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Distribution characteristics of heavy metals in surface soils from the western area of Nansi Lake, China

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Abstract Surface soil samples collected from the western area of Nansi Lake, China, were analyzed for selected heavy metals including As, Cd, Pb, and Zn, to determine their spatial distributions and environmental effects. The average concentrations of As, Cd, Pb, and Zn in soil were 13.21 mg/kg, 0.20 mg/kg, 23.94 mg/kg, and 79.95 mg/kg, respectively. The concentration of As, Cd, and Zn was approximately 1.44-, 2.33-, and 1.25-fold higher than its background values in study area, respectively. Meanwhile, the concentrations of heavy metals progressively decreased from east to west within the study area, in a step-function distribution. The differences in the heavy metal distribution characteristics might be caused by the lake water irrigation and agricultural activities such as fertilizer and pesticide use. There were significant positive correlations between the values of OrgC, Al_2O_3, and Fe_2O_3 and concentrations of heavy metals. According to the Geo-accumulation index (I_{geo}) and the potential ecological risk index (PERI), Cd posed higher potential ecological risk in surface soil when compared with As, Pb, and Zn. These results could provide the scientific basis on which to evaluate the distribution of heavy metals under natural and anthropogenic influences in the surface soil near Nansi Lake, China.

Keywords Heavy metal · Spatial distribution · Environmental impact factor · Pollution evaluation

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Introduction

Soil is an important part of the ecological environment and is a crucial natural resource that mankind depends on for existence and development (Ungureanu et al. 2017). Heavy metals are highly toxic, and only a small amount can potentially harm the quality and safety of agricultural products (Lei et al. 2015). Contamination from heavy metals causes decreased soil quality, reduced crop yields, and is a danger to human health (Tipayno et al. 2011). In 2015, researchers estimated that over 8.1×10^4 km^2 of farmland in China was contaminated by heavy metals such as As, Cd, Pb, and Zn (Si et al. 2015). Studies showed that during the last decade, farmland soils in China were mainly contaminated by Cd and Pb (Wei and Yang 2010). In agricultural soil from the middle and upper reaches of the Huangpu River, Cd, As, and Pb concentrations exceeded the soil background values by 60%, 19%, and 45%, respectively (Chen and Zhou 2014). Studying heavy metal pollution in soil and factors that influence the severity of the pollution is essential in understanding the mechanism by which heavy metals enrich farmland soils.

The distributions of heavy metals are closely related to the physical and chemical properties of the soil, the land-use type, and the agricultural irrigation type, and if there have been those reasons—meaning that both natural and anthropogenic factors play roles (Yang et al. 2003). In general, heavy metals in the soil originate from natural sources such as the soil's parent material (Wang et al. 2015). However, with rapid industrialization and urbanization activities, a variety of heavy metals now enter the soil through atmospheric deposition, sewage irrigation, fertilizer application, and waste dumping (Guan et al. 2017). Contamination can enrich in the soil through the soil-plant system and bio-accumulate in animals, causing serious threats to human health (Cao et al. 2015). Agricultural sources of pollution are the main anthropogenic source of heavy metals in soil (Yang et al. 2018). In Michigan in the USA, the frequent application of pesticides has resulted in the As soil concentration to be as high as 112 mg/kg (Howard and Olszewska 2011). According to a survey conducted by the Ministry of Agriculture of the People's Republic of China, the area impacted by sewage irrigation covers approximately 1.4×10^4 km^2 in China (Liu et al. 2015). There has been limited research concerning heavy metal concentration in the surface sediments of Nansi Lake (Wang et al. 2014), although the spatial distribution characteristics and factors influencing the distribution of heavy metal in soil from the western area of the lake have not been previously studied.

In this study, the spatial distribution characteristics of As, Cd, Pb, and Zn in the farmland soil from the western area of Nansi Lake were investigated. Furthermore, the Geo-accumulation index (Igeo) and the potential ecological risk index (PERI) methods were used to evaluate and assess the heavy metal pollution severity. These results can provide a scientific baseline for which to evaluate future soil quality in the Nansi Lake catchment.

Materials and methods

Study area

The study region is comprised of the western area of Nansi Lake (34° 52′–35° 37′ N, 116° 06′–116°49′ E), situated in the Yellow River Flood Plain, southwest of Shandong, China (the border region of Shandong and Jiangsu). The study area covers 3.16×10^3 km^2, including Rencheng District, Jiaxiang County, Jinxiang County, and Yutai County. The terrain of this region slopes gently, and the main rivers are wide, shallow, and slow moving, including the Liangji Canal, the Zhuzhaoxin River, the old Wanfu River, the Dongyu River, and the Fuxing River (Fig. 1).

The western area of Nansi Lake is well-known as a national production base for commodity grain, high-quality garlic, high-quality rice, and freshwater fish. Its superior geographic position offers advantages for communication with other significant cities, as well as providing the resources needed for economic development and trade.

