross domestic product (GDP) was 69.623 billion yuan. The industry in the whole district is relatively developed and forms four pillar industries of agricultural product processing, electromechanical auto parts, equipment manufacturing, and textile and clothing. The Xiangzhou area is rich in minerals. As many as 56 kinds of mineral resources have been recognized and exploited. As can be seen in Fig. 1a, geographically, the entire Xiangzhou area presents a half-moon structure. The overall geography of Longgang area in the north is the main structure. The southern and central areas are bottom hills and floodplains, respectively. According to statistics and Fig. 1b, by the end of 2019, the total length of roads in Xiangzhou District reached 4,419 km, including three expressways of 104.09 km, class I highway of 238.18 km, and class II highway of 289.73 km.

CATREG

The factors affecting heavy metal contents of soil were classified per the survey data. Ordinary linear regression has strict data requirements and cannot precisely correspond to the distances of different values of categorical variables. So, ordinary linear regression cannot be used to analyze the data. CATREG, which is a nonparametric multiple regression analysis, can be performed when only categorical variables or both categorical and numerical variables are available. It transcends the limitations of categorical variables on the choice of analysis model and enhances the capabilities of regression analysis. Therefore, CATREG is a better choice (Almeida and Garrod 2018; Figueiredo et al. 2019; Lu and Fu 2019).

The key step in the CATREG method is to convert qualitative variables into quantitative variables through the optimal scaling process (Yang et al. 2020). Optimal scaling is used to allocate quantitative values to the category of each variable, which enables the use of the standard process to find the solution of the quantified variable (Majumdar and Pujari 2021). The optimal scale value is allocated to each variable according to the optimization criteria of the process used. These scale values possess metric properties in contrast to the original labels of nominal or ordered variables in the analysis (Borishade et al. 2021). Regarding most classification tools and methods, an iterative method, namely alternating least squares, uses the current quantitation to measure the optimal quantification of each scaled variable (Lin et al. 2020). The quantitation used to find the solution in this case is updated as well. The updated quantitation is, in turn, used to find a new solution, which is further used to update the quantitation (Gundacker et al. 2009). This process continues until a certain criterion for notifying the process to stop is reached (IBM 2020).



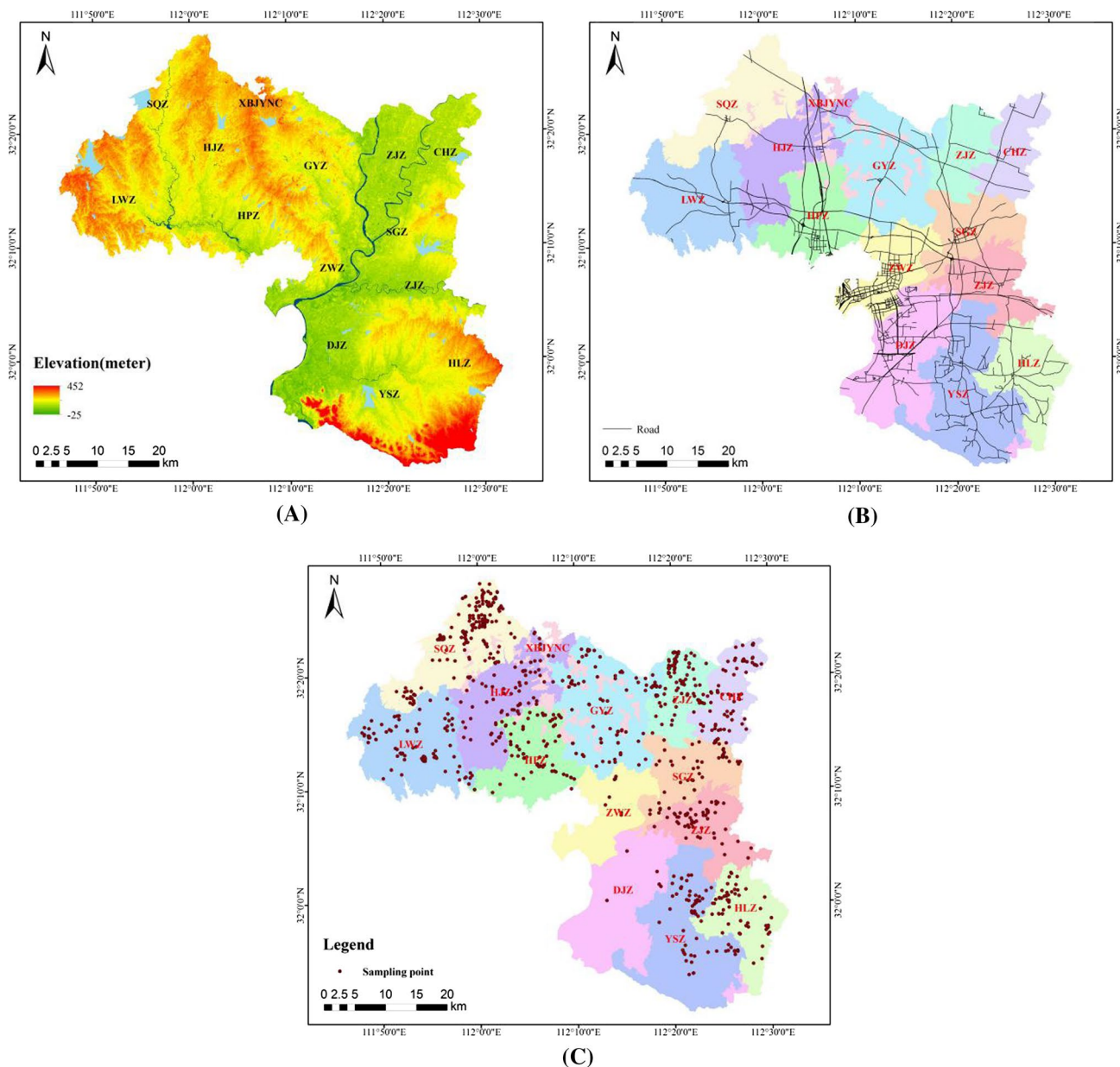


Fig. 1 Key information about the area under study. **a** Topography and elevation, **b** traffic network, and **c** distribution of sampling points

The analysis menu from the menu bar of SPSS 26.0 software was selected, and then, the optimal scale (CATREG) from the drop-down menu of regression was selected. In the pop-up dialog box, independent variables, the values and proportions of dependent variables, and regularization and discretization are set, and then the program is executed. According to the results, whether the predictor itself is significant in the field of statistics also needs to be scientifically verified. Therefore, when qualitative predictors are replaced by transformed (quantified) values, CATREG is equivalent to ordinary linear regression (Xu et al. 2015).

Influence factors

Natural and human factors impact the heavy metal components of soil significantly. As is evident from Table 1 and Fig. 2, after combining the analysis of the above factors, eight core influencing factors were selected. Soil parent material, soil type, and topography are important components of natural factors. Among human factors, the land use type, population density, contaminated area, industrial activities, and traffic actions are causes of varying degrees of the heavy metal pollution of soil.

Table 1 Variables and its categories

Influence factors	Input type	Categories
Soil parent material	Nominal	1 = Recent sediment, 2 = quaternary sediment, 3 = carbonate
Types of soil	Nominal	1 = Alluvial soil, 2 = submerged paddy soil, 3 = calcareous alluvial soil, 4 = brown rendzina, 5 = yellow-cinnamon soil, 6 = waterlogged paddy soil, 7 = yellow brown soil
Types of land use	Nominal	1 = Dry land, 2 = irrigated land, 3 = paddy field
Contaminated area	Ordinal	1 = Noncontaminated area, 2 = scope of pollution
Slope (°)	Numeric	–
Traffic action (m)	Numeric	–
Industrial output (million yuan/km ²)	Numeric	–
Population concentration (people/km ²)	Numeric	–

Soil parent material

The basic substance that forms the soil is called the soil parent material. Soil formation is directly impacted by some of the soil parent material characteristics, such as mechanical composition, mineral composition, and chemical properties. In other words, the soil parent material is an important natural origin of the heavy metal contents of soil, because of which the heavy metal contents of soil are also differ (Verbree et al. 2015; Augusto et al. 2017; Zinn et al. 2020). Hong et al. evaluated the influence of parent materials on how potential toxic elements (PTEs) are distributed in the soil. The results showed that oxides and phosphorus differently concentrate in soils with different parent materials and this difference is systematic, indicating that the parent materials mainly impact the soil element distribution (Hou et al. 2020). In Fig. 2a, the soil map of Xiangzhou District shows that there are three kinds of soil parent materials: carbonate, quaternary sediment, and recent sediment.

