Impact Imposed by Urbanization on Soil Heavy Metal Content of Lake Wetland and Evaluation of Ecological Risks in East Dongting Lake in China

Yang Lin (Yanglin9098@csuft.edu.cn)
Central South University of Forestry and Technology
Kai Luo
Central South University of Forestry and Technology
Zilin Su
Central South University of Forestry and Technology
Yang Wu
Central South University of Forestry and Technology
Wei Xiao
Central South University of Forestry and Technology
Mingxun Qin
Central South University of Forestry and Technology
Jing Lin
Central South University of Forestry and Technology
Shijie Zhang
Central South University of Forestry and Technology
Yi Zhang
Central South University of Forestry and Technology
Yuqi Jiang
Central South University of Forestry and Technology
Bojin Peng
Central South University of Forestry and Technology
Yujing Guo
Central South University of Forestry and Technology
Xuan Wang
Central South University of Forestry and Technology

Research Article

Keywords: Urbanization, East Dongting Wetland, Soil Heavy Metals, Ecological Risks, Spatial Distribution, Land Use

Posted Date: April 2nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-339557/v1

Abstract

The urbanization is regarded as the major factor related to human activities that may interfere with the natural ecosystem. In this study, we have selected the wetland of East Dongting Lake as the research area. We have collected 180 soil samples (within the range of 0–20 cm, and 20cm-40cm), and we have measured the contents of their physicochemical properties (including salinity, pH value, soil particle composition, soil organic carbon, nitrate nitrogen and rapidly available phosphorus) as well as heavy metal elements (including As, Hg, Cd, Pb, Ni and Cr). We have adopted the methods of multivariate statistical analysis and inverse distance weighted (IDW) interpolation, so as to to reveal the sources and distribution characteristics of heavy metal content in soil in the research area. By adopting the potential ecological risk index (PERI) method proposed by Hakanson, we intend to assess the PERI values of heavy metals. Our research findings have shown that: (1) 8 sorts of heavy metals have shown positive correlation with each other. As, Hg and Zn have shown a significantly positive correlation with SOC ($P < 0.01$); As, Ni, Cr and Zn have shown a significantly positive correlation with AP ($P < 0.01$); As and Pb have shown a significantly positive correlation with Clay ($P < 0.01$); whereas Hg and Zn have shown a significantly negative correlation with Silt ($P < 0.01$); As and Pb have shown a significantly negative correlation with Sand ($P < 0.01$). (2) During urbanization, the elements of Cd, Ni, As, Hg and Pb might be enriched due to agricultural and industrial activities, whereas the use of fertilizers and pesticides constitute one of the major factors contributing to the increase of Cd and Pb contents in soil. (3) Influenced by the varying land patterns and with exception to Cu, the Fe-normalized concentrations have shown significant variations among different types of land use ($P < 0.05$). Specifically, there is a significantly higher level of Cd, Zn, Pb and Hg contents in the agricultural land than other types of land use, whereas there is a slightly higher level of heavy metal content in the mudflats than that in the grassland. In addition, the content of heavy metals in woodland remains relatively stable, and with exception to As, the content of heavy metals in woodland is the lowest among the five types of land. (4) The average value of the comprehensive PERI in heavy metals amounts to 555.03, representing a strong degree of ecological risks. Specifically, the proportion of sampling points of Cd that have a high level of ecological risks amounts to 36.51%, which is the primary element contributing to heavy metal pollution in the region, especially in the agricultural land.

1 Introduction

Wetlands refer to the swamps naturally or artificially formed with stationary or flowing water bodies in stretches of shallow areas. Along with forests and oceans, wetlands are known as one of the three most vital ecosystems around the world, and are referred to as the kidney of the earth. Widely distributed around the globe, wetlands comprise swamps, rivers, peatlands, lakes, beaches and salt marshes (Lao et al. 2019). In addition, wetlands can meet people's varying needs of production and resources, thus offering a significant ecological function and bringing huge benefits. Furthermore, wetlands can play an irreplaceable role in such areas as preventing floods and drought, cleaning pollutants, regulating climatic conditions, managing water bodies and achieving regional ecological balance. Soil constitutes a critical part of wetland ecosystems, and it is also part of the wetland itself, which is rich in nutrients and features numerous ecological functions while playing a vital role in the balance of wetland ecology (Alzahrani et al. 2018). However, due to the excessive discharge of heavy metals in the soil from human activities during urbanization, the content of heavy metals in the soil exceeds the standards. Consequently, such kind of pollutants have gradually become the major factor threatening the safety of regional ecosystem. In addition, they have a significant impact on the ecological environment of wetlands (Ghosh et al. 2019). Therefore, it is of great significance to study the influence imposed by urbanization on the varying contents of heavy metals in wetland soil throughout different periods across regions, along with the potential ecological risks that might be brought along. Such study can serve as effective guidance for us to prevent and control soil pollution across regions, and to utilize wetland resources in a more reasonable and secure manner.

Urbanization can lead to changes in the physicochemical properties of wetland soil. Unfortunately, due to the influence of hydrodynamic and sediment adsorption, wetland ecosystem is oftentimes subject to the agglomeration of heavy metal elements (Kalbitz and Wennrich 1998). Worse still, the rapid industrial and agricultural development has led to the concentration of heavy metals in wetland soil that far exceeds its environmental background value (Bai et al. 2011b). Due to the increasingly intense activities of human interference, especially the use of inorganic fertilizers, feces and pesticides in agricultural land, there has been a higher level of enrichment of heavy metals in soil. Such pollution will cause harm to human health in a direct or indirect manner and may undermine the stability of ecosystem (Hu et al. 2020). Therefore, over the recent years, scholars both at home and abroad have increasingly paid attention to the study on characteristics of heavy metals in agricultural land, including their potential sources, spatial distribution, ecological risks and the issue of food security (Al Mukaimi et al. 2018). Existing studies on the response of soil environment to human activities tend to focus predominantly on a certain time scale. However, given that the soil environment is also subject to temporal and spatial variations, it has become ever more important to study ways of exploring the spatial evolution of soil heavy metals under human interference (He et al. 2019). In addition, land use is the most fundamental and factor of human control that may lead to changes in the physicochemical properties of soil, and also constitutes one of the most vital factors that can reflect the impact imposed by existing human activities on soil ecosystem (Bai et al. 2011a; Feng et al. 2020). However, there have been rather fewer studies on the evolution of land use modes during urbanization for further analysis of the temporal and spatial variations of heavy metals across regions, their sources as well as potential ecological risks (Zhang et al. 2019a).

Dongting Lake ranks as the second largest freshwater lake in China. In terms of environmental protection, this lake area is regarded as one of the most critical wetlands in the country. It not only serves the function of preventing floods and protecting the middle and lower reaches of the Yangtze River, but also serves as the foundation for the nearby population to survive and thrive throughout its long history. Located in the eastern part of the Dongting Lake, the East Dongting Lake is in the middle and lower reaches of the Yangtze River and situated in the northern part of Hunan Province. In addition, the East Dongting Lake covers a total area of 190,000 hm^2, of which the water area amounts to 65,400 hm^2, and the core area amounts to 29,000 hm^2. The East Dongting Lake is known as the largest and most well-preserved natural seasonal lake in Dongting Lake. However, nowadays the wetlands are threatened by heavy metal pollution. Therefore, in this paper, we intend to explore the influence imposed by varying land use modes on the distribution of heavy metal concentration in soil. In addition, we have assessed the potential ecological risks based on source analysis, so as to provide scientific reference for the environmental control of soil and the rational utilization of resources in the wetland of Dongting Lake.