Sample collection

The western area of Nansi Lake was divided into square sampling grids with sides of 2 km. Samples were collected at the center of the grid, and then the four sampling points adjacent to each site were combined to form a mixed sample. A total of 860 soil samples were collected in study area. Samples were collected so as to avoid the fertilization period and were taken from sites without landfills, ridges, or other anomalies. Each soil sample was taken from 0 to 20 cm below the surface using a Luoyang shovel. The part of the soil that contacted the metal of the shovel was removed. Weeds, gravel, fertilizer, and other debris were removed from the soil samples to ensure that they were as uncontaminated as possible. Every sample (about 50 g) was then ground to be able to pass through a 100-mesh nylon sieve and stored for further analyses.

Under laboratory conditions, soil samples were spread into thin layers and air dried naturally. During the drying process, soil samples were tumbled several times to break up large clumps, and any roots or other pieces in the samples were removed. After grinding, all samples were put through a 2-mm polyethylene sieve and fully mixed in sample bags for further analysis.

Fig. 1 The study western area of Nansi Lake in Shandong Province, China

Chemical analysis

The extractor used for metals and other environmental factors is microwave acid dissolution technique. The specific digestion steps of soil samples are as follows: Firstly, 0.25 g of dry soil samples was poured into Teflon cans. Secondly, 10 mL mixed acid solution (mix HNO3 and HClO4 in a ratio of 4:1) was put into Teflon cans to dissolve soil samples. Thirdly, Teflon cans were microwaved at the appropriate temperature. Finally, the dissolved samples were diluted with ultra-pure water to constant volume.

The concentration of As in the soil samples was measured using Atomic Fluorescence Spectroscopy (AFS, AFS-230E, Beijing, China). The concentrations of Cd, Pb, and Zn were analyzed using X-Ray Fluorescence Spectroscopy (XRF, ADVANT' XP, ARL, Switzerland). Al_2O_3 and Fe_2O_3 concentration was measured using Graphite Furnace Atomic Absorption Spectrometry (GF-AAS, M6, Thermo Elemental, USA), and the pH was measured via potentiometry. Geological survey technical standards (DD2005-03) of the China Geological Survey were used to determine pH and OrgC. For the purposes of this study, the 15-year average concentrations of heavy metals in soils of Shandong Province were regarded as the background values of the study area (Liu et al. 2017).

In order to improve accuracy, a system blank was measured before the experiment. The use of a blank can minimize the impact of the laboratory apparatus on heavy metal concentration. Parallel samples at three times were taken to reflect the precision of the test.

Results and discussion

Concentrations of heavy metals in the surface soil

Table 1 shows the statistics of heavy metals, the background values, and environmental quality standards for soil samples from the western area of Nansi Lake. The concentrations of As, Cd, Pb, and Zn in soils ranged from 3.4 to 34.1 mg/kg, 0.08 to 1.52 mg/kg, 15.9 to 56.7 mg/kg, and 50.8 to 214.3 mg/kg, respectively. The average concentrations of As, Cd, and Zn were 1.42, 2.33, and 1.25 times higher than the background soil values in Shandong Province, respectively. However, the average concentration of Pb did not exceed the background value.

The order of degree of enrichment of the tested metals decreased: Cd > As > Zn > Pb. Other studies also done in the wetlands of the Yellow River estuary gave concentrations of As, Cd, Pb, and Zn of 6.0 mg/kg, 0.168 mg/kg, 56.1 mg/kg, and 75.8 mg/kg, respectively (Sun et al. 2015). Our study showed that As and Cd concentrations in the study area were higher than previously determined concentrations in the wetlands of the Yellow River estuary. When compared to the threshold values for environmental quality standards for soils by the State Environmental Protection Administration of China (SEPAC 1995), the average concentrations of heavy metals were below the National secondary standard limit, which guarantees local agricultural production and viability.

The coefficient of variation represents the degree of dispersion of the data set (Yu et al. 2018). The coefficients of variation for As, Cd, Pb, and Zn were 0.354, 0.416, 0.178, and 0.211 (Table 1), respectively. The concentrations of As and Cd from some sites were higher than the concentrations of the other heavy metals. The coefficients of variation for Pb and Zn were smaller than those of the other samples. The pH of all soil samples ranged from 6.77 to 8.93, with a mean of 8.07, meaning that the soil was weakly alkaline. The coefficient of variation of the pH was 0.03, which indicated that soil pH values were evenly distributed. The percentage of soil organic matter was between 0.31 and 2.56%, with a mean of 1.07%, and the coefficient of variation was 0.389. The average soil concentration of SiO_2 was 56.73%, the average concentration of Al_2O_3 was 13.59%, and the average concentration of Fe_2O_3 was 5.36%. The coefficient of variation of these species was relatively small, indicating that the soil texture of the study area had homogenous structure and was biased toward clay (Kalm et al. 1996).