Soil type

Different soil types lead to great differences in some indicators of the soil, such as soil texture, soil nutrient status, and soil aggregate structure. As a result, the extent to which heavy metals in the soil are enriched also varies, as does the impact transfer process of heavy metals in the surficial milieu (Dube et al. 2001). Kandpal et al. reported that the capacities of different soil types naturally adsorb heavy metal ions are quite different, resulting in different heavy metal contents (Kandpal et al. 2005). In Fig. 2b, it can be seen from the classification standard of soil genesis that there are seven types of soil in Xiangzhou District: brown rendzina, alluvial soil, submerged paddy soil, waterlogged paddy soil, yellow-cinnamon soil, calcareous alluvial soil, and yellow–brown soil.

Slope

A larger slope will produce larger-scale runoff, leading to larger erosion of soil particles carrying heavy metals, changing the original pattern of how heavy metal contents are

spatially distributed in the soil (Ciszewski et al. 2012). Chen et al. used DEM data, remote sensing images, and land use data to map the copper's and lead's distributions on the surface of Le'an River and its tributaries. The results showed that the spatial distribution of copper and lead is mainly influenced by topography (Chen et al. 2012). In ArcGIS software, spatial analysis is used to obtain the slope value of each sample point. As shown in Fig. 2c, from the perspective of topography, the entire Xiangzhou District is flat; only some places at the southernmost end have a slope greater than 25°.

Land use type

Land uses differ because of the differences in the investments of the region's administration in human resources, leading to the setting up of different industries, such as agricultural industry, plastic film, machinery, and pesticides and fertilizer, resulting in different heavy metal contents of soil (Kuusisto-Hjort and Hjort 2013; Qinghe et al. 2013). Xu et al. identified the heavy metals As, Hg, Zn, Ni, Pb, Cd, and Cu in 107 soil samples from farmlands, orchards, greenhouses, and woodlands in Beijing suburbs and found that the gradation of noncancerous hazards due to different land use types for children and adults is as follows: greenhouses > orchards > woodlands > crop lands (Xu et al. 2016). As shown in Fig. 2d, three kinds of land usage are found in Xiangzhou District: irrigated land, dry land, and paddy field.

Traffic activity

The soil distributed on both sides of the road is polluted by heavy metals produced by traffic activities, and the pollutants deposited by the exhaust gas from automobiles can be detected within 50 m on both sides of the road (Swaleh et al. 2004). The results of some studies show that the heavy metal contents of the soil on both sides of the road are affected not only by the distance between the main road and the branch road but also by the traffic volume (Wang et al. 2016; Du et al. 2019). Regarding the distance between the sample and the road, the quantification calculation is mainly performed



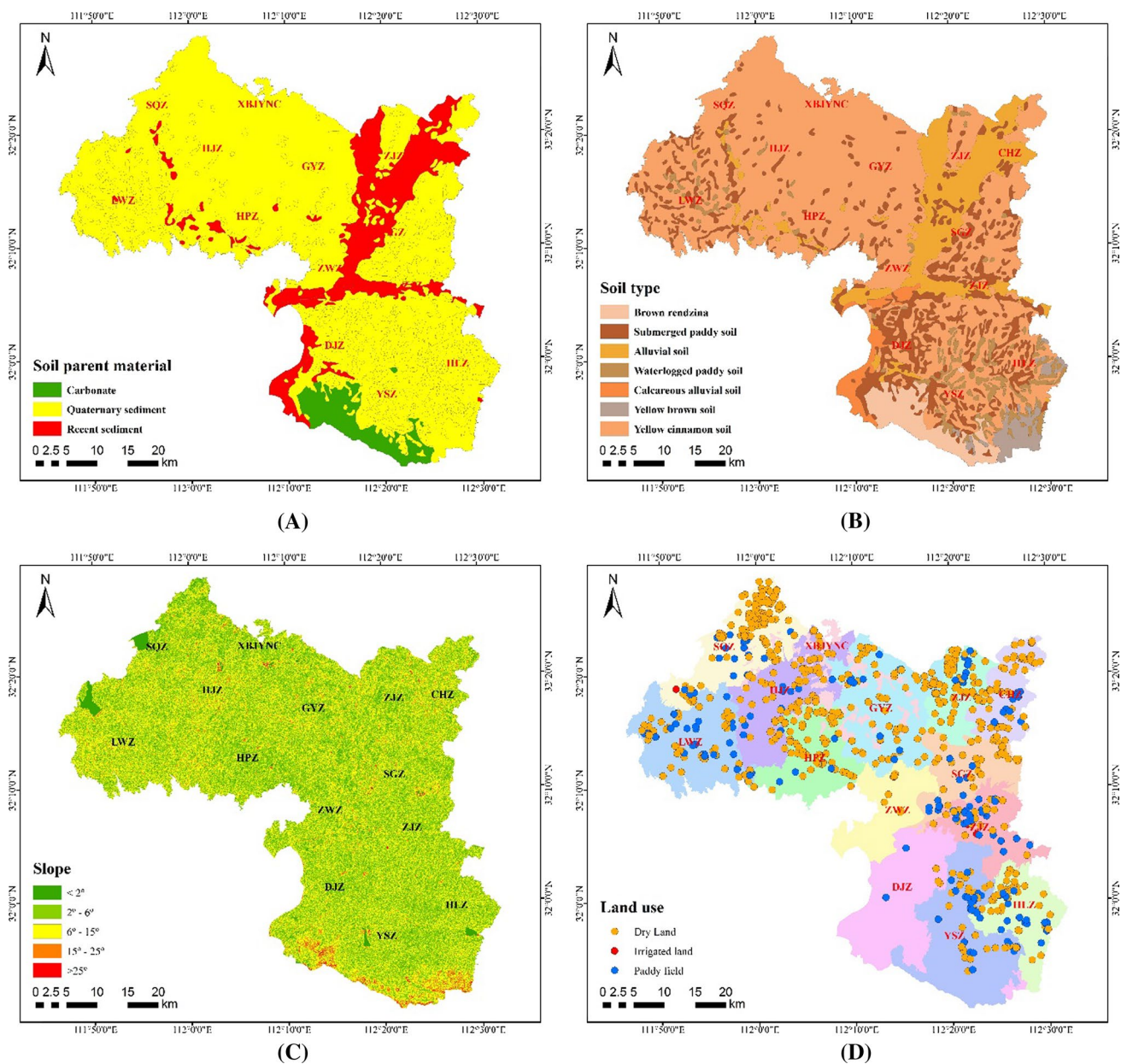


Fig. 2 Factors affecting heavy metals in the soil. **a** Soil parent material, **b** soil type, **c** slope, **d** type of land usage, **e** traffic activity, **f** contaminated area, **g** industrial production, and **h** population density

with the help of the ArcGIS distance function. Combined with the content presented in Fig. 2e, the red area reflects the buffer area corresponding to the 70 m position of the road, the orange area represents the corresponding buffer area within 70 to 150 m on the road, light green is used to represent the 150–300 m buffer zone on the road, and green is used for the area 300 m away from the road.

Contaminated area

Pollution emissions can cause heavy metal contamination of soil. Considering the characteristics of farmland soil

irrigation and pollutant discharge, Xiangzhou District can be divided into a pollution-free and a polluted area. According to the content of Fig. 2f, the purple dots refer to pollution sources that cause the pollution, mainly water pollution, soil pollutions, and air pollution. The red dots represent the location of the city's mining areas. These locations will inevitably have heavy metals exceeding the standard, and the impact on the surrounding environment is inevitable. The yellow zone represents a 2 km buffer zone for each pollution source and the mining area, and the soil within this area is highly likely to be contaminated.