2 Research Methodology And Data Sources

2.1 Overview of the study area

Located on the south side of Jingjiang River in the middle reaches of the Yangtze River, the East Dongting Lake is positioned between 28°59" and 29°38" north latitude, and falls in the range between 112°43" and 113°15" east longitude. The lake area is adjacent to Yueyang City, a renowned historical and cultural city in northern Hunan Province, and covers a total area of 190,000 hm². Moreover, the East Dongting Lake National Nature Reserve constitutes one of the 21 wetland nature reserves of international importance. These sites are designated by the Chinese government for inclusion into the International Convention Wetlands (also known as the Ramsar Convention), and the reserve in East Dongting Lake mainly serves the purpose of protecting the wetland ecology and biological resources in the lake area. Located in the subtropical humid climate zone, this region features ample sunshine and rainfall as well as annual average temperature of 17 C°. In addition, the regional precipitation ranges between 1,200 and 1,300 mm, whereas its frost-free period lasts for 285 days. Thanks to the distinct ecological environment of the East Dongting Lake, the region is richly endowed with natural resources, whereas the local species feature long history, uniqueness and high rarity. As one of the only two natural river-connected lakes in the middle and lower reaches of the Yangtze River, the Dongting Lake plays a significant role in regulating the flood runoff of the Yangtze River and preserving the genes of species or biodiversity.

2.2 Statistical sources and data processing

2.2.1 Land use data

In this study, we have adopted the data extracted from Landsat OLI remote sensing images for the location map of Dongting Lake. First, we have conducted the remote sensing image preprocessing by using the ENVI5.1 software (Kulkarni et al. 2018). Second, we have divided the types of land use by object-oriented and visual interpretation methods (into 6 categories, namely, construction land, grassland, cultivated land, woodland, beach and water body) (Bierschenk et al. 2019). In addition, we have assessed the accuracy of the classification map by adopting the error matrix and analyzing the 180 ground control points recorded during field investigation (Huang et al. 2019). Our research findings have shown that the classification accuracy and Kappa coefficient amount to over 87% and 0.92, respectively, proving the optimal accuracy of classification (Ghosh et al., 2019).

2.2.2 Collection of soil samples and test analysis

Based on the principles of sample availability, representativeness and uniformity, we have taken into full account of the varying history of wetlands, patterns of land use, coverage of vegetation and types of soil in the region (Crocker et al. 2021), We have collected 180 soil samples in 2019 and 2020, and we have recorded the field coordinates via GPS with precision of 3–5 m (Xiao et al., 2019). In the vicinity of each sampling point, we have taken samples three times for every 50–100 m and fully mixed them to form a complete soil sample (Gu et al. 2019). We have packed all soil samples in polyethylene bags. In the meantime, we have recorded relevant information (i.e., type of landscape, type of soil, coverage of vegetation) in detail, while bringing the samples back to the laboratory for air drying under natural conditions (Chen and Hu 2019). We have collected 180 soil surface (with depth ranging between 0 and 20 cm) samples.

Subsequent to the air drying, we have removed the soil debris and carried out grinding and sifting. In addition, we have further grinded some of the soil in the sample until it can pass through a nylon sieve of 0.149 mm, so as to measure the metal items in soil (Keshta et al., 2020). To reveal the features of soil quality and environmental conditions, we have selected 17 indexes representing the physicochemical properties as well as heavy metals in soil by integrating the methods of both outdoor and indoor measurements (La Colla et al., 2018). Specifically, we have adopted soil pH meter during field measurements (Li et al., 2020). To measure and determine the composition of soil particles (clay, silt and sand) by adopting the laser particle size analyzer (Microtrac S3500, made in USA) during laboratory experiments (Huang et al., 2018). We have selected three indicators, namely, soil organic carbon (SOC), nitrate nitrogen (NO3-N) and available phosphorus (AP), fore the determination of soil nutrients. Specifically, we have adopted the total organic carbon analyzer (HT1300, made in Jena of Germany) to determine the SOC subsequent to the elimination of soil calcium carbonate with hydrochloric acid (Huang et al., 2018). We have determined the NO3–N with ultraviolet spectrophotometry (Chai et al., 2019). In the meantime, we have measured the content of AP through the photoelectric colorimetric method (Lyu and Wang, 2018).

We have selected 10 indexes in total for the measurements of heavy metals in soil (Xu et al., 2019), including As, Hg, Cd, Pb, Cu, Zn, Mn, Fe, Ni and Cr, respectively. Predominantly influenced by rock and soil weathering (Liu et al. 2019), there is abundant content of Fe and Mn in nature, and thus they are oftentimes selected as standardized elements so as to eliminate the impact imposed by natural processes on the spatial differentiation of heavy metals (Manuel Trujillo-Gonzalez et al., 2019). We have sifted the soil sample with a 0.149 mm nylon sieve, and subsequent to 6 hours of high temperature digestion of the mixture of nitric acid, hydrofluoric acid and perchloric acid, we have adopted the inductively coupled plasma-atomic emission spectrometry (HITACHIP4010, made in Japan) for measurements (Manzoor et al. 2018). Once we have determined the measurement results, we have conducted experiments by using parallel tests and standard controls (GBW-07401, made by National Institute of Metrology in China) to evaluate effects of quality assurance and control. The standard recovery rate ranges between 95.12% and 104.47%, whereas the analytical results could meet the standard requirements of HJ/T1662004 set out in the Technical Specification for Soil Environmental Monitoring by the State Environmental Protection Administration (Marchand et al., 2010).

2.3 Research methodology

2.3.1 Method of statistical analysis for soil data

Descriptive statistics are available to compute the physicochemical properties of soil as well as the statistical parameters of metal elements, which could facilitate the assessment of the distribution characteristics of data (Guan et al. 2018). We have adopted the Kolmogorov-Smirnov (K-S) test to verify the normality of the distribution of probability in soil variables (Men et al., 2018). In case such variables failed to pass the normal test at 0.05 significance, we would either adopt the logarithmic or the Box-Cox transformations to ensure that the variables conform to normal distribution (Saxena et al., 2020). Furthermore, we have carried out the Pearson correlation analysis and factor analysis to evaluate the relationship between the physicochemical properties of

soil and the elements of heavy metals, in addition to the identification of pollution sources (Meng et al., 2017). Last but not least, we have adopted the method of Multivariate Analysis of Variance, MANOVA) in this study to explore the distribution of heavy metal concentration among varying modes of land use (Sodango et al., 2018). We have conducted all statistical analyses through the software SPSS18.0, whereas we have applied the softwares of MiniTab17.0 and Origin8.6 to data conversion and statistical mapping respectively (Naylo et al., 2019).

2.3.2 Potential ecological risk assessment of heavy metals in soil

The method of potential ecological risk index (PERI) proposed by Hakanson (Othman et al., 2018) has taken into account the environmental background value, toxicity response coefficient, pollution level and environmental sensitivity of numerous heavy metal elements, and is thus the most commonly used method at home and abroad at present for assessing the ecological risks brought along by heavy metals (Rinklebe et al., 2019). The calculation formula is as set out as follows:

$$PERI = \sum_{i}^{m} E_r^i = \sum_{i}^{m} T_r^i \times C_f^i = \sum_{i}^{m} T_r^i \times \frac{C^i}{C_n^i} \quad (1)$$

In the formula, PERI refers to the comprehensive potential ecological risk index (Grybos et al., 2007); E^i_r refers to the single potential ecological risk index of heavy metal element i in the soil; T^i_r refers to the toxicity response coefficient of heavy metal element i (Cr = 2, Cd = 30, As = 10, Hg = 40, Cu = Ni = Pb = 5, Zn = 1) (Ciarkowska 2018); C^i_f refers to the pollution index of heavy metal element i; Ci refers to the measured value of the heavy metal element i, mg/kg; C^i_n refers to the environmental background value of heavy metal element i (Rastmanesh et al., 2018) (Cu, Cr, Cd, Ni, Zn, As, Hg and Pb are 26.0, 68.0, 0.10, 32.0, 94.0, 14.0, 0.10 and 27.0 mg/kg, respectively). In this study, the classification criteria of PERI of heavy metals in soil are shown in Table 1. Specifically, Eir is divided into 5 grades, PERI is divided into 4 grades.