Spatial distribution of heavy metals in the surface soil

Based on the geostatistical analysis, the spatial distribution of As, Cd, Pb, and Zn was mapped (Fig. 2) to visualize the variation of each heavy metal. The distribution characteristics of all the metals were similar: concentrations were higher in the eastern and northwestern areas of the region, and lower in the southwestern area. The highest values of As and Cd both appeared in the eastern part of the study area, while the highest value of Pb and Zn appeared in Rencheng District near the northeastern region.

The concentrations of heavy metals in soils exhibited significant differences when compared by county (Table 2), with Rencheng District showing the lowest concentrations. There was no significant difference between Jiaxiang and Jinxiang County. Of the three counties, only heavy metal concentrations in Yutai County exceeded the background value, with As and Cd accumulating in the surface soil. The concentrations of As, Cd, Pb, and Zn in Yutai County were 16.94 mg/kg, 0.27 mg/kg, 26.47 mg/kg, and 91.84 mg/kg and were approximately 1.82-, 3.22-, 1.06-, and 1.44-fold higher than their background values, respectively.

The spatial distribution characteristics of As, Cd, Pb, and Zn in soil from the study area showed a step-wise distribution. The relationship between heavy metal concentration and the distance from the lake was plotted by selecting 178 sample points for analysis (Fig. 3). Results showed that the concentrations of heavy metals decreased with increasing distance from the lake, and that there was a significant negative correlation between the distance and concentration. The fluctuations of the concentrations of different heavy metals were synergistic, and As, Cd, Pb, and Zn had high correlation coefficients.

The trend of heavy metal concentrations decreasing with increased distance from the lake may be due to irrigation water taken from Nansi Lake. Studies have revealed that the Dongyu River estuary is contaminated, exhibiting moderately enriched EF (enrichment factor) values of Cd (Cao et al. 2018). Heavy metal pollutants can enter Nansi Lake along these polluted rivers. The concentration of studied metals in the Nansi lake sediments showed variations in both spatial distribution and pollution level. The results showed that As and Pb ranged from unpolluted to moderately polluted, while Cd was moderately polluted (Wang et al. 2014). Lake water was being pumped from the lake and used to irrigate nearby crops, thereby putting polluted water on the land. These findings suggested that heavy metals in the lake water can be induced into soil near the lake via irrigation.

Table 1 Statistics of heavy metal concentrations and the environmental standards in surface soil

	Unit	Max	Min	Ave	SD	CV	The background value[a]	National secondary standard
As	mg/kg	34.10	3.40	13.21	4.68	0.35	9.3	20
Cd		1.52	0.08	0.20	0.08	0.42	0.084	0.3
Pb		56.70	15.90	23.94	4.26	0.18	25.8	300
Zn		214.30	50.80	79.95	16.84	0.22	63.9	250
pH	–	8.93	6.77	8.07	0.27	0.03	–	–
OrgC	%	2.56	0.31	1.07	0.42	0.39	–	–
SiO_2		70.58	45.61	56.73	6.12	0.11	61.26	–
Al_2O_3		17.78	11.03	13.59	1.20	0.09	11.95	–
Fe_2O_3		8.47	3.54	5.36	1.08	0.20	4.20	–

—, not available; *CV*, coefficient of variation; *SD*, standard deviation

[a] Liu et al. (2017)