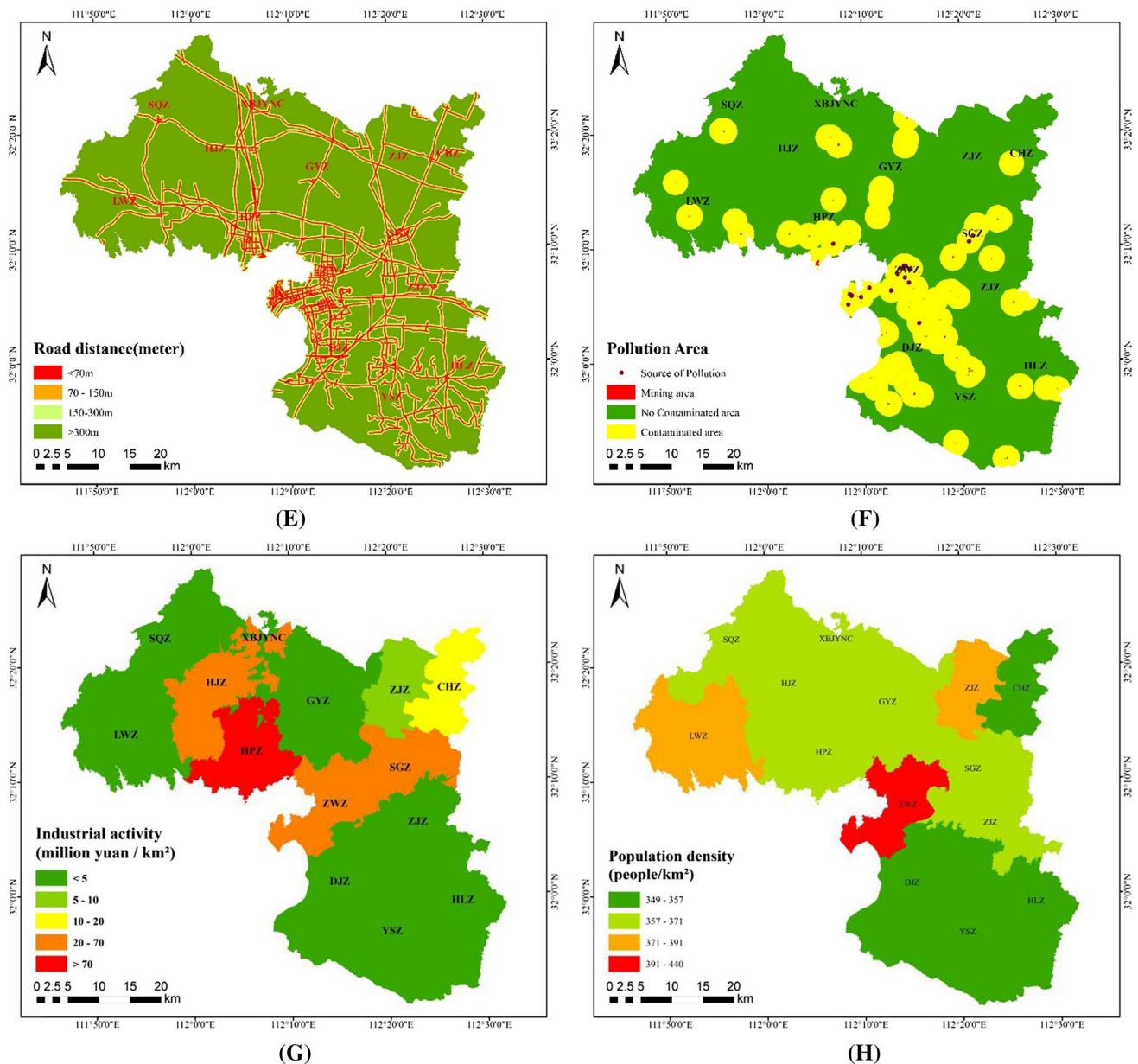


Fig. 2 (continued)

Industrial production

Solid, liquid, and gaseous wastes are produced in industrial activities, which plays a very critical role in causing heavy metal pollution of the soil. Crop safety and productivity can be seriously compromised in the long term because of heavy metal pollution of agricultural land, to prevent which continuous safety assessment is required. In the soil close to industrial sites, the increase in specific metals related to industrial activities is a concern that needs to be considered when managing the agricultural soil around these industrial complexes and the industrial complexes themselves in the future (Popadic et al. 2013; Kim et al. 2020).

In this study, industrial production itself reflects the situation of regional industrial activities, and the industrial production value of each soil sample was obtained by cross-analysis using ArcGIS software. It can be observed from Fig. 2g that the industrial output value of the central area of Xiangzhou District is the highest, and the figure shows a spatial pattern gradually decreasing from the middle of Hopai Town to the surrounding areas.

Population density

In most cases, population density has a crucial impact on the heavy metal contents of soil. The greater the population



density in an area, the more the human activities in the area, and the more obvious the impact on the natural environment. As shown in the research carried out by Acosta and others, the analysis and research on the soil are mainly performed in terms of physical and chemical properties, considering the total amount of metals (e.g., Cd, Zn, Cr, Pb, Cu, Co, and Ni) and the corresponding chemical formulas of the pollutants, in the dust particles found in the street and soil of cities and natural areas with various population densities, to determine the impact of human actions on the dispersion and migration of metals in the milieu. Results show that the correlation between dust's metal contents and the population density is positive (Acosta et al. 2015). After reviewing district statistics on population density data and administrative districts, according to the natural discontinuous classification method, the population density of Xiangzhou District can be divided into four levels. As shown in Fig. 2h, Zhangwan Town, as the most densely populated area in Xiangzhou District, maintains the same traffic and road distribution.

Data source

As can be seen in Fig. 1c, 975 soil samples were collected from agricultural land in Xiangzhou District according to GPS positioning. Surface soil was collected from a depth of 0–5 cm in the cultivated layer, and weeds, stones, and sundry debris removed. The soil samples were fully mixed according to the quartering method, and 1 kg of the soil samples was retained at each sample point. Finally, the soil samples were naturally air-dried in the laboratory, ground, and passed through a nylon mesh sieve for subsequent analysis and testing. Graphite furnace atomic absorption spectrophotometry (GB/T 17141) was used to determine the content of Cd in the soil samples. The flame atomic absorption method (HJ 491) was used to determine Cr content, and atomic fluorescence spectrometry (GB/T 22105) was used for detecting Hg, Pb, and As.

The total industrial output value of Xiangzhou District was taken from the "Statistical Data of National Economy." To describe with better accuracy the impact of industrial activities on the dispersion of heavy metal components in the soil, the value of production of industry per square kilometer

was employed to define the intensity of industrial activities. The population density data came from China's population spatial distribution kilometer grid dataset (<http://www.resdc.cn>). Land use data come from the local natural resource bureau. Digital elevation model (DEM) data are obtained from geospatial data cloud (<http://www.gscloud.cn>). Soil types and soil parent materials were provided by the local agricultural bureau. The analysis of influencing factors with the help of CATREG mainly relies on SPSS 26.0. Multi-factor analysis of factor interaction was performed by using SPSS 26.0 software, and ArcGIS 10.7 software was used to complete the hot spot analysis (Moran's *I*) and mapping of spatial distribution characteristics.

Results and discussion

Descriptive statistical analysis of heavy metal contents of soil

As can be seen in Table 2, this paper makes a comprehensive statistical analysis of the heavy metal data of soil from each sample point: The average amount of Cd, Hg, Pb, As, and Cr is 0.136, 0.052, 29.061, 12.618, and 78.406 $\mu\text{g/g}$, respectively. Taking the background value of the soil in Hubei Province as a reference (China Environmental Monitoring Station 1990), the Cr, Cd, and Hg content was less in comparison with background values, while the average Pb content was higher in comparison with the background value. The highest content of Pb is 47.5 $\mu\text{g/g}$, measuring 1.78 times that of the Hubei background value, showing increased concentration of Pb. The coefficient of variation (CV) indicates the extent of the dispersion of statistical metal data, which also denote the extent to which heavy metal contents of the soil vary among sample points. The heavy metal contents were in the following order: Hg > Cd > As > Pb > Cr.