Table 1
Classification of the Potential Ecological Risks of Heavy Metals

	Risk level				
Index	Low risk	Medium risk	Stronger risk	Strong risk	Extremely high risk
Individual Potential Ecological Risk Index	< 40	40–80	80–160	160–320	≧ 320
Integrated Potential Ecological Risk Index PERI	< 50	50–300	-	300–600	≧ 640

3 Results And Analysis

3.1 Descriptive statistics of soil data

Descriptive statistics of the physicochemical properties of soil and heavy metal concentrations are shown in Table 2. The results of statistical analysis have shown that the soil texture is mainly composed of silty loam and sandy loam. The pH value of soil ranges between 5.10 and 8.40, representing weak acidity to weak alkalinity. Moreover, the variation of the contents of soil organic carbon, nitrate nitrogen and available phosphorus fall in the range of 0.05%~2.88%, 0.25 ~ 10.72 mg/kg and 0.72 ~ 26.46 mg/kg. Based on the nutrient classification standard adopted in the National Second Soil Census in China (Saranya et al., 2018), the nutrients of soil in the research area remain at a low level. In addition, the contents of Cu, Cr, CD, Ni, Zn, As, Hg and Pb fall in the range of 10.65 mg/kg ~ 39.48mg/kg, 22.19 ~ 76.54mg/kg, 0.8 ~ 1.08mg/kg, 23.09 ~ 54.23mg/kg, 31.34 ~ 114.37mg/kg, 17.91 ~ 148.95mg/kg, 0.15 ~ 0.56mg/kg and 3.98 ~ 35.57mg/kg. By referring to the soil background value and the national second-level standard for the 8 heavy metals in Dongting Lake (Sharma et al. 2019), we have found that the contents of As, Cd and Hg of all soil samples exceed the soil background value, whereas part of the other heavy metal samples exceed the standard. The coefficient of variation of heavy metal elements vary within the range of 0.22 ~ 36.99% (Sibal and Espino, 2018). Specifically, the concentrations of the elements of Cr, Ni, As and Hg feature a high coefficient of variation (> 17%). By contrast, the concentrations of the elements of Cd, Cu, Pb and Zn feature a low coefficient of variation (< 17%), indicating that they have led to a wide coverage of pollution in the research area (Cardwell et al., 2002).

3.2 Correlation of soil data

As shown by Table 3, the relationships among the 8 heavy metals are as follows: There is a significantly positive correlation between As and Hg, As and Pb, As and Zn, Hg and Zn.

Table 2
Descriptive statistics for soil properties and heavy metal concentrations in topsoil

Variable	Minimum value	Median	Maximum value	Mean value	Standard deviation	Variable coefficient	Background value of Hunan	National standard level
As/(mg/kg)	17.91	93.44	148.95	88.72	32.82	36.99	14	25
Hg/(mg/kg)	0.15	0.48	0.56	0.46	0.08	17.39	0.1	0.3
Cd/(mg/kg)	0.8	0.99	1.08	0.99	0.6	0.61	0.1	0.3
Pb/(mg/kg)	3.98	23.23	35.57	22.01	7.13	0.32	27	300
Ni/(mg/kg)	23.09	40.56	54.23	40.95	7	17.09	32	50
Cr/(mg/kg)	22.19	47.85	76.54	49.33	15.92	32.27	68	200
Cu/(mg/kg)	10.65	26.45	221.98	25.33	16.02	0.63	26	100
Zn/(mg/kg)	31.43	80.88	114.37	75.59	24.79	0.33	94	250
Mn/(mg/kg)	27.45	86.37	110.63	77.77	21.55	0.28		
Fe/(mg/kg)	0.64	1.25	1.64	1.16	0.25	0.22		
pH	0.72	7.22	8.4	7.14	0.84	0.12		
SOC/%	0.39	1.49	2.88	1.55	0.76	0.49		
NO3-N/(mg/kg)	0.02	6.55	14.25	6.27	3.57	0.57		
AP/(mg/kg)	4.87	26.39	44.21	25.04	10.67	0.43		
Clay/%	5.3	13.97	24.23	13.77	4.87	0.35		
Silt/%	63.72	67.69	75.23	67.97	2.24	0.03		
Sand/%	5.54	18.22	30.3	18.26	5.16	0.28		

Cd and Pb, Cd and Pb, Ni and Cr, Ni and Zn, in addition to Cu and Zn with each other ($P < 0.01$) (Xie et al. 2019). Among them, the content of As is closely correlated with the concentrations of Hg and Pb concentrations (the correlation coefficients amount to 0.272 and 0.268, respectively). Moreover, the coefficients of correlation between Hg and Cd, Hg and Cu, in addition to Hg and Zn, amount to 0.155,0.160 and 0.309 respectively. The results indicate that these metals may come from the same anthropogenic activities (Froger et al., 2018). However, Pb and Cr show a weak correlation with each other, suggesting that the contents of Pb and Cr may originate from different sources (Shehzad et al., 2019). The studies carried out by Turer et al. 01:50 PM have shown that the atmospheric deposition constitutes a vital source of Pb in soil and sediment (Sun et al., 2019). On the other hand, there is a significantly positive correlation in the distribution of concentrations of Fe and Mn ($P < 0.01$), indicating that the two elements share similar chemical behaviors, which partly exist in the form of oxidation and partly exist in the form of hydroxide in nature (Trung Kien et al., 2018).

Table 3
Person's correlation matrix for soil properties and heavy metal concentrations

	As	Hg	Cd	Pb	Ni	Cr	Cu	Zn	Mn	Fe	pH	SOC	No3
As	1												
Hg	0.272**	1											
Cd	0.047	0.155*	1										
Pb	0.268**	0.107	0.303**	1									
Ni	0.184*	0.066	0.050	0.055	1								
Cr	0.099	0.043	0.059	-0.133	0.463**	1							
Cu	0.088	0.160*	0.108	0.137	0.180*	0.017	1						
Zn	0.256**	0.309**	0.041	0.008	0.420**	0.154*	0.267**	1					
Mn	0.163*	0.353*	-0.048	-0.014	0.281**	-0.102	0.284**	0.790**	1				
Fe	0.337**	0.119**	0.001**	0.020**	0.158**	0.370**	0.079**	0.502**	0.303**	1			
pH	0.190*	-0.001	-0.118	0.015	-0.329**	-0.360**	-0.053	-0.116	-0.07	0.023	1		
SOC	0.537**	0.220**	-0.018	0.031	0.102	-0.215**	0.041	0.478**	0.448	0.261	0.289**	1	
NO3	0.140	0.175*	0.150*	0.212**	0.121	0.122	0.159*	-0.03	0.018	-0.124	-0.307**	-0.161*	1
AP	0.557**	0.115	0.032**	0.299**	0.314**	0.198**	0.131	0.380**	0.304**	0.350**	-0.111	0.193**	0.341**
Clay	0.254**	0.083	-0.098	0.222**	0.046	0.115	0.166*	0.054	0.104	0.014	0.020	-0.054	0.388**
Silt	0.112	-0.244**	-0.104	0.079	-0.087	-0.067	-0.170*	-0.256**	-0.217**	-0.074	-0.071	-0.017	-0.075
Sand	-0.288**	0.028	0.138	-0.244**	-0.006	-0.080	-0.083	0.060	-0.004	0.019	0.011	0.059	-0.334**
(Note: ∗P < 0.05; ∗∗P < 0.01)													

The soil organic matter, pH values and soil texture can impose a direct or indirect impact on the migration and dissolution of heavy metal elements in sediments (Chen and Hu, 2019). As shown by the analysis of correlation matrix (according to Table 3), the elements of As, Hg and Zn are positively correlated with SOC (P < 0.01); the elements of As, Ni, Cr and Zn are positively correlated with AP (P < 0.01); moreover, the elements of As and Pb are positively correlated with Clay (P < 0.01). On the other hand, the elements of Hg and Zn are negatively correlated with Silt (P < 0.01); whreas the elements o As and Pb have shown a significantly negative correlation with Sand (P < 0.01). Relevant studies have shown that the strong absorption capacity of soil organic matter and fine particles (including clay and powder) would facilitate the accumulation of heavy metal elements (Ghosh et al., 2019). However, there has been no significant correlation between Mn and Fe with soil organic carbon, indicating that the input of soil organic carbon may be subject to the influence of external factors (Vongdala et al., 2019).