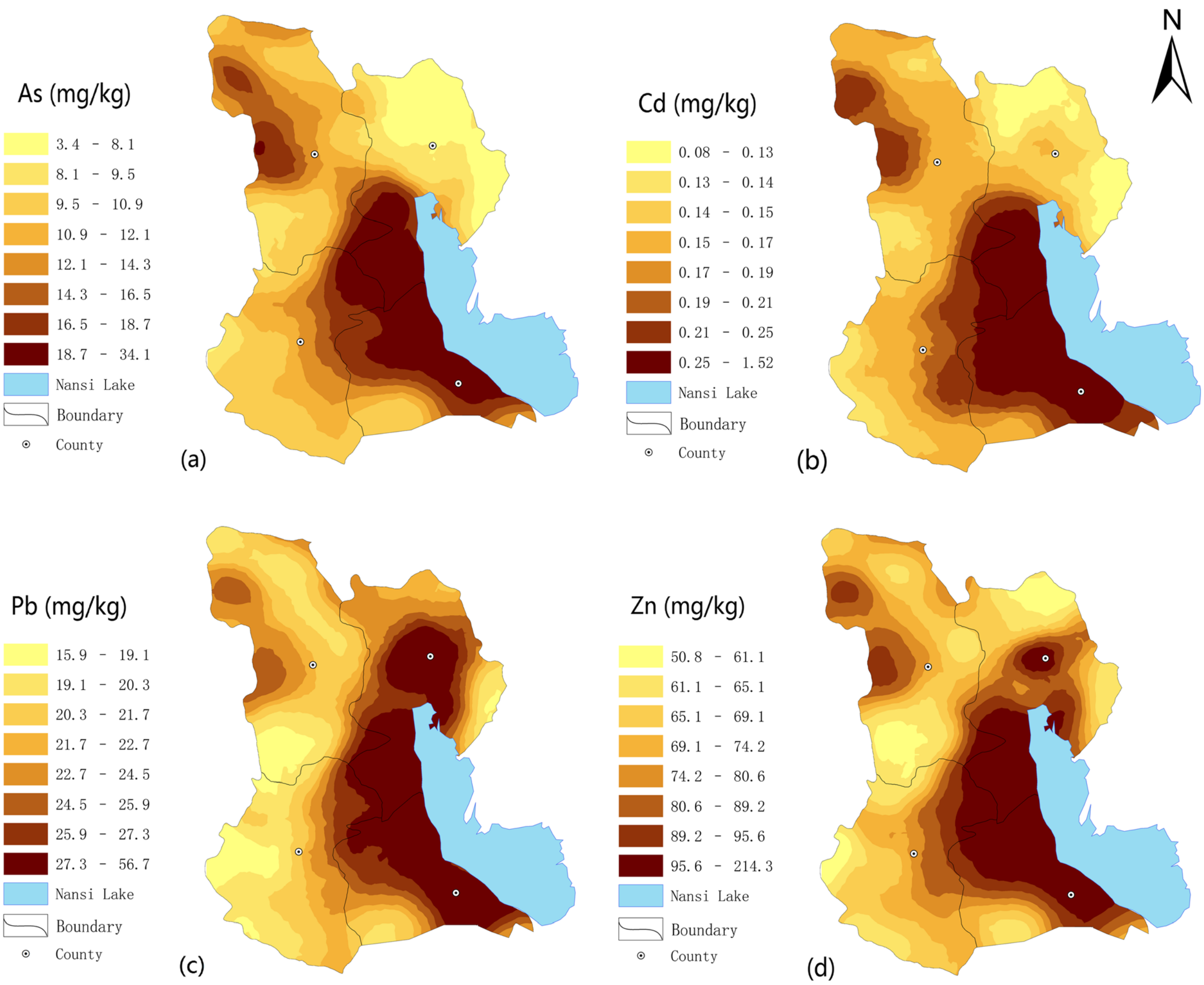

Fig. 2 The distribution of heavy metals in surface soil in the western area of Nansi Lake

Table 2 Statistics of heavy metals concentrations (mg/kg) in the surface soil separated by county

	Rencheng District Mean ± SD	Jiaxiang County Mean ± SD	Jinxiang County Mean ± SD	Yutai County Mean ± SD	The background value
As	11.08 ± 5.54	13.02 ± 3.55	12.62 ± 3.62	16.94 ± 3.88	9.3
Cd	0.19 ± 0.31	0.18 ± 0.04	0.18 ± 0.05	0.27 ± 0.12	0.084
Pb	26.09 ± 5.09	22.20 ± 2.87	21.72 ± 3.15	26.47 ± 3.17	25.8
Zn	81.38 ± 20.83	74.75 ± 12.48	74.96 ± 12.73	91.84 ± 14.75	63.9
pH	7.92 ± 0.34	8.29 ± 0.18	7.96 ± 0.17	8.10 ± 0.14	–
OrgC	1.29 ± 0.44	0.92 ± 0.19	0.78 ± 0.20	1.37 ± 0.47	–
SiO_2	59.88 ± 7.66	57.24 ± 4.26	57.08 ± 4.00	51.56 ± 5.04	61.26
Al_2O_3	14.32 ± 1.19	13.18 ± 0.94	12.95 ± 1.00	14.07 ± 1.09	11.95
Fe_2O_3	5.60 ± 1.17	5.05 ± 0.83	4.92 ± 0.90	6.06 ± 1.06	4.20

Additionally, the concentrations and distribution of heavy metals and their relationships with different soil properties were studied. There were significant differences in the concentrations of heavy metals with different land-use types in the study area, which included paddy soil, cinnamon soil, and aquic soil, characterized by the zonal distribution in east-west strike (Fig. 2). Figures 2 and 4 show that the concentration of heavy metals from paddy soils was the highest in the study area. Under the influence of temperature, pH, organic carbon, and water concentration, paddy soil in the Taihu Lake of China tended