Analysis of important factors influencing the spatial distribution of heavy metals in soil

The range of R^2 values of the fitting models for the five heavy metals was 0.01–0.156. Among the five fitting models, only

Table 2 Characteristic values of the heavy metals in soil

Heavy metal	Min	Max	Mean	SD	ANOVA	CV	Hubei background value
Cd	0.053	0.360	0.13623	0.029157	0.001	21.402%	0.17
Hg	0.015	1.560	0.05244	0.080910	0.007	154.290%	0.08
As	5.76	21.50	12.6181	2.69657	7.271	21.371%	12.3
Pb	19.6	47.5	29.061	3.9077	15.270	13.447%	26.7
Cr	51.6	103.0	78.406	9.7286	94.646	12.408%	86



the fitting model of Hg failed *F*-test ($p < 0.05$). As shown in Table 3, the regression coefficient's implications of various impacting factors for the same heavy metal were different. Cd, Hg, As, Pb, and Cr were affected significantly by soil type. Traffic distance, industrial production, land use type, and soil type significantly impacted the contents of metals such as As and Pb. Soil As, Pb, and Cr were significantly affected by industrial activities and soil types. Based on the significance test, it can be seen from Table 4 that Pratt's relative importance measurement helps explain the contribution of predictors to regression. Compared with other values, the larger individual importance value corresponds to the prediction value, which is important for regression. For instance, slope, industrial production, and land use type are the main factors affecting soil Cd. Similarly, according to Table 4, it is clear that there are factors affecting other heavy metals. In short, type of soil, land use type, and production of industries are the key elements that lead to the heavy metal distribution in the soil in Xiangzhou District. However, in some towns and villages of Xiangzhou District, the heavy metal contents of the soil are obviously impacted by human elements. There are low amounts of Cd, Hg, and Cr components of the soil in Xiangzhou District, causing less pollution in comparison with Pb and As (8.84% and 2.58%, respectively), which are higher than the background values. Human activities play an important role in the dispersion and contents of Pb and As.

Impact of interaction of factors on heavy metal contents of soil

It is observed from Table 5 that interaction has a significant impact on Cr, Cd, Pb, Hg, and As contents of the soil. For instance, the interaction between slope and factors (such as soil type, land use type, and traffic distance) affects the Pb, Cd, and Hg contents of the soil. The interaction between population density with other two factors (soil parent material and soil type) causes a clear impact on the As and Pb contents of soil. Additionally, the interaction between soil type and other three factors (land use type, population

density, and contaminated area) significantly affects the Cd, Hg, and As contents of the soil.

Hot spot distribution of heavy metals in soil

By combining the contents of Fig. 2, there is a significant correlation between factors such as population meters, density of soil, and industrial activities and the dispersion of heavy metals. Some hot spots where the soil is polluted by heavy metals correspond to indicators such as population density and industrial activities. For instance, areas with high industrial output have a higher distribution of Cr and As hot spots, which corresponds to the spatial pattern of industrial activities. In addition, Cd hot spots are mainly distributed in the northwest of Xiangzhou District, which are not concentrated areas of industrialized production and are densely populated (Fig. 3a takes Cd as an example), which indicates that heavy metal sources in soil are diverse and multiple factors impact them. Therefore, the spatial patterns of heavy metals are not completely consistent with the factors that affect them. Hot spot analysis (Fig. 3b) shows that areas with high Cr concentrations correspond to the spatial dispersion of the industrial output values of > 70 million yuan/km², mainly in Hopai town. However, this kind of situation also arises in Yushan Town, Huanglong Town, and Dongjin Town, which are areas with relatively low industrial

Table 4 Importance of different factors

Influence factor	Cd	Hg	As	Pb	Cr
Traffic distance	0.115	0.111	0.101	0.171	0.025
Slope	0.173	0.222	0.008	0.01	0.012
Population density	0.096	0.072	0.015	0.007	0.001
Industrial production	0.351	0.019	0.499	0.313	0.709
Land use type	0.141	0.202	0.03	0.044	0.026
Contaminated area	-0.01	0.063	0.003	0.005	0.033
Soil parent material	-0.005	-0.04	0.072	-0.024	-0.015
Soil type	0.139	0.351	0.272	0.474	0.21

Table 3 Coefficients and significance test of different factors

Influence factor	Cd		Hg		As		Pb		Cr	
	Beta	Sig	Beta	Sig	Beta	Sig	Beta	Sig	Beta	Sig
Traffic distance	0.038	0.241	0.026	0.435	0.125	0	0.124	0	0.039	0.286
Slope	0.06	0.056	0.046	0.14	-0.038	0.178	-0.038	0.201	-0.018	0.553
Population density	0.036	0.251	0.026	0.456	-0.048	0.12	0.025	0.367	-0.002	0.941
Industrial production	-0.088	0.003	-0.01	0.737	0.272	0	0.193	0	0.15	0
Land use type	0.056	0.034	-0.059	0.033	0.062	0.01	-0.052	0.024	0.026	0.388
Contaminated area	0.011	0.656	-0.023	0.399	0.012	0.575	-0.023	0.35	0.027	0.315
Soil parent material	0.004	0.85	-0.016	0.397	0.046	0.111	-0.015	0.439	0.013	0.529
Soil type	0.055	0.001	-0.067	0	0.168	0	-0.22	0	0.084	0



Table 5 Interactive relationship between different factors

Heavy metal	Interaction	Sig
Cd	Traffic distance—slope	0.017
	Slope—type of soil	0.024
	Types of land usage—soil type	0.011
Hg	Slope—type of land usage	0.001
	Contaminated area—type of soil	0.031
As	Slope – production of industries	0
	Population density—Soil type	0.044
Pb	Slope—Soil parent material	0.012
	Population density—Soil parent material	0.044
Cr	Slope—type of land usage	0.001
	Contaminated area – type of soil	0.019

output values but are Cr hot spots. It can be seen that these areas are relatively close to heavy metal pollution sources and are greatly affected. Therefore, it can be concluded that the Cr hot spot in this place is mainly due to solid discharge, and gas and liquid waste.

Discussion

Heavy metal pollution in soil and its sources

A descriptive analysis of the heavy metal contents of the soil in Xiangzhou District can be obtained from Table 2. The average content of Cd, Hg, and Cr in the soil in Xiangzhou District is slightly lower than that in Hubei Province, which indirectly indicates that the influence of natural factors cannot be ignored. Hg, Cd, and Cr contents of the soil in Xiangzhou District are less in comparison with soil Pb and As contents. The contents of Pb and As were 8.84% and 2.58% higher than the background value of Hubei Province, respectively. At the same time, human activities significantly affect the dispersion of Pb and As in the soil. The analysis of multi-source environmental variables also confirmed the factors that impact heavy metal distribution in Xiangzhou District's soil from another perspective.

Key factors impact the heavy metal contents of soil

Soil parent material is the key factor that impacts heavy metal dispersion as well as the geochemical characteristics of the soil (Salonen and Korkka-Niemi 2007). Heavy metal contents of soils with varying parent materials are significantly different. For example, Zhai Fei and others collected 257 soil samples from six types of soil parent materials (typical sand shale, old weathering crust, limestone, shale, river alluvium, and mudstone) in Huangping County and analyzed the heavy metal contents. The results indicate that

there is significant heavy metal contents variation in the soil due to varying parent materials (Fei et al. 2020).

Land use type is also among the key elements impacting the dispersion and contents of heavy metals in the soil in Xiangzhou District. A significant number of studies show that there are considerable differences in heavy metal contents of soil per varying land use. Zhang et al. showed that the heavy metals' concentrations in soils from farmlands and the Shizuishan Industrial Park in Zhongwei City of Ningxia are different, which is closely linked to the way the lands is used (Min et al. 2020). As the most representative sewage irrigation area in China, Longkou has mainly applied five different land use types, involving as many as 148 top soil samples. Li et al. found that Cd, As, Cu, and Zn and Pb accumulate in different ways according to five different land use types (Li et al. 2020).

The dispersion of heavy metals of the soil in Xiangzhou District is also affected by soil types. Weathering of various soil parent materials over long periods forms varying types of soil, and so the clay minerals, oxides, and organic matters formed in the soil are also different (Mahmoodi et al. 2016). Clay minerals are highly used adsorptive materials for fixing heavy metals and also have high availability, stable physical properties, large adsorption capacity, and excellent chemical properties. Existing research shows that there is a close correlation between the adsorption–desorption process of heavy metals and the properties of soil (Zhou et al. 2017). Heavy metals vary in their migration and accumulation according to different soil types, which causes considerable differences in the concentrations of heavy metal contents of different soil types.