3.3 Factor analysis of soil data

In terms of the heavy metal elements distributed in soil, we could draw on reference elements to eliminate the influence of natural processes, so as to facilitate the quantitative description of human factors (Wang et al., 2018). Fe is primarily originated from the weathering of rocks and soils and is less affected by human factors in general (Cardwell et al., 2002). According to Table 2 and Table 3, the concentration of Fe features a low coefficient of variation and has shown a significantly positive correlation with other metals in soil, which indicates that Fe can be used as a reference element for standardized data and can correct the effect imposed by the size of soil particles on the distribution of metals (Feng et al., 2004). Therefore, we have analyzed the raw data and the Fe-normalized data (i.e., the ratios of Cu, Cr, Cd, Ni, Zn, As, Hg and Pb to Fe) to further determine the relationship between soil physicochemical properties and heavy metals, in addition to the sources of heavy metal elements (see Fig .2 and Table 4) (Jiang and Guo, 2019)

Variance. As shown by the rotation factor load matrix, Factor 1 (F1) accounts for 18.03% of the total variance, which includes As, Fe, Mn, Zn and soil organic carbon. This result also conforms to our research findings during the analysis of correlation matrix. Factor 2 (F2) mainly includes nitrate ammonia, Pb and soil particles, and the factor load all exceeds 0.50. Ni and Cr constitute the primary control factors of Factor 3 (F3), whereas the factor load amounts to 0.6, accounting for 10.69% of the total variance. The closely related indexes in Factor 4 (F4) include heavy metals Cd and Hg, whereas their factor load amount to 0.57 and 0.55, respectively. For the Fe-normalized data, we have also extracted four factors, accounting for 65.34% of the total variance. F1 only includes the elements of Pb, Ni, Hg and Cd, whereas their loads all exceed 0.70; F2 includes the Fe-normalized AP and particle composition of soil, with their loads all exceeding 0.70. This indicates that the effect imposed by soil particle size on heavy metals becomes smaller after Fe standardization. F3 extracted from the Fe-normalized data contains the elements of Mn and Zn, whose loads amount to 0.7 and 0.8, respectively. F4 of the Fe-normalized data contains the pH value, soil organic carbon and Cr, whose loads amount to 0.70, 0.79 and 0.67, respectively. In general, soil particle components can impose a significant impact on the physicochemical properties of soil and the distribution of heavy metals. The average contents of Cd, Ni, As, Hg and Pb in the research area all exceed the soil background value of Hunan Province. Therefore, based on the results of factor analysis, we may infer that the contents of Cd, Ni, As, Hg and Pb are mainly subject to the influence of human factors.The surrounding area of the East Dongting Lake is the major area of agricultural production in northern Hunan Province. Consequently, a large amount of agricultural wastewater originated from non-point pollution sources flows into the Liaohe River every year. Hence,

human activities may be one of the primary reasons for the enrichment of the aforementioned five elements of heavy metals.The relationship between the contents of Cd, Pb and AP indicate that the use of chemical fertilizers and pesticides in the research area may be one of the major reasons behind the increase of Cd and Pb contents in soil. In certain developed countries in Europe and America, the cadmium content in phosphate fertilizer is subject to legislative restrictions. Furthermore the content of cadmium permitted for use is continuously reduced in the standard, whereas the application amount is kept under stringent control (Khalifa and Gad, 2018). However, in the agricultural area surrounding the East Dongting Lake, the application of phosphorus fertilizer has not been subject to stringent control, and consequently the area is plagued with the abuse of phosphorus fertilizer. Based on relevant studies, the largest source of phosphorus was net input of food/feed in 1985–1994. However the application of phosphorus fertilizer took its place to become the largest input source in 1995–2015 (Wijesiri et al., 2018), followed by food/feed net phosphorus input, whereas the smallest source of input was non-food phosphorus. Agricultural production and population growth constitute the major sources of phosphorus input derived from human activities, and their negative ecological effects cannot be neglected (Ciarkowska, 2018). In terms of the element Pb, the application of pesticides may lead to increased concentration of the heavy metal Pb in surface soil. However, as the human activity becomes increasingly intense, the irrigation and drainage of the water used for agricultural irrigation can easily lead to the migration of the element Pb (Ye et al. 2019). Therefore, the Pb content of surface soil is rather low, which conforms to data extracted from the site that indicate a lower content of Pb than background value.

Table 4
Rotation Sums of Squared Loadings for Soil Properties and Heavy Metals

Original data				**Fe-standardized data**			
Compnent	Characteristic value	Contribution rate	Accumulating contribution rate	Compnent	Characteristic value	Contribution rate%	/Accumulating contribution rate%
1	3.066	18.033	18.033	1	3.582	22.387	22.387
2	2.829	16.640	34.674	2	2.723	17.018	39.406
3	2.065	12.149	46.823	3	2.149	13.433	52.838
4	1.817	10.686	57.509	4	2.000	12.500	65.338
Extraction methods: Principal component analysis; rotation method: orthogonal rotation method							

3.4 Effects of urbanization on heavy metals in soil

Over the past few decades, there has been a large-scale renovation and urban development in the vicinity of the East Dongting Lake, leading to constantly increasing population in the region. In particular, the recent development of economic circles, new farms and industrial parks around the East Dongting Lake has led to a large amount of domestic sewage and waste. Along with the industrial and agricultural sewage, such pollution enters into the East Dongting Lake from the ground surface, imposing a severe impact on the ecological quality. Given that these heavy metals will persist in wetlands, they will seriously undermine the stability of wetland ecosystem (Ghosh et al., 2019). During urbanization, heavy metal concentrations in soil will increase over time in general, but not all the elements of heavy metals in the research area reveal the same trend (Huang et al., 2019). In different regions and with exception to Cu, the Fe-normalized heavy metal concentrations have shown significant variation among different types of land use, indicating that the progress made in urbanization can impose a significant impact on the distribution of heavy metal elements. As shown in Fig. 3, in the agricultural land, there is a significantly higher level of Cd, Zn, Pb and Hg contents in the agricultural land than other types of land use ($P < 0.05$) (Mama et al. 2020), and relevant studies have shown that these four kinds of heavy metals are related to the application of phosphate fertilizer (Imchen et al., 2018). In the grassland, there is a rather lower level of agricultural and industrial pollution, contributing to a relatively low overall content of heavy metals in this region (Zhang et al., 2019b). In addition, the effects of natural leaching facilitate the migration of heavy metals from the surface to the deep soil, among which Pb and Zn are the elements that have experienced the most migrations (Li et al. 2018). In the mudflats, due to the evaporation of water, a large area of open space has been formed. Part of the space is used for waterfowl breeding, resulting in contamination to some extent, whereas the reed and miscanthus sacchariflorus have massively grown on other parts of the mudflats. Through the enrichment of soil nutrients, they have effectively improved the soil quality by absorbing a certain concentration of heavy metal elements in soil. Nevertheless, its content of heavy metals is slightly higher than grassland (Wang et al., 2020). In the woodland, the lamellar structure of plant community can weaken the effects of leaching and soil erosion, leading to enhanced physicochemical properties of soil. Moreover, the content of heavy metals accumulated in the woodland is relatively stable, which has the lowest level of heavy metal contents among the five types of land with exception to As (Gao et al., 2018). Along with the advancement of urbanization, and with exception to the heavy metal Cu that does not change significantly, the contents of heavy metals in other types of land all vary to a certain extent (Konstantinova et al., 2019).

The concentrations of 8 sorts of Fe-normalized heavy metals and their significant differences are shown in Fig. 3. Overall, the element of As has shown the highest median value, followed by Zn, Cr, Ni, Cu, Pb, Cd and Hg. However, although the concentrations of all sorts of Fe-normalized heavy metals in agricultural land are much higher than in other land-use patterns, the analysis of variance indicates that the concentration of Cu and Ni normalized against Fe has no significant variation among the 8 sorts of heavy metals in varying types of land use ($P > 0.05$). The Fe-normalized As concentration amounts to 99.52 mg/kg in the agricultural land, significantly higher than the concentration of 70.99 mg/kg in grassland. Similarly, the Fe-normalized Hg concentration amounts to 0.56 mg/kg in agricultural land, significantly higher than 0.38 mg/kg in woodland and and 0.37 mg/kg in grassland. The Fe-normalized Cd concentration in agricultural land amounts to 1.02 mg/kg, significantly higher than that of woodland and grassland, which amounts to 0.77 mg/kg, and also higher than the concentration of 0.81 mg/kg in the construction land. The Fe-normalized Pb concentration amounts to 26.48 mg/kg in agricultural land, significantly higher than that in woodland and grassland (19.52 mg/kg) as well as construction land (19.76 mg/kg). In general, except for the high concentration of Fe-normalized

heavy metals in agricultural land, and the relatively low concentration in grassland and woodland, the concentration of heavy metals is lower in natural area than in areas subject to human activities.