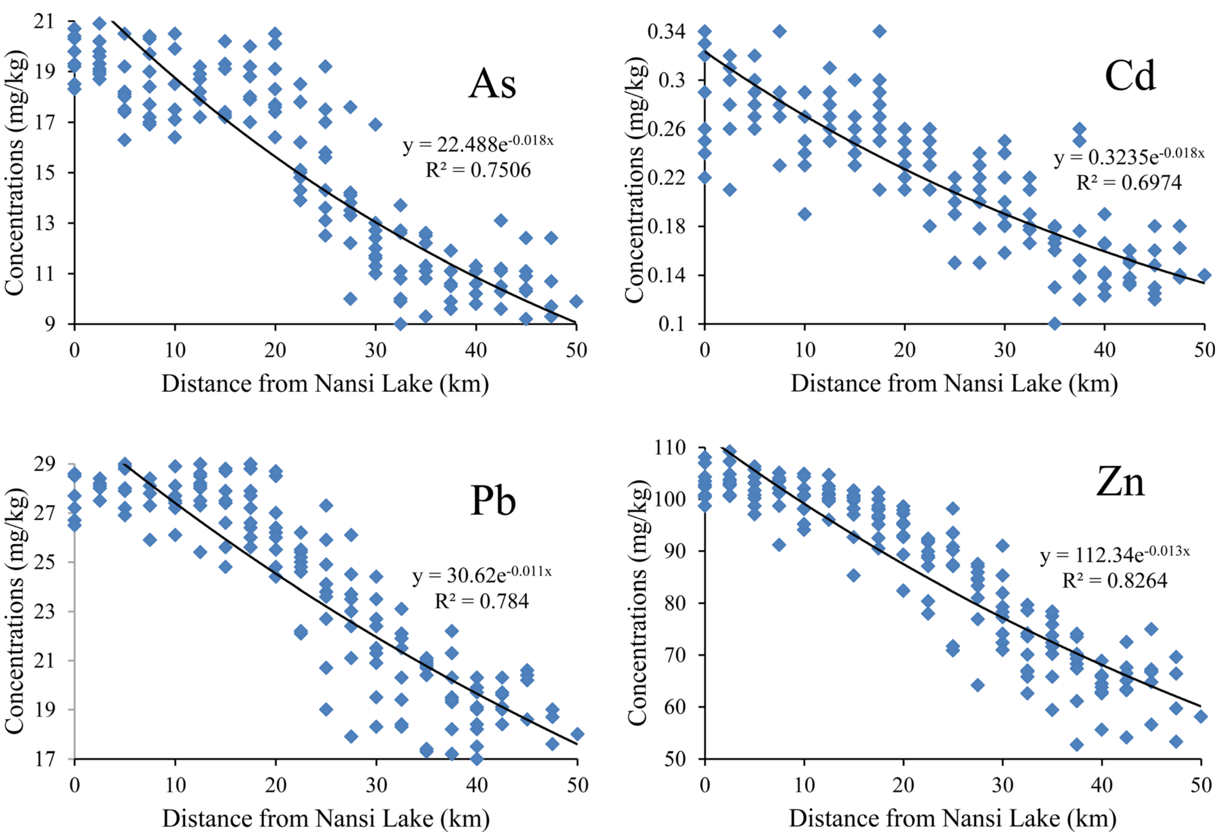

Fig. 3 Fluctuation curve of the concentration of heavy metal in the soil with distance from Nansi Lake

to accumulate heavy metal concentration more than other land uses, especially at the surface (Shen et al. 2005). This finding implies that paddy soil helps accumulate heavy metals as compared with other soils.

Different planting patterns had specific effects on the concentrations of heavy metals. The main crop east of Yutai County and in the southern part of Rencheng District was rice paddy, while corn and wheat were the most widely distributed in Jinxiang and Jiaxiang County (Fig. 4). Paddy planted area comprised a total of 54.4% of the entire agricultural acreage of Yutai County (Table 2). As discussed above, the concentration of heavy metals in paddy growing areas was significantly higher than that in areas growing other crops. There was also a larger water-covered area in Yutai County and Rencheng District, indicating that these areas experienced a greater effect of irrigation on the heavy metal concentration.

Fertilization is an important method that helps ensure high and stable crop yields. However, environmental problems such as soil salt collapse and heavy metal pollution caused by improper or excessive application of fertilizers cannot be ignored as potential consequences of their use. For example, on the Sanjiang Plain in China, researchers found that agricultural irrigation and the wide application of fertilizers and pesticides were the main factors affecting the distribution of heavy metals, especially As, in farmland (Ouyang et al. 2013).

Studies on heavy metal contamination demonstrated that the use of pesticides and fertilizers and increased urbanization accelerated the accumulation of Pb in farmland soil (Li and Jia 2018). Cd can be used as an element to help identify agricultural activities such as pesticide and fertilizer application (Yang et al. 2013), as well as Pb and Zn (Maliki et al. 2015). The concentration of Cd in phosphate fertilizer is higher than other heavy metals' concentrations, and about 37 tons of Cd is put into the soil with phosphate fertilizer every year in China (Xu et al. 2014). Statistics describing annual agricultural production in the western area of Nansi Lake are shown in Table 3. Average annual fertilizer use in Jiaxiang County was 57,915 tons/year (Table 3) and may have contributed to the higher concentration of heavy metals in the soil northwest of Jiaxiang County.