Industrial activities have considerable influence on the heavy metal concentration in the soil in Xiangzhou District. Varying industrial activities are responsible for differences in the extent to which heavy metals are accumulated. Every industrial activity is usually associated with certain metals. Industrial activities affect soil Cd, As, Cr, and Pb significantly. Zhe et al. found that the traffic and industrial activities in the Gaoshawo Industrial Development Plan area critically affect the soil environment (Xu et al. 2020). Xie et al. pointed out that mining and industrial activities release large amounts of heavy metal into the surrounding environment, drawing people's attention to the harm to physical and mental health caused by environmental problems (Xie et al. 2018).

Population density and traffic activities also affect the heavy metal contents of. This research is indicative of population density impacting the concentration of Pb in soil. According to the survey and research results, the heavy metal contents of the soil corresponding to a high population density are also higher.

In addition, being near the pollution source is usually a significant reason for the deposition of heavy metals in the

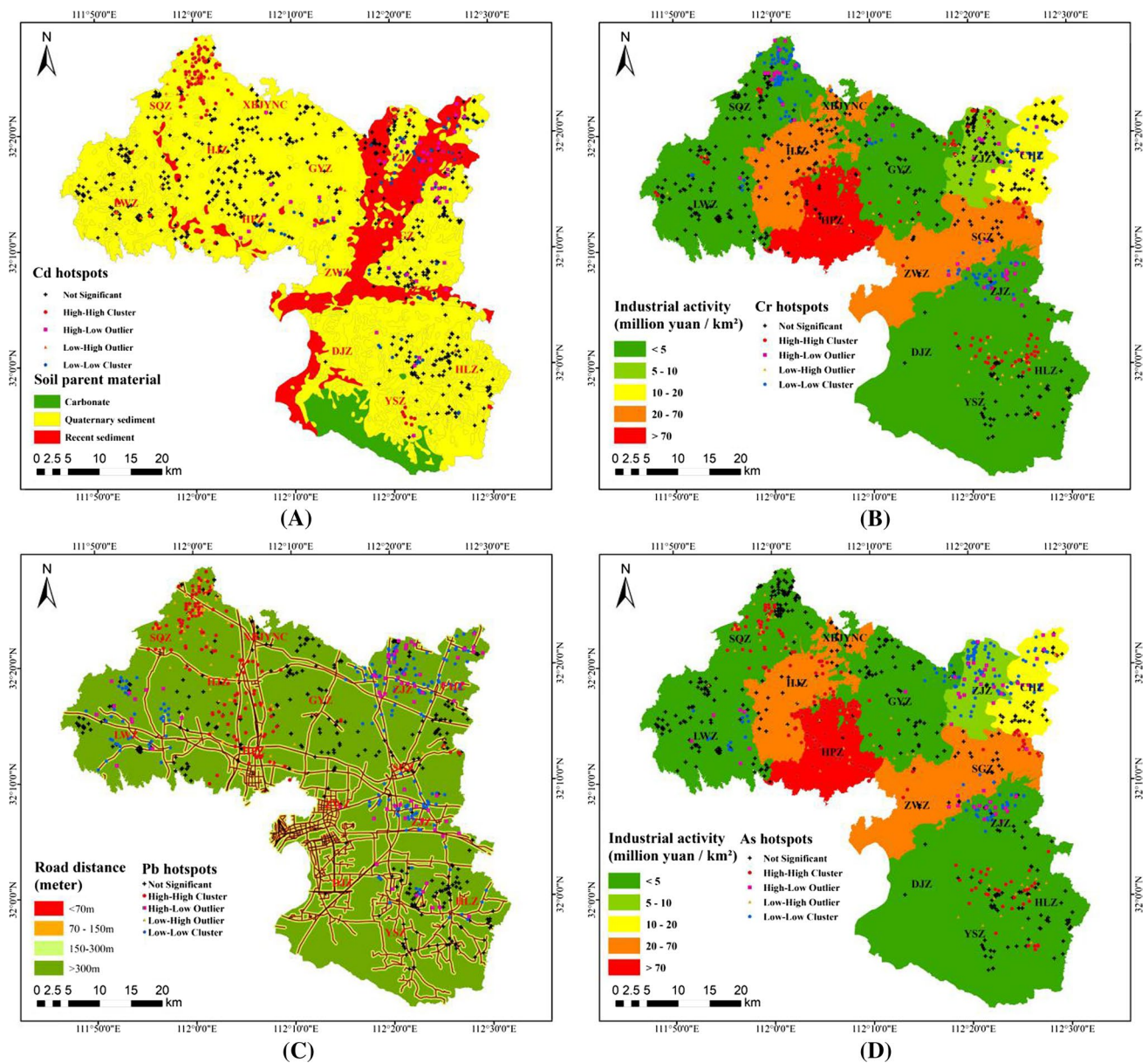


Fig. 3 Spatial distribution of heavy metals hot spots in the soil and the influencing factors. **a** Cd hot spots and the soil parent material, **b** Cr hot spots and industrial activity, **c** Pb hot spots and traffic activity, **d** As hot spots and industrial production

soil. However, the contaminated area does not play a key role in the formation of heavy metals contents in the soil in Xiangzhou District, which may correspond with the scale of the study. Overall, the impact range of the polluted area is small, because of which the impact of heavy metal contents of the soil in Xiangzhou District is not that evident.

Impact of interaction among the factors on the heavy metal contents of soil

The internal interplay of multiple elements also affects the spatial dispersion and heavy metal contents of the soil. From

a general perspective, areas with intensive industrial activity have a larger demand for labor, so the population density is usually higher and the transportation system generally more developed. Because the transportation demand of industries requires convenient traffic conditions, the traffic conditions in such areas have been significantly optimized and improved. The waste generated by industrial production can cause changes in the heavy metal contents of the soil to a large extent. If crops are planted on lands contaminated with heavy metals, the heavy metals will accumulate in the crops and then enter the human body, harming people's health. The interaction between soil type and other three



factors (population density, contaminated area, and type of land usage) has a huge influence on the spatial dispersion of heavy metals, including As, Cd, and Hg in the soil.

Key characteristics of the method used in this study

It is observed from the results that CATREG is a potential method for determining the factors affecting the heavy metal contents of soil. CATREG is employed when nominal, sequence, and numerical variables are simultaneously employed. When factor analysis is used to analyze influencing factors, the final results are mainly based on prior knowledge inference, which is greatly limited (Dragović et al. 2008). In geostatistics, spatial coverage analysis and qualitative analysis are often used to infer the sources of heavy metal pollution of soil.

As can be seen in Table 6, the geographical detector relies on the spatial variability of geographical variables. Considering the data required by geological exploration methods, factor analysis methods, and geostatistics, the data used in this research can be numerical, nominal, or ordinal. The environmental data can be analyzed using prior knowledge, and the impact of environmental factors on the heavy metal contents of soil can be subjected to objective analysis. The CATREG method can clearly analyze the core factors that can impact the spatial distribution and content of heavy metals in soil. It can also solve the multi-source problem of the isotope-tracing method in identifying multiple sources.

While employing CATREG, the following factors need to be considered for research and analysis: To begin with, the final results are approximated to the data of impacting factors. To obtain results with greater precision, it is necessary to find more thoroughgoing data of influencing factors. In addition, both the contaminated area and the population density impact on soil Cd level.

However, when using CATREG, the following aspects need special attention: First, more robust data of impactful factors need to be found in order to obtain more accurate results. Second, there may be more than one sources (e.g., land use and industrial activities) that cause heavy metal pollution of the soil. Third, the final result will be different from the actual situation because the data of all influencing factors cannot be obtained. However, compared with the currently used methods, this analysis method can more clearly analyze the key factors that impact the heavy metal contents of the soil.