3.5 Potential ecological risk assessment of the heavy metals in soil

Judging from the potential ecological risk coefficient of single heavy metal Eir (Table 5), Cd features the highest risk coefficient with the mean value of 292, whereas the sampling points that have their E.56ir ≧ 320 account for 36.51% of the total, indicating strong ecological risks. As for other heavy metals, including Cu, Zn, As, Hg, Pb, Ni and Cr, the average value of their potential ecological risk coefficients amount to 4.66, 0.80, 63.37, 182.10, 3.69, 6.40 and 1.45, respectively, indicating a low level of ecological risks. Judging from the research results, the coefficients of variation of Zn, As, Cr and Pb are relatively large, each accounting for 32.71%, 36.89%, 41.91% and 32.18%., The results indicate that in the East Dongting Lake, the elements of Zn, As, Cr and Pb have large variations of ecological risks, which are related to the distribution of pollution sources in the research area. According to Table 5, the average value of the comprehensive potential ecological risk index (PERI) for heavy metals amounts to 555.03, representing strong ecological risks. The maximum PERI value amounts to 637.74, whereas the minimum value amounts to 360.88. In addition, the coefficient of variation is 9.17%, indicating that PERI of heavy metals is subject to little variation, and the elements of Hg and Cd constitute the major contributing factors.

Judging from the spatial distribution of potential ecological risks of heavy metals (Fig .4), there is an evident pattern of spatial distribution for the heavy metals of soil in the research area. The 8 sorts of heavy metals have shown varying PERI values under different land use patterns. However, all heavy metals in the woodland in the northwest of East Dongting Lake have relatively lower PERI values. Furthermore, the elements of Cd, Cr, Cu, Hg, Ni, Pb and Zn have shown high ecological risks in the agricultural land in the west of Dongting Lake wetland. The elements of As, Ni, Hg, Pb and Zn have shown extremely high ecological risks in the central part of Dongting Lake wetland, especially in the areas dedicated to aquaculture and rice planting. Over the past few decades, a considerable number of lakes and wetlands have been reclaimed for agricultural cultivation and fishery breeding. While improving the soil fertility, the long term use of fertilizers and pesticides can lead to increased content of heavy metals in soil. As a result, the extensive application of chemical fertilizers and pesticides will not only lead to the contamination of surface soil by heavy metals, but also exacerbate the potential food safety risks derived from heavy metals. Therefore, judging from the perspective of food safety, we shall pay extra attention to the bioaccumulation of Cd in aquatic products, rice and other sorts of food crops. In the northwest and southeast of East Dongting Lake, the agricultural land and mudflats have shown high comprehensive PERI values.

Table 5
Single Potential Ecological Risks and Comprehensive Potential Ecological Risks of Heavy Metals

Item	Single potential ecological risk of heavy metals								Comprehensive potential ecological risk of heavy metals (PERI)
	Cu	Zn	As	Hg	Cd	Pb	Ni	Cr	
Maximum value	7.59	1.22	106.39	224.00	327.00	6.59	8.47	2.25	637.74
Minimum value	2.05	0.33	12.79	60.00	261.00	0.58	3.61	0.65	360.88
Mean value	4.66	0.80	63.37	182.10	292.56	3.69	6.40	1.45	555.03
Standard deviation	1.19	0.26	23.38	33.30	18.39	1.55	1.09	0.47	50.88
Variable coefficient/%	25.50	32.71	36.89	18.29	6.28	41.91	17.04	32.18	9.17

4. Discussion

Based on the aforementioned analysis of the distribution characteristics of heavy metals, the identification of pollution sources and the assessment of heavy metal pollution, we may conclude that the heavy metals in the wetland soil of Dongting Lake have already shown strong ecological risks. Therefore, it is urgent to restore the wetland soil in this area. Subsequent to contamination, the soil can impose threats to human health through the food chain. To avoid their harm to human health, it is necessary to eliminate the heavy metals from the soil.

The Dongting Lake Wetland is located at the end of several major rivers in Hunan Province, and constitutes a necessary place to enter into the Yangtze River. The discharge of agricultural, industrial and domestic sewage in the surrounding areas has led to significant enrichment of heavy metals in sediments, and has imposed severe negative effects on the ecological environment of the wetland. Besides the interference of human factors, the composition of fine soil particles and anaerobic conditions of wetlands also constitute the primary environmental factors contributing to the adsorption of heavy metals in sediments. The East Dongting Lake has significant implications for the safe production of food and the regional ecological security in central and southern parts of China. The particular background of sediments and the unreasonable interference with human activities will elevate the accumulation of heavy metals in wetland soil to toxic levels. This will cause huge risks to human environment and food health, and ultimately compromising the sustainable utilization of regional natural resources. At present, increasing efforts of returning farmland to lake and ecological protection are made in the entire Dongting Lake area. To cope with the problem, we must first trace back to its original source and identify the key issues.

Therefore, during future studies, we intend to add more detailed collection and analysis of the samples of heavy metals in soil influenced by industrial and agricultural production activities. Moreover, we will adopt more scientific methods of source analysis to identify the features of spatial variation for heavy metals in soil at small scales, so as to reveal the interference factors in a more accurate manner, and provide useful reference for the ecological environment protection in the region.

5. Conclusion

(1)Among the 8 typical heavy metals of pollution measured in the research area of the East Dongting Lake, only the average concentrations of Cu, Cr, Zn and Pb are lower than the soil background values, whereas the concentrations of Cd, As, Ni and Hg all exceed the soil background values in Hunan Province. Except for Cd, Hg and As contents that are higher than the national standard, the rest of the heavy metal contents are lower than the national standard. The composition of soil particles is the primary physical factor of control affecting the distribution of heavy metal concentrations. The elements of Cd, Cu, Ni and Zn may derived from a common source of human activities, especially the impact imposed by industrial activities. Continuous application of agricultural fertilizers may increase the contents of Cd and Pb in the soil.

(2) The progress made in urbanization can well reflect the evolution of heavy metal concentration. The effects of early soil erosion and natural leaching can impose a certain impact on the distribution of heavy metals in soil. As the human interference becomes ever more intense, the continuous application of agricultural fertilizers, industrial activities and urban expansion have significantly increased the accumulation of heavy metal contents in soil.

(3) Influenced by the varying modes of land use, the Fe-normalized heavy metal concentrations are relatively low in woodland, except for the high concentrations of Fe-normalized heavy metals in agricultural land.

(4) The element Cd exists as the most severe form of heavy metal pollution in the East Dongting Lake area, which has brought along extremely high ecological risks. In addition, the distribution tendency is consistent with the spatial distribution of comprehensive potential ecological risks, especially in the areas dedicated to aquaculture and agriculture. Measures including but not limited to the expansion of ecological land, development of ecological agriculture (such as rice crab breeding), strengthening of the management of Dongting Lake Nature Reserve and regular dredging of ditches, can effectively enable us to reduce the possibility of heavy metals entering into wetlands, thus alleviating the threats imposed by heavy metals to the soil and water environment in the research area. Last but not least, the excessive enrichment of Cd may lead to health issues. Therefore, from the perspective of food safety, we ought to extra attention to the bioconcentration of the Cd element in aquatic products and rice.

Declarations

1) Ethics approval and consent to participate: Not applicable.

2) Consent for publication: All authors read and approved the final manuscript.

3) Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

4) Competing interests: No conflict of interest exits in the submission of this manuscript.

5) Funding: The research was supported by the general projects of the Nature Science Foundation provided by the Science and Technology Department of Hunan Province, China (approval No. S2019JJMSXM0531).

6) Authors' contributions: Conceptualization and methodology: YL and KL. Data collection and statistical analysis: ZS, WY, WX and MXQ. Validation: JL. Visualization: SJZ. Writing - original draft preparation: YZ. Writing - review and editing: YQJ and BJP. Funding acquisition: YJG and XW.