Correlation analysis of heavy metal concentration and environmental factors

A correlation coefficient is generally used to quantify whether there is a similar source path between various heavy metals (Wang et al. 2012). In general, the higher the correlation coefficient between heavy metals, the stronger the dependence of the relationship, indicating a potential common source. If the correlation coefficient is low and the dependence relationship is weak, the contamination sources are much more varied. Correlation analysis of the heavy metal elements and other environmental factors in the study area was conducted, and results are shown in Table 4. As, Cd, Pb, and Zn had significant positive correlations ($P < 0.01$) and may share a common source. The concentration of heavy metals is closely related to the physical and chemical properties of the soil. With the exception of SiO_2, there were significant positive correlations between OrgC, Al_2O_3, Fe_2O_3, and the four heavy metals.

The primary factor that affects the existing forms and bioavailability of heavy metals in soil is the pH (Ai et al. 2018). The lower the pH of soil, the stronger the activity of the heavy metal and the more easily they migrate in the soil where they can potentially be absorbed by crops (Weber and Karczewska 2004). As can be seen from Table 4, the correlation between the pH values and the concentration of As was 0.314. However, it could be seen from Table 2 that pH values of different counties are similar. This indicated that pH has little influence on the total concentration of heavy metals in soil.

The relationship between heavy metals and organic matter in soil has also received a great deal of study. Organic matter can not only affect the accumulation of heavy metals in soil, but also forms complexes with heavy metals, which can affect the migration and transformation of heavy metals, further affecting their availability (Six et al. 2002). One study found that the long-term application of organic manure could significantly enhance the concentrations of Cd and Zn in soil (Sleutel et al. 2006). There is a functional relationship between organic carbon and organic matter. This paper analyzed the correlation between organic carbon and heavy metal concentration in soil. Table 4 indicates that the correlation coefficients between organic carbon and all heavy metals were greater than 0.5. Thus, organic matter had a significant effect on the distribution gradient of heavy metals in soil from the western area of Nansi Lake.