Conclusion

Industrial production, land use type, and soil type are the key elements determining the dispersion of heavy metals in the soil in Xiangzhou District. The soil type has a significant effect on the soil Cd, Hg, As, Pb, and Cr contents. Traffic distance, industrial production, land use type, and soil type affect soil As and Pb contents crucially. Industrial activities and soil types are two key factors that affect the spatial

Table 6 Analysis of several source identification methods

Method	Characteristic	Shortcoming
Factor analysis	By using the idea of dimensionality reduction, starting with the study of the dependency relationship in the original variable correlation matrix, some variables with complex relations are reduced into several comprehensive factors	It is difficult to completely clarify which factors are primary and which are secondary. At the same time, due to the limitation of information, many conclusions are mainly obtained by speculation
Geostatistics	Based on the assumption that adjacent data can be converted into each other in the internal space, and assuming that the relationship expressing the degree of correlation can be analyzed and counted with a function, the internal relevance of the above variables is researched and analyzed	It is limited to overlay analysis on the map, and spatial proximity is needed
Isotope tracer	The data is objective and accurate	More than three sources of pollution cannot be determined
Geographical detector	A geographical detector comprises a group of statistical methods for identifying spatial heterogeneity to explain the driving forces behind them. Its core idea assumes that if the independent variable has a great influence on the dependent variable, then the spatial distributions of the independent variable and the dependent variable have similar characteristics	Data needs to be transformed into classified data. In addition, in data processing, prior knowledge is mainly used as the basis. Therefore, there is a certain degree of subjectivity, and there are usually certain differences in conclusions
CATREG	It can deal with nominal variables, sequence variables, and numerical data to identify the influence of multiple factors on heavy metals	Large amounts of data are required



distribution and contents of metals contents such as Pb, As, and Cr in the soil.

The interaction between slope and other factors (type of soil, land use type, and traffic distance) has a considerable impact on the contents of Cd, Hg, and Pb. The interaction between population density and two factors (soil parent material and soil type) impacts As and Pb contents of the soil. The interaction of soil type with the three factors (land use type, population density, and contaminated area) considerably influences the soil Cd, Hg, and As contents.

Based on the analysis of the advantages and disadvantages of various methods in determining the sources of heavy metal pollution, the CATREG method is employed to objectively identify the effect of different environmental elements on the heavy metal contents of soil. It is also used for research and analysis of the main influencing factors so as to provide guidance on how to control heavy metal pollution and protect environment.

Author contributions Jie Xu helped in conceptualization and writing—original draft preparation; Pengnan Xiao helped in methodology; Jie Xu and Pengnan Xiao developed the software; all authors have read and agreed to the published version of the manuscript.

Funding This work was financially supported by Classification project of cultivated land soil environmental quality in Xiangzhou District (Grant Number HBJX-2019-ZC0901).

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Human and animal rights This article does not contain any studies with human participants or animals performed by any of the authors.

References

- Acosta JA, Gabarron M, Faz A, Martinez-Martinez S, Zornoza R, Arocena JM (2015) Influence of population density on the concentration and speciation of metals in the soil and street dust from urban areas. *Chemosphere* 134:328–337. <https://doi.org/10.1016/j.chemosphere.2015.04.038>
- Afu MS, Isong IA, Ene AE, John K (2020) Heavy metals in agricultural soils developed on diverse parent materials in cross river state, Nigeria. *Arch Agron Soil Sci*. <https://doi.org/10.1080/03650340.2020.1795642>
- Ahn B, Lee J (2011) Relationships between soil physico-chemical properties and topography in Jeonbuk orchard fields. *Korean J Soil Sci Fertil* 44(5):859–865. <https://doi.org/10.7745/KJSSF.2011.44.5.859>
- Almeida A, Garrod B (2018) A catreg model of destination choice for a mature island destination. *J Destin Mark Manag* 8:32–40. <https://doi.org/10.1016/j.jdmm.2016.11.005>
- Augusto L, Achat DL, Jonard M, Vidal D, Ringeval B (2017) Soil parent material—a major driver of plant nutrient limitations in terrestrial ecosystems. *Glob Change Biol* 23(9):3808–3824. <https://doi.org/10.1111/gcb.13691>
- Borishade TT, Worlu R, Ogunnaike OO, Aka DO, Dirisu JI (2021) Customer experience management: a study of mechanic versus humanic clues and student loyalty in Nigerian higher education institution. *Sustainability-Basel* 13(12):6563. <https://doi.org/10.3390/su13126563>
- Chen Y, Liu Y, Liu Y, Lin A, Kong X, Liu D, Li X, Zhang Y, Gao Y, Wang D (2012) Mapping of Cu and Pb contaminations in soil using combined geochemistry, topography, and remote sensing: a case study in the Le'an River Floodplain, China. *Int J Environ Res Public Health* 9(5):1874–1886. <https://doi.org/10.3390/ijerph9051874>
- China Environmental Monitoring Station (1990) Background values of soil elements in China. Environmental Science Press, Beijing
- Ciszewski D, Kubsik U, Aleksander-Kwaterczak U (2012) Long-term dispersal of heavy metals in a catchment affected by historic lead and zinc mining. *J Soil Sediment* 12(9):1445–1462. <https://doi.org/10.1007/s11368-012-0558-1>
- De Silva S, Ball AS, Huynh T, Reichman SM (2016) Metal accumulation in roadside soil in Melbourne, Australia: effect of road age, traffic density and vehicular speed. *Environ Pollut* 208(SIA):102–109. <https://doi.org/10.1016/j.envpol.2015.09.032>
- Dongping S, Qirong L, Chengyu X (2019) Distribution of heavy metal Cr content in soils on both sides of traffic roads and its ecological health risk assessment. *IOP Conf Ser Earth Environ Sci* 252:42012–42018. <https://doi.org/10.1088/1755-1315/252/4/042018>
- Dragović S, Mihailović N, Gajić B (2008) Heavy metals in soils: distribution, relationship with soil characteristics and radionuclides and multivariate assessment of contamination sources. *Chemosphere* 72(3):491–495. <https://doi.org/10.1016/j.chemosphere.2008.02.063>
- Du X, Zhu Y, Han Q, Yu Z (2019) The influence of traffic density on heavy metals distribution in urban road runoff in Beijing, China. *Environ Sci Pollut R* 26(1):886–895. <https://doi.org/10.1007/s11356-018-3685-4>
- Dube A, Zbytniewski R, Kowalkowski T, Cukrowska E, Buszewski B (2001) Adsorption and migration of heavy metals in soil. *Polut J Environ Stud* 10:1–10. [https://doi.org/10.1016/S0738-3991\(00\)00095-1](https://doi.org/10.1016/S0738-3991(00)00095-1)
- Fei Q, Linhong W, Chengwu F, Guihua L, Song Q (2020) Heavy metal contents in soils developed from different parent materials and their ecological risk assessment. *Acta Mineral Sin* 40(06):677–684. <https://doi.org/10.16461/j.cnki.1000-4734.2020.40.128>
- Figueiredo MPS, Santos DF, Lima SMS, Ferreira TAE, Mota CMM (2019) Study on self-assessment of health in the elderly population of Brazil using the multiple categorical regression model—CATREG. *SIGMAE* 8(2SI):36–48
- Gao J, Wang L (2018) Ecological and human health risk assessments in the context of soil heavy metal pollution in a typical industrial area of Shanghai, China. *Environ Sci Pollut Res* 25(27SI):27090–27105. <https://doi.org/10.1007/s11356-018-2705-8>
- Gundacker C, Wittmann KJ, Kukuckova M, Komarnicki G, Hikkel I, Gencik M (2009) Genetic background of lead and mercury metabolism in a group of medical students in Austria. *Environ Res* 109(6):786–796. <https://doi.org/10.1016/j.envres.2009.05.003>
- Guney M, Onay TT, Copty NK (2010) Impact of overland traffic on heavy metal levels in highway dust and soils of Istanbul, Turkey. *Environ Monit Assess* 164(1–4):101–110. <https://doi.org/10.1007/s10661-009-0878-9>
- He S, Lu Q, Li W, Ren Z, Zhou Z, Feng X, Zhang Y, Li Y (2017) Factors controlling cadmium and lead activities in different parent material-derived soils from the Pearl River basin. *Chemosphere* 182:509–516. <https://doi.org/10.1016/j.chemosphere.2017.05.007>