7) Acknowledgements: The authors are grateful to the Forestry Bureau of Hunan Province (FBHP) for providing the case study data. The authors would like to thank the reviewers for helping to substantially improve the quality of the article. The authors would also like to thank the Editage consultant team for reviewing the English language of the manuscript and for their helpful suggestions

References

Adimalla, N., Chen, J., & Qian, H. (2020). Spatial characteristics of heavy metal contamination and potential human health risk assessment of urban soils: A case study from an urban region of South India. Ecotoxicology and Environmental Safety, 194

Al Mukaimi, M.E., Kaiser, K., Williams, J.R., Dellapenna, T.M., Louchouarn, P., & Santschi, P.H. (2018). Centennial record of anthropogenic impacts in Galveston Bay: Evidence from trace metals (Hg, Pb, Ni, Zn) and lignin oxidation products. Environmental Pollution, 237, 887-899

Alzahrani, D.A., Selim, E.-M.M., & El-Sherbiny, M.M. (2018). Ecological assessment of heavy metals in the grey mangrove (Avicennia marina) and associated sediments along the Red Sea coast of Saudi Arabia. Oceanologia, 60, 513-526

Bai, J., Cui, B., Chen, B., Zhang, K., Deng, W., Gao, H., & Xiao, R. (2011a). Spatial distribution and ecological risk assessment of heavy metals in surface sediments from a typical plateau lake wetland, China. Ecological Modelling, 222, 301-306

Bai, J., Xiao, R., Cui, B., Zhang, K., Wang, Q., Liu, X., Gao, H., & Huang, L. (2011b). Assessment: of heavy metal pollution in wetland soils from the young and old reclaimed regions in the Pearl River Estuary, South China. Environmental Pollution, 159, 817-824

Bierschenk, A.M., Mueller, M., Pander, J., & Geist, J. (2019). Impact of catchment land use on fish community composition in the headwater areas of Elbe, Danube and Main. Science of the Total Environment, 652, 66-74

Cai, L.-M., Jiang, H.-H., & Luo, J. (2019). Metals in soils from a typical rapidly developing county, Southern China: levels, distribution, and source apportionment. Environmental Science and Pollution Research, 26, 19282-19293

Cardwell, A.J., Hawker, D.W., & Greenway, M. (2002). Metal accumulation in aquatic macrophytes from southeast Queensland, Australia. Chemosphere, 48, 653-663

Chai, M., Li, R., Ding, H., & Zan, Q. (2019). Occurrence and contamination of heavy metals in urban mangroves: A case study in Shenzhen, China. Chemosphere, 219, 165-173

Chen, Z., & Hu, S. (2019). Heavy metals distribution and their bioavailability in earthworm assistant sludge treatment wetland. Journal of Hazardous Materials, 366, 615-623

Ciarkowska, K. (2018). Assessment of heavy metal pollution risks and enzyme activity of meadow soils in urban area under tourism load: a case study from Zakopane (Poland). Environmental Science and Pollution Research, 25, 13709-13718

Crocker, R., Blake, W.H., Hutchinson, T.H., & Comber, S. (2021). Spatial distribution of sediment phosphorus in a Ramsar wetland. The Science of the total environment, 765, 142749-142749

Deng, A., Ye, C., & Liu, W. (2018). Spatial and Seasonal Patterns of Nutrients and Heavy Metals in Twenty-Seven Rivers Draining into the South China Sea. Water, 10

Feng, H., Han, X., Zhang, W., & Yu, L. (2004). A preliminary study of heavy metal contamination in Yangtze River intertidal zone due to urbanization. Marine pollution bulletin, 49, 910-915

Feng, S.S., Lu, H.W., Tian, P.P., Xue, Y.X., Lu, J.Z., Tang, M., Feng, W. (2020). Analysis of microplastics in a remote region of the Tibetan Plateau: Implications for natural environmental response to human activities. The Science of the Total Environment, 739, 140087.

Froger, C., Ayrault, S., Evrard, O., Monvoisin, G., Bordier, L., Lefevre, I., & Quantin, C. (2018). Tracing the sources of suspended sediment and particle-bound trace metal elements in an urban catchment coupling elemental and isotopic geochemistry, and fallout radionuclides. Environmental Science and Pollution Research, 25, 28667-28681

Gao, C., Zhang, S., Liu, H., Cong, J., Li, Y., & Wang, G. (2018). The impacts of land reclamation on the accumulation of key elements in wetland ecosystems in the Sanjiang Plain, northeast China. Environmental Pollution, 237, 487-498

Ghosh, S., Bakshi, M., Kumar, A., Ramanathan, A.L., Biswas, J.K., Bhattacharyya, S., Chaudhuri, P., Shaheen, S.M., & Rinklebe, J. (2019). Assessing the potential ecological risk of Co, Cr, Cu, Fe and Zn in the sediments of Hooghly-Matla estuarine system, India. Environmental Geochemistry and Health, 41, 53-70

Grybos, M., Davranche, M., Gruau, G., & Petitjean, P. (2007). Is trace metal release in wetland soils controlled by organic matter mobility or Fe-oxyhydroxides reduction? Journal of colloid and interface science, 314, 490-501

Gu, S., Kang, X., Wang, L., Lichtfouse, E., & Wang, C. (2019). Clay mineral adsorbents for heavy metal removal from wastewater: a review. Environmental Chemistry Letters, 17, 629-654

Guan, J., Wang, J., Pan, H., Yang, C., Qu, J., Lu, N., & Yuan, X. (2018). Heavy metals in Yinma River sediment in a major Phaeozems zone, Northeast China: Distribution, chemical fraction, contamination assessment and source apportionment. Scientific Reports, 8

He, B., Zhao, H., Wang, T.-Y., Meng, J., Xiao, R.-B., Liu, S.-R., Zhou, Y.-Q., & Shi, B. (2019). Spatial Distribution and Risk Assessment of Heavy Metals in Soils from a Typical Urbanized Area. Huan jing ke xue= Huanjing kexue, 40, 2869-2876

Hu, B., Zhou, Y., Jiang, Y., Ji, W., Fu, Z., Shao, S., Li, S., Huang, M., Zhou, L., & Shi, Z. (2020). Spatio-temporal variation and source changes of potentially toxic elements in soil on a typical plain of the Yangtze River Delta, China (2002-2012). Journal of Environmental Management, 271

Huang, S., Shao, G., Wang, L., Wang, L., & Tang, L. (2019). Distribution and Health Risk Assessment of Trace Metals in Soils in the Golden Triangle of Southern Fujian Province, China. International Journal of Environmental Research and Public Health, 16

Huang, S., Tu, J., Jin, Y., Hua, M., Wu, X., Xu, W., Yang, Y., Wang, H., Su, Y., & Cai, L. (2018). Contamination Assessment and Source Identification of Heavy Metals in River Sediments in Nantong, Eastern China. International Journal of Environmental Research, 12, 373-389

Imchen, M., Kumavath, R., Barh, D., Vaz, A., Goes-Neto, A., Tiwari, S., Ghosh, P., Wattam, A.R., & Azevedo, V. (2018). Comparative mangrove metagenome reveals global prevalence of heavy metals and antibiotic resistome across different ecosystems. Scientific Reports, 8

Jiang, Y., & Guo, X. (2019). Multivariate and geostatistical analyses of heavy metal pollution from different sources among farmlands in the Poyang Lake region, China. Journal of Soils and Sediments, 19, 2472-2484

Kalbitz, K., & Wennrich, R. (1998). Mobilization of heavy metals and arsenic in polluted wetland soils and its dependence on dissolved organic matter. The Science of the total environment, 209, 27-39

Keshta, A.E., Shaltout, K.H., Baldwin, A.H., & El-Din, A.A.S. (2020). Sediment clays are trapping heavy metals in urban lakes: An indicator for severe industrial and agricultural influence on coastal wetlands at the Mediterranean coast of Egypt. Marine pollution bulletin, 151

Khalifa, M., & Gad, A. (2018). Assessment of Heavy Metals Contamination in Agricultural Soil of Southwestern Nile Delta, Egypt. Soil & Sediment Contamination, 27, 619-642