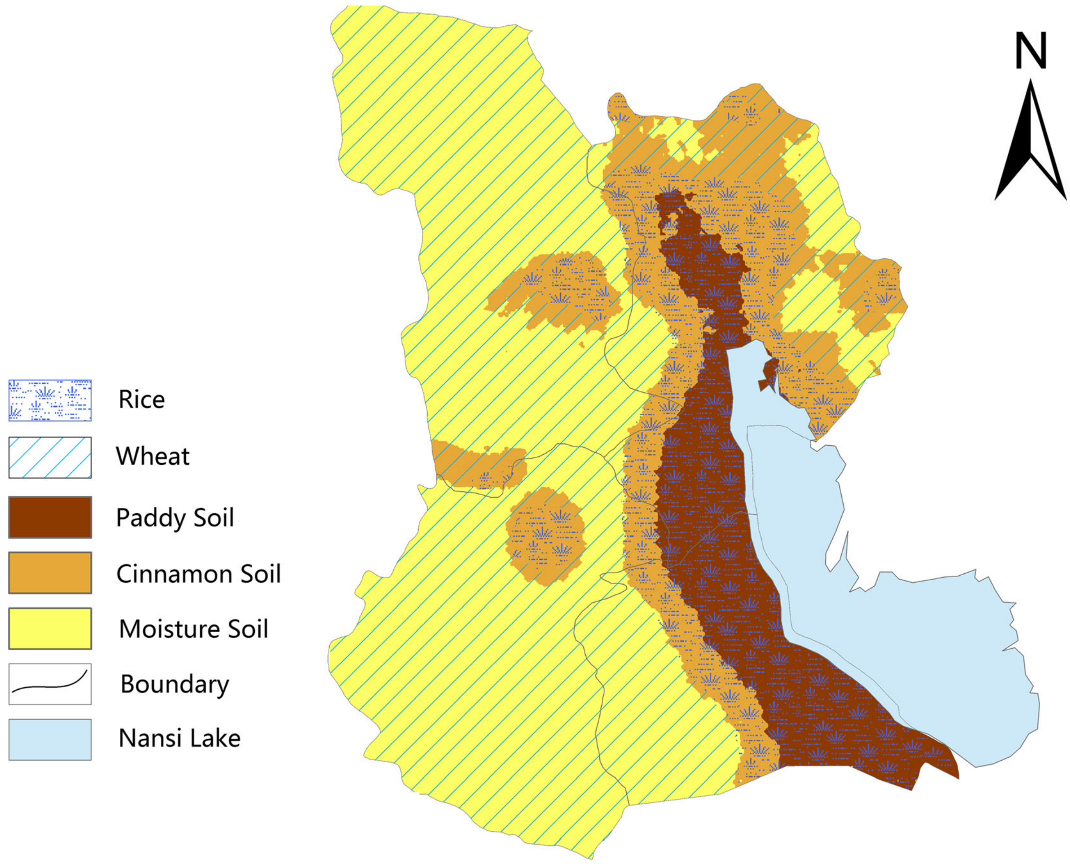

Fig. 4 Land-use and soil type in the western area of Nansi Lake

In natural conditions, the soil parent material is closely related to the concentration of the heavy metals found in that soil, while the concentration of SiO_2, Al_2O_3, and Fe_2O_3 can reflect the texture of the soil. Compared with the results of the multi-target regional geochemical survey in the lower Yellow River (Wang et al. 2016), the concentration of SiO_2 in the study area was lower, while that of Al_2O_3 and Fe_2O_3 was higher, which reflected that the soil texture in the study area was biased toward clay (Ren et al. 2018). Clay has a strong adsorption capacity for heavy metals and promoted the enrichment of heavy metals in soil in the study area. There was a significant negative correlation between SiO_2 and heavy metal concentration, while there was a significant positive correlation with Al_2O_3 and Fe_2O_3 (Table 4). Soil texture was one of the important factors affecting the distribution gradient of heavy metals in soil from the western area of Nansi Lake.

Source analysis of heavy metals in soil

The spatial distribution of As, Cd, Pb, and Zn in study area was similar, so it could be inferred that

Table 3 Annual agricultural production statistics (2006–2016) in the western area of Nansi Lake

District	Agricultural acreage (hm^2)	Paddy plant area (hm^2)	Water area (hm^2)	Fertilizer use (t)	Pesticide use (t)
Rencheng District	51,308	15,800	3384	31,402	2082
Jiaxiang County	66,487	4100	1652	57,915	1614
Jinxiang County	62,286	1000	1557	51,410	1494
Yutai County	39,521	21,500	2726	24,603	1415

*The data came from the Jining statistical yearbook

Table 4 Correlation analysis of soil heavy metals and environmental factors in the western area of Nansi Lake

	As	Cd	Pb	Zn	pH	OrgC	SiO_2	Al_2O_3	Fe_2O_3
As	1								
Cd	0.661**	1							
Pb	0.513**	0.443**	1						
Zn	0.734**	0.596**	0.775**	1					
pH	0.314**	0.142**	0.029	0.144**	1				
OrgC	0.550**	0.543**	0.702**	0.699**	0.029	1			
SiO_2	−0.934**	−0.677**	−0.484**	−0.756**	−0.304**	−0.606**	1		
Al_2O_3	0.515**	0.371**	0.708**	0.705**	−0.003	0.670**	−0.527**	1	
Fe_2O_3	0.784**	0.569**	0.706**	0.836**	0.115**	0.751**	−0.809**	0.898**	1

**Correlation is significant at $P < 0.01$ (two-tailed)

they have the same source. The spatial distribution characteristics of As, Cd, Pb, and Zn in soil from the study area showed a step-wise distribution. According to the field investigation, the lake water was often used to irrigate the farmland in the lakeside region. Some of the heavy metals in the lake water entered the soil during irrigation. The lakeside region had a wide rice planting area, so it needs a large amount of water for irrigation. Far from the lake region, there was no favorable condition to use lake water for irrigation. However, the main crop type was wheat in the east of study area. Less lake water was used for irrigation, and the amount of heavy metals entering the soil was also small. Therefore, the main source of heavy metals in the soil in the study area was lake water irrigation.

The highest value of Pb appeared in Rencheng District near the northeastern region. Previous studies have shown that lead dust and lead vapor contained in automobile exhaust enter the soil environment through atmospheric sedimentation (Gulson et al. 1995). As the downtown of the city, Rencheng District has developed transportation, and atmospheric deposition may be the main source of Pb.

The enrichment of heavy metals in soil is affected by many factors, especially the physical and chemical properties of soil (Aldrich et al. 2002; Bradl 2004). The results of correlation analysis showed that there was a significant positive correlation between heavy metals and OrgC, Al_2O_3, and Fe_2O_3. The concentrations of OrgC, Al_2O_3, and Fe_2O_3 decreased with increasing distance from the lake. The concentration of SiO_2 in the study area was lower, while that of Al_2O_3 and Fe_2O_3 was higher, which reflected that the soil texture in the study area was biased toward clay (Ren et al. 2018). It was found that the adsorption of heavy metals by soil increased significantly with the increase of iron oxide, aluminum oxide, and clay concentration (Covelo et al. 2007). Organic matter could form complexes with a series of metal ions, which increased the concentration of heavy metals in soil (Bertin and Bourgm 1995). Therefore, the concentrations of heavy metals decreased with increasing distance from the lake, and that there was a significant negative correlation between the distance and concentration.