- Hou Q, Yang Z, Yu T, You Y, Dou L, Li K (2020) Impacts of parent material on distributions of potentially toxic elements in soils from pearl river delta in South China. *Sci Rep*. <https://doi.org/10.1038/s41598-020-74490-2>
- Huo X, Li H, Sun D, Zhou L, Li B (2012) Combining geostatistics with Moran's I analysis for mapping soil heavy metals in Beijing, China. *Int J Environ Res Public Health* 9(3):995–1017. <https://doi.org/10.3390/ijerph9030995>
- Ibm (2020) Introduction to optimal scaling procedures for categorical data and what is optimal scaling? https://www.ibm.com/support/knowledgecenter/en/SSLVMB_25.0.0/statistics_mainhelp_ddita/spss/categories/optimal_scaling_what.html. Accessed 2020.12.20
- Iftikhar S, Turan V, Tauqeer HM, Rasool B, Zubair M, Mahmood-Ur-Rahman, Khan MA, Akhtar S, Khan SA, Basharat Z, Zulfiqar I, Iqbal J, Iqbal M, Ramzani PMA (2021) Chapter 5—phytomanagement of as-contaminated matrix: physiological and molecular basis. In: Hasanuzzaman M, Prasad MNV (eds) *Handbook of Bioremediation*. Academic Press, Cambridge, pp 61–79
- Jiang S, Luo J, Ye Y, Yang G, Pi W, He W (2019) Using Pb isotope to quantify the effect of various sources on multi-metal polluted soil in Guiyu. *Bull Environ Contam Toxicol* 102(3):413–418. <https://doi.org/10.1007/s00128-018-02534-5>
- Kandpal G, Srivastava PC, Ram B (2005) Kinetics of desorption of heavy metals from polluted soils: influence of soil type and metal source. *Water Air Soil Pollut* 161(1–4):353–363. <https://doi.org/10.1007/s11270-005-5548-0>
- Kim H, Lee M, Lee J, Kim K, Owens G, Kim K (2020) Distribution and extent of heavy metal(loid) contamination in agricultural soils as affected by industrial activity. *Appl Biol Chem*. <https://doi.org/10.1186/s13765-020-00517-x>
- Kuusisto-Hjort P, Hjort J (2013) Land use impacts on trace metal concentrations of suburban stream sediments in the Helsinki Region, Finland. *Sci Total Environ* 456–457:222–230. <https://doi.org/10.1016/j.scitotenv.2013.03.086>
- Li C, Cao J, Yao L, Wu Q, Lv J (2020) Pollution status and ecological risk of heavy metals in the soils of five land-use types in a typical sewage irrigation area, eastern china. *Environ Monit Assess* 192(7):471. <https://doi.org/10.1007/s10661-020-08384-1>
- Lin C, Wang K, Wu D, Gong B (2020) Passenger flow prediction based on land use around metro stations: a case study. *Sustainability-Basel* 12(17):6844. <https://doi.org/10.3390/su12176844>
- Liu H, Xiong Z, Jiang X, Liu G, Liu W (2016) Heavy metal concentrations in riparian soils along the Han River, China: the importance of soil properties, topography and upland land use. *Ecol Eng* 97:545–552. <https://doi.org/10.1016/j.ecoleng.2016.10.060>
- Lu M, Fu J (2019) Attention restoration space on a university campus: exploring restorative campus design based on environmental preferences of students. *Int J Environ Res Public Health* 16(14):2629. <https://doi.org/10.3390/ijerph16142629>
- Luo L, Mei K, Qua L, Zhang C, Chen H, Wang S, Di D, Huang H, Wang Z, Xia F, Dahlgren RA, Zhang M (2019) Assessment of the geographical detector method for investigating heavy metal source apportionment in an urban watershed of Eastern China. *Sci Total Environ* 653:714–722. <https://doi.org/10.1016/j.scitotenv.2018.10.424>
- Lv J (2019) Multivariate receptor models and robust geostatistics to estimate source apportionment of heavy metals in soils. *Environ Pollut* 244:72–83. <https://doi.org/10.1016/j.envpol.2018.09.147>
- Mahmoodi M, Khormali F, Amini A, Ayoubi S (2016) Weathering and soils formation on different parent materials in Golestan Province, Northern Iran. *J Mt Sci-Engl* 13(5):870–881. <https://doi.org/10.1007/s11629-015-3567-x>
- Majumdar S, Pujari V (2021) Exploring usage of mobile banking apps in the UAE: a categorical regression analysis. *J Financ Serv Market*. <https://doi.org/10.1057/s41264-021-00112-1>
- Min Z, Xueping W, Chang L, Jiayu L, Yuhong Q, Yunkan M, Pengjun X, Ying L (2020) Quantitative source identification and apportionment of heavy metals under two different land use types: comparison of two receptor models APCS-MLR and PMF. *Environ Sci Pollut Res Int* 27:42996–43010
- Nawab J, Khan S, Shah MT, Khan K, Huang Q, Ali R (2015) Quantification of heavy metals in mining affected soil and their bioaccumulation in native plant species. *Int J Phytoremediat* 17(9):801–813. <https://doi.org/10.1080/15226514.2014.981246>
- Ning C, Gao P, Wang B, Lin W, Jiang N, Cai K (2017) Impacts of chemical fertilizer reduction and organic amendments supplementation on soil nutrient, enzyme activity and heavy metal content. *J Integr Agric* 16(8):1819–1831. [https://doi.org/10.1016/S2095-3119\(16\)61476-4](https://doi.org/10.1016/S2095-3119(16)61476-4)
- Norbu N, Shuguang W, Yan X, Jianqiang Y, Qiang L (2017) Application of zinc isotope tracer technology in tracing soil heavy metal pollution. *AIP Conf Proc* 1864:20223–20224. <https://doi.org/10.1063/1.4993040>
- Popadic A, Vidovic J, Cosovic V, Medakovic D, Dolenc M, Felja I (2013) Impact evaluation of the industrial activities in the Bay of Bakar (Adriatic Sea, Croatia): recent benthic foraminifera and heavy metals. *Mar Pollut Bull* 76(1–2):333–348. <https://doi.org/10.1016/j.marpolbul.2013.09.039>
- Qiao P, Lei M, Guo G, Yang J, Zhou X, Chen T (2017) Quantitative analysis of the factors influencing soil heavy metal lateral migration in rainfalls based on geographical detector software: a case study in Huanjiang County, China. *Sustainability-Basel* 9(7):1227. <https://doi.org/10.3390/su9071227>
- Qiao P, Yang S, Lei M, Chen T, Dong N (2019) Quantitative analysis of the factors influencing spatial distribution of soil heavy metals based on geographical detector. *Sci Total Environ* 664:392–413. <https://doi.org/10.1016/j.scitotenv.2019.01.310>
- Qin Y, Huang C (2019) Review of heavy metal pollution by mining. *E3S Web Conf* 118:4024–4028. <https://doi.org/10.1051/e3sconf/201911804028>
- Qinghe Z, Shiliang L, Cong W, Li D, Shikui D (2013) Effects of water-level fluctuations and land use type on heavy metal accumulation along a dam reservoir, Southwest China. *Fresenius Environ Bull* 22(4A):1118–1125
- Rui Y, Liu S, Li S, Liu L (2016) Effects of fertilizer input on heavy metal in different soils. *Fresenius Environ Bull* 25(10):4381–4386
- Salonen V, Korkka-Niemi K (2007) Influence of parent sediments on the concentration of heavy metals in urban and suburban soils in Turku, Finland. *Appl Geochem* 22(5):906–918. <https://doi.org/10.1016/j.apgeochem.2007.02.003>
- Shi K, Li D, Zhao B (2013) Investigation of soil heavy metal in Zhehai Town Huize County Yunnan based on gis-approach and geostatistics. *Adv Mater Res* 610–613:3067–3074
- Sucharova J, Suchara I, Hola M, Reimann C, Boyd R, Filzmoser P, Englmaier P (2011) Linking chemical elements in forest floor humus (Oh-horizon) in the Czech Republic to contamination sources. *Environ Pollut* 159(5):1205–1214. <https://doi.org/10.1016/j.envpol.2011.01.041>
- Sun J, Yu R, Hu G, Su G, Wang X (2017) Assessment of heavy metal pollution and tracing sources by Pb & Sr isotope in the soil profile of woodland in Quanzhou. *Huanjing Kexue* 38(4):1566–1575. <https://doi.org/10.13227/j.hjkk.201609131>
- Sun C, Zhu S, Zhao B, Li W, Gao X, Wang X (2020) Effect of land use conversion on surface soil heavy metal contamination in a typical karst plateau lakeshore wetland of Southwest China. *Int J Environ Res Public Health* 17(1):84. <https://doi.org/10.3390/ijerph17010084>
- Swaleh KM, Hussein RM, Abu-Elhaj S (2004) Assessment of heavy metal contamination in roadside surface soil and vegetation from the west bank. *Arch Environ Contam Toxicol* 47(1):23–30. <https://doi.org/10.1007/s00244-003-3045-2>