Konstantinova, E., Minkina, T., Sushkova, S., Konstantinov, A., Rajput, V.D., & Sherstnev, A. (2019). Urban soil geochemistry of an intensively developing Siberian city: A case study of Tyumen, Russia. Journal of Environmental Management, 239, 366-375

Kulkarni, R., Deobagkar, D., & Zinjarde, S. (2018). Metals in mangrove ecosystems and associated biota: A global perspective. Ecotoxicology and Environmental Safety, 153, 215-228

La Colla, N.S., Botte, S.E., Negrin, V.L., Serra, A.V., & Marcovecchio, J.E. (2018). Influence of human-induced pressures on dissolved and particulate metal concentrations in a South American estuary. Environmental Monitoring and Assessment, 190

Lao, Q., Su, Q., Liu, G., Shen, Y., Chen, F., Lei, X., Qing, S., Wei, C., Zhang, C., & Gao, J. (2019). Spatial distribution of and historical changes in heavy metals in the surface seawater and sediments of the Beibu Gulf, China. Marine pollution bulletin, 146, 427-434

Li, C., Sanchez, G.M., Wu, Z., Cheng, J., Zhang, S., Wang, Q., Li, F., Sun, G., & Meentemeyer, R.K. (2020). Spatiotemporal patterns and drivers of soil contamination with heavy metals during an intensive urbanization period (1989-2018) in southern China. Environmental Pollution, 260

Li, Q., Zhang, Y., Lu, Y., Wang, P., Suriyanarayanan, S., Meng, J., Zhou, Y., Liang, R., & Khan, K. (2018). Risk ranking of environmental contaminants in Xiaoqing River, a heavily polluted river along urbanizing Bohai Rim. Chemosphere, 204, 28-35

Liu, S., Pan, G., Zhang, Y., Xu, J., Ma, R., Shen, Z., & Dong, S. (2019). Risk assessment of soil heavy metals associated with land use variations in the riparian zones of a typical urban river gradient. Ecotoxicology and Environmental Safety, 181, 435-444

Lu, Y., Zang, X., Yao, H., Zhang, S., Sun, S., & Liu, F. (2018). Assessment of trace metal contamination in groundwater in a highly urbanizing area of Shenfu New District, Northeast China. Frontiers of Earth Science, 12, 569-582

Lv, J., & Wang, Y. (2018). Multi-scale analysis of heavy metals sources in soils of Jiangsu Coast, Eastern China. Chemosphere, 212, 964-973

Mama, C.N., Nnaji, C.C., Emenike, R.C., & Chibueze, C.V. (2020). Potential environmental and human health risk of soil and roadside dust in a rapidly growing urban settlement. International Journal of Environmental Science and Technology, 17, 2385-2400

Manuel Trujillo-Gonzalez, J., Aurelio Torres-Mora, M., Jimenez-Ballesta, R., & Zhang, J. (2019). Land-use-dependent spatial variation and exposure risk of heavy metals in road-deposited sediment in Villavicencio, Colombia. Environmental Geochemistry and Health, 41, 667-679

Manzoor, R., Zhang, T., Zhang, X., Wang, M., Pan, J.-F., Wang, Z., & Zhang, B. (2018). Single and combined metal contamination in coastal environments in China: current status and potential ecological risk evaluation. Environmental Science and Pollution Research, 25, 1044-1054

Marchand, L., Mench, M., Jacob, D.L., & Otte, M.L. (2010). Metal and metalloid removal in constructed wetlands, with emphasis on the importance of plants and standardized measurements: A review. Environmental Pollution, 158, 3447-3461

Men, C., Liu, R., Xu, F., Wang, Q., Guo, L., & Shen, Z. (2018). Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China. Science of the Total Environment, 612, 138-147

Meng, W., He, M., Hu, B., Mo, X., Li, H., Liu, B., & Wang, Z. (2017). Status of wetlands in China: A review of extent, degradation, issues and recommendations for improvement. Ocean & Coastal Management, 146, 50-59

Naylo, A., Almeida Pereira, S.L., Benidirel, L., El Khalil, H., Castro, P.M.L., Ouvrard, S., Schwartz, C., & Boularbah, A. (2019). Trace and major element contents, microbial communities, and enzymatic activities of urban soils of Marrakech city along an anthropization gradient. Journal of Soils and Sediments, 19, 2153-2165

Othman, F., Chowdhury, M.S.U., Jaafar, W.Z.W., Faresh, E.M.M., & Shirazi, S.M. (2018). Assessing Risk and Sources of Heavy Metals in a Tropical River Basin: A Case Study of the Selangor River, Malaysia. Polish Journal of Environmental Studies, 27, 1659-1671

Rastmanesh, F., Safaie, S., Zarasvandi, A.R., & Edraki, M. (2018). Heavy metal enrichment and ecological risk assessment of surface sediments in Khorramabad River, West Iran. Environmental Monitoring and Assessment, 190

Rinklebe, J., Antoniadis, V., Shaheen, S.M., Rosche, O., & Altermann, M. (2019). Health risk assessment of potentially toxic elements in soils along the Central Elbe River, Germany. Environment international, 126, 76-88

Saranya, K., Sundaramanickam, A., Shekhar, S., Meena, M., Sathishkumar, R.S., & Balasubramanian, T. (2018). Biosorption of multi-heavy metals by coral associated phosphate solubilising bacteria Cronobacter muytjensii KSCAS2. Journal of Environmental Management, 222, 396-401

Saxena, G., Purchase, D., Mulla, S.I., Saratale, G.D., & Bharagava, R.N. (2020). Phytoremediation of Heavy Metal-Contaminated Sites: Eco-environmental Concerns, Field Studies, Sustainability Issues, and Future Prospects. In P. DeVoogt (Ed.), Reviews of Environmental Contamination and Toxicology, Vol 249 (pp. 71-131)

Sharma, S., Nagpal, A.K., & Kaur, I. (2019). Appraisal of heavy metal contents in groundwater and associated health hazards posed to human population of Ropar wetland, Punjab, India and its environs. Chemosphere, 227, 179-190

Shehzad, M.T., Murtaza, G., Shafeeque, M., Sabir, M., Nawaz, H., & Khan, M.J. (2019). Assessment of trace elements in urban topsoils of Rawalpindi-Pakistan: a principal component analysis approach. Environmental Monitoring and Assessment, 191

Sibal, L.N., & Espino, M.P.B. (2018). Heavy metals in lake water: a review on occurrence and analytical determination. International Journal of Environmental Analytical Chemistry, 98, 536-554

Sodango, T.H., Li, X., Sha, J., & Bao, Z. (2018). Review of the Spatial Distribution, Source and Extent of Heavy Metal Pollution of Soil in China: Impacts and Mitigation Approaches. Journal of health & pollution, 8, 53-70

Sun, C., Zhang, Z., Cao, H., Xu, M., & Xu, L. (2019). Concentrations, speciation, and ecological risk of heavy metals in the sediment of the Songhua River in an urban area with petrochemical industries. Chemosphere, 219, 538-545

Trung Kien, H., Probst, A., Orange, D., Gilbert, F., Elger, A., Kallerhoff, J., Laurent, F., Bassil, S., Thi Thuy, D., & Gerino, M. (2018). Bioturbation effects on bioaccumulation of cadmium in the wetland plant Typha latifolia: A nature-based experiment. Science of the Total Environment, 618, 1284-1297

Vongdala, N., Hoang-Dung, T., Tran Dang, X., Teschke, R., & Tran Dang, K. (2019). Heavy Metal Accumulation in Water, Soil, and Plants of Municipal Solid Waste Landfill in Vientiane, Laos. International Journal of Environmental Research and Public Health, 16

Wang, M., Liu, R., Chen, W., Peng, C., & Markert, B. (2018). Effects of urbanization on heavy metal accumulation in surface soils, Beijing. Journal of Environmental Sciences, 64, 328-334

Wang, Y., Duan, X., & Wang, L. (2020). Spatial distribution and source analysis of heavy metals in soils influenced by industrial enterprise distribution: Case study in Jiangsu Province. Science of the Total Environment, 710