- Tauqeer HM, Fatima M, Rashid A, Shahbaz AK, Ramzani PMA, Farhad M, Basharat Z, Turan V, Iqbal M (2021a) The current scenario and prospects of immobilization remediation technique for the management of heavy metals contaminated soils. In: Hasanuzzaman M (ed) Approaches to the remediation of inorganic pollutants. Springer, Singapore, pp 155–185
- Tauqeer HM, Karczewska A, Lewińska K, Fatima M, Khan SA, Farhad M, Turan V, Ramzani PMA, Iqbal M (2021b) Chapter 36—environmental concerns associated with explosives (HMX, TNT, and RDX), heavy metals and metalloids from shooting range soils: prevailing issues, leading management practices, and future perspectives. In: Hasanuzzaman M, Prasad MNV (eds) Handbook of Bioremediation. Academic Press, Cambridge, pp 569–590
- Tian H, Wang Y, Xie J, Li H, Zhu Y (2020a) Effects of soil properties and land use types on the bioaccessibility of Cd, Pb, Cr, and Cu in Dongguan City, China. Bull Environ Contam Toxicol 104(1):64–70. <https://doi.org/10.1007/s00128-019-02740-9>
- Tian H, Wang Y, Xie J, Li H, Zhu Y (2020b) Effects of soil properties and land use types on the bioaccessibility of Cd, Pb, Cr, and Cu in Dongguan City, China. Bull Environ Contam Toxicol 104(1):64–70. <https://doi.org/10.1007/s00128-019-02740-9>
- Tumanyan AF, Shcherbakova NA, Tusaint F, Seliverstova AP, Tyutyuma NV (2019) Heavy metal contents in soils and vegetables of Southern Russia. Chem Technol Fuels Oil 54(6):766–770. <https://doi.org/10.1007/s10553-019-00985-y>
- Turan V (2019) Confident performance of chitosan and pistachio shell biochar on reducing Ni bioavailability in soil and plant plus improved the soil enzymatic activities, antioxidant defense system and nutritional quality of lettuce. Ecotox Environ Saf 183:109594. <https://doi.org/10.1016/j.ecoenv.2019.109594>
- Turan V (2020) Potential of pistachio shell biochar and dicalcium phosphate combination to reduce Pb speciation in spinach, improved soil enzymatic activities, plant nutritional quality, and antioxidant defense system. Chemosphere 245:125611. <https://doi.org/10.1016/j.chemosphere.2019.125611>
- Turan V (2021a) Calcite in combination with olive pulp biochar reduces Ni mobility in soil and its distribution in chili plant. Int J Phytoremediat. <https://doi.org/10.1080/15226514.2021.1929826>
- Turan V (2021b) Arbuscular mycorrhizal fungi and pistachio husk biochar combination reduces Ni distribution in mungbean plant and improves plant antioxidants and soil enzymes. Physiol Plant 12:12. <https://doi.org/10.1111/ppl.13490>
- Turan V, Ramzani PMA, Ali Q, Abbas F, Iqbal M, Irum A, Khan W (2017) Alleviation of nickel toxicity and an improvement in zinc bioavailability in sunflower seed with chitosan and biochar application in PH adjusted nickel contaminated soil. Arch Agron Soil Sci 64(8):1053–1067. <https://doi.org/10.1080/03650340.2017.1410542>
- Turan V, Khan SA, Mahmood-Ur-Rahman IM, Ramzani PMA, Fatima M (2018) Promoting the productivity and quality of brinjal aligned with heavy metals immobilization in a wastewater irrigated heavy metal polluted soil with biochar and chitosan. Ecotox Environ Safe 161:409–419. <https://doi.org/10.1016/j.ecoenv.2018.05.082>
- Uchimiya M, Lima IM, Klasson KT, Wartelle LH (2010) Biochar soil amendment: impact of soil types on heavy metal sorption–desorption behaviors and repeated nutrient leaching, Washington, USA
- Verbree CL, Aitkenhead-Peterson JA, Loeppert RH, Awika JM, Payne WA (2015) Shea (*Vitellaria paradoxa*) tree and soil parent material effects on soil properties and intercropped sorghum grain-Zn in Southern Mali, West Africa. Plant Soil 386(1/2):21–33. <https://doi.org/10.1007/s11104-014-2244-0>
- Wang C, Ye Z, Wang W, Jin M (2016) Traffic-related heavy metal contamination in urban areas and correlation with traffic activity in China. Transp Res Rec J Transp Res Board 2571(1):80–89. <https://doi.org/10.3141/2571-09>
- Wang B, Chu C, Wei H, Zhang L, Ahmad Z, Wu S, Xie B (2020a) Ameliorative effects of silicon fertilizer on soil bacterial community and Pakchoi (*Brassica chinensis* L.) grown on soil contaminated with multiple heavy metals. Environ Pollut 267:115411. <https://doi.org/10.1016/j.envpol.2020.115411>
- Wang W, Fu M, Hu Q (2020b) The behavioral pattern of Chinese public cultural participation in museums. Sustainability 12(7):2890. <https://doi.org/10.3390/su12072890>
- Xie W, Peng C, Wang H, Chen W (2018) Bioaccessibility and source identification of heavy metals in agricultural soils contaminated by mining activities. Environ Earth Sci 77(17):1–12. <https://doi.org/10.1007/s12665-018-7783-x>
- Xu J, Ho D, Capretz LF (2015) Building an OSS quality estimation model with CATREG. Int J Comput Sci Eng 02(06):1952–1958
- Xu L, Lu A, Wang J, Ma Z, Pan L, Feng X (2016) Effect of land use type on metals accumulation and risk assessment in soil in the peri-urban area of Beijing, China. Hum Ecol Risk Assess Int J 22(1):265–278. <https://doi.org/10.1080/10807039.2015.1060408>
- Xu Z, Mi W, Mi N, Fan X, Zhou Y, Tian Y (2020) Characteristics and sources of heavy metal pollution in desert steppe soil related to transportation and industrial activities. Environ Sci Pollut Res 27(31):38835–38848. <https://doi.org/10.1007/s11356-020-09877-9>
- Yang J, Wang J, Qiao P, Zheng Y, Yang J, Chen T, Lei M, Wan X, Zhou X (2020) Identifying factors that influence soil heavy metals by using categorical regression analysis: a case study in Beijing, China. Front Environ Sci Eng 14(3):37. <https://doi.org/10.1007/s11783-019-1216-2>
- Zhang K, Qiang C, Liu J (2018) Spatial distribution characteristics of heavy metals in the soil of coal chemical industrial areas. J Soil Sediment 18(5):2044–2052. <https://doi.org/10.1007/s11368-018-1972-9>
- Zhou J, Feng K, Pei Z, Meng F, Sun J (2016) Multivariate analysis combined with GIS to source identification of heavy metals in soils around an abandoned industrial area, Eastern China. Ecotoxicology 25(2):380–388. <https://doi.org/10.1007/s10646-015-1596-4>
- Zhou W, Ren L, Zhu L (2017) Reducement of cadmium adsorption on clay minerals by the presence of dissolved organic matter from animal manure. Environ Pollut 223:247–254. <https://doi.org/10.1016/j.envpol.2017.01.019>
- Zhu D, Wei Y, Zhao Y, Wang Q, Han J (2018) Heavy metal pollution and ecological risk assessment of the agriculture soil in Xunyang mining area, Shaanxi Province, Northwestern China. Bull Environ Contam Toxic 101(2):178–184. <https://doi.org/10.1007/s00128-018-2374-9>
- Zinn YL, de Faria JA, de Araujo MA, Araujo Skorupa AL (2020) Soil parent material is the main control on heavy metal concentrations in tropical highlands of Brazil. CATENA 185:104319. <https://doi.org/10.1016/j.catena.2019.104319>