Weis, J.S., & Weis, P. (2004). Metal uptake, transport and release by wetland plants: implications for phytoremediation and restoration. Environment international, 30, 685-700

Wijesiri, B., Liu, A., Gunawardana, C., Hong, N., Zhu, P., Guan, Y., & Goonetilleke, A. (2018). Influence of urbanisation characteristics on the variability of particle-bound heavy metals build-up: A comparative study between China and Australia. Environmental Pollution, 242, 1067-1077

Xiao, H., Shahab, A., Li, J., Xi, B., Sun, X., He, H., & Yu, G. (2019). Distribution, ecological risk assessment and source identification of heavy metals in surface sediments of Huixian karst wetland, China. Ecotoxicology and Environmental Safety, 185

Xie, T., Wang, M., Chen, W., & Uwizeyimana, H. (2019). Impacts of urbanization and landscape patterns on the accumulation of heavy metals in soils in residential areas in Beijing. Journal of Soils and Sediments, 19, 148-158

Xu, T., Weng, B., Yan, D., Wang, K., Li, X., Bi, W., Li, M., Cheng, X., & Liu, Y. (2019). Wetlands of International Importance: Status, Threats, and Future Protection. International Journal of Environmental Research and Public Health, 16

Ye, S., Zeng, G., Wu, H., Liang, J., Zhang, C., Dai, J., Xiong, W., Song, B., Wu, S., & Yu, J. (2019). The effects of activated biochar addition on remediation efficiency of co-composting with contaminated wetland soil. Resources Conservation and Recycling, 140, 278-285

Zhang, K., Wang, Q. Q., Chao, L.J., Ye, J.Y., Li, Z.J., Yu, Z.B., Yang, T., Ju, Q. (2019a). Ground observation-based analysis of soil moisture spatiotemporal variability across a humid to semi-humid transitional zone in China. Journal of Hydrology (Amsterdam), 574, 903-914

Zhang, M., He, P., Qiao, G., Huang, J., Yuan, X., & Li, Q. (2019b). Heavy metal contamination assessment of surface sediments of the Subei Shoal, China: Spatial distribution, source apportionment and ecological risk. Chemosphere, 223, 211-222

Figures

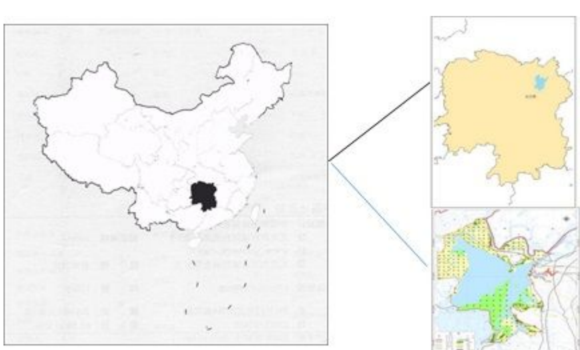

Figure 1

Maps on the Geographical Location of Research Area and the Distribution of Sampling Points. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

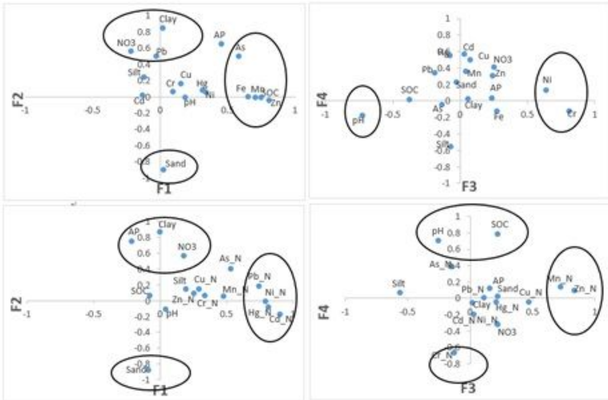

Figure 2

Scatter Diagram on the Physicochemical Properties of Soil and the Rotation Factor Load Matrix of Heavy Metals (Raw data and Fe-normalized data)

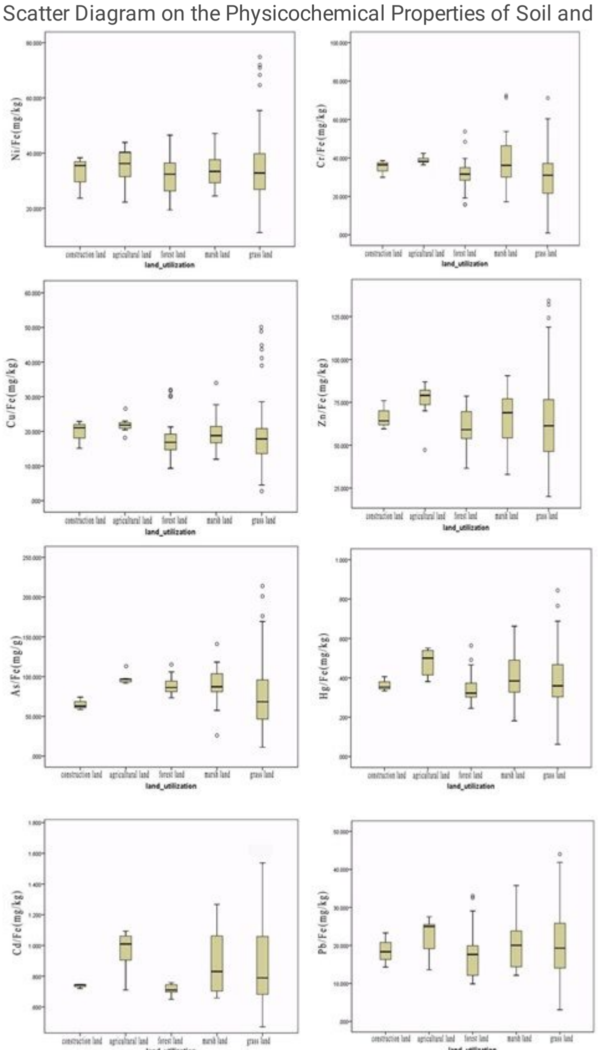

Figure 3

Multiple Comparison Analysis of ANOVA and Plots for Fe-normalized Heavy Metal Concentrations in Different Zones

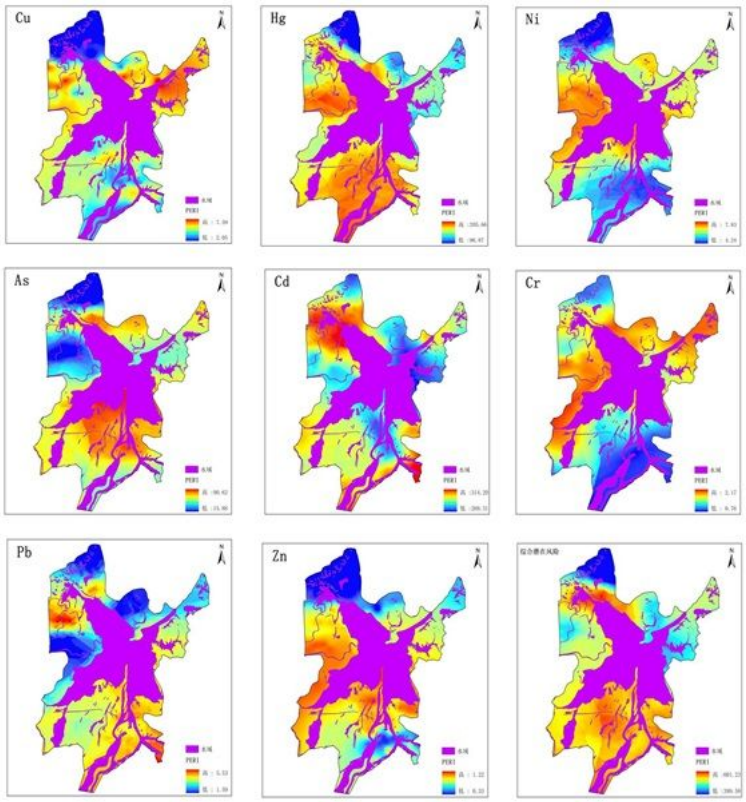

Figure 4

Spatial Distribution of Single Potential Ecological Risks and Comprehensive Potential Ecological Risks of Heavy Metals. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.