Pollution assessment

Pollution with typical heavy metals in soil from the study area was also investigated. Methods used included the geological accumulation index (I_{geo}) and the potential ecological risk assessment method (E_r). Specific evaluation procedures and evaluation criteria can be found in Ren et al. (2018).

Geological accumulation index

I_{geo} values are shown in Table 5. The mean accumulation indexes of As, Pb, and Zn in the study area were less than zero, meaning that as a whole, these elements were non-polluting, while Cd ranged from an unpolluted to moderately polluted state (Table 5). There were major differences in the spatial distribution of heavy metals in the study area. We can classify the different levels of contaminated areas

Table 5 Results of risk assessment for heavy metals in soil from the western area of Nansi Lake

		As	Cd	Pb	Zn
Igeo	Max	1.29	3.59	0.55	1.16
	Min	− 2.04	− 0.66	− 1.28	− 0.92
	Ave	− 0.17	0.55	− 0.71	− 0.29
	Pollution level	Unpolluted	Unpolluted to moderately	Unpolluted	Unpolluted
Er	Max	36.67	542.86	10.99	3.35
	Min	3.66	28.57	3.08	0.79
	Ave	14.20	69.93	4.64	1.25
	Ecological risk	Low risk	Moderate risk	Low risk	Low risk

of typical heavy metals by applying Geostatistical Analysis via ArcGIS (Fig. 5). As, Zn, and Cd in the lakeside area showed aggravated accumulation, indicating that human activities were more frequent and had a negative impact on the ecological environment. Consequently, the lakeside area of Nansi Lake should be designated as a key area for environmental monitoring and management.

Potential ecological risk assessment

The results from the evaluation of the potential ecological risk assessment for typical heavy metals in the soil in the study area are shown in Table 4. The mean value of the potential ecological risk index for Cd was 69.93, implying moderate ecological harm. The potential ecological risk index of other elements was less than 40, meaning there was no risk in the study area. In order to better understand the degree of heavy metal pollution, Kriging interpolation was used to calculate the distribution of ecological risk of Cd in soil (Fig. 5). The entire study area had reached a moderate ecological risk level, and Cd in the lakeside area had reached a considerable ecological risk status.

The lakeside region near Yutai Country has a huge paddy planting area of 21,500 hm^2. Local agricultural activities are frequent, and industrial activities have

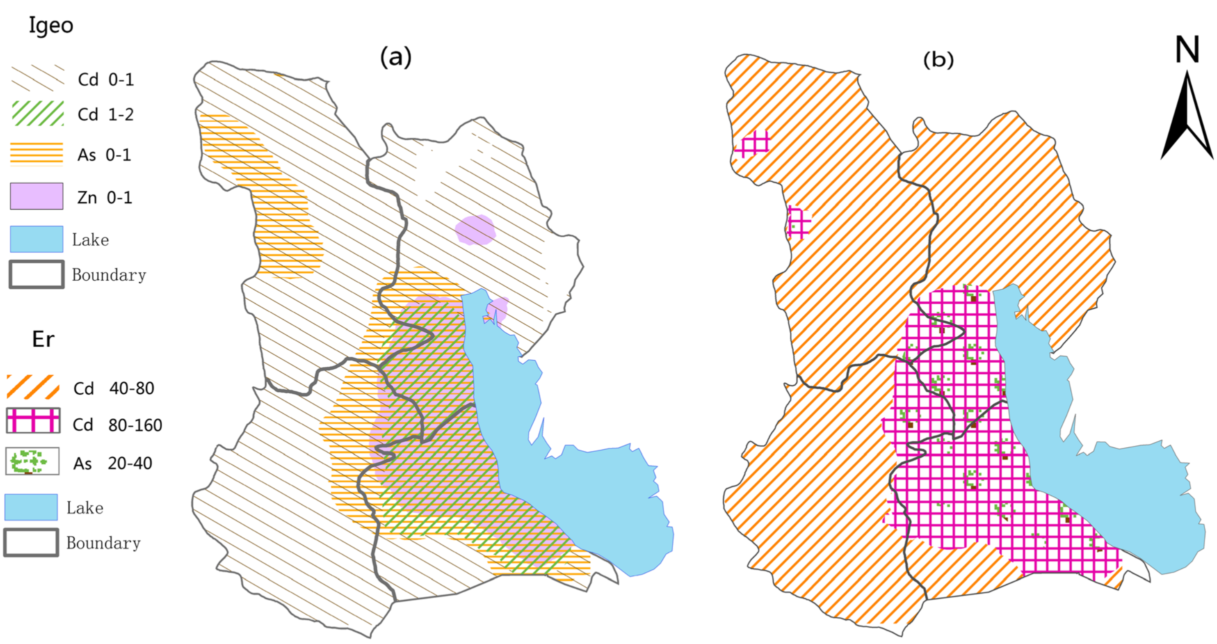

Fig. 5 Spatial distribution of (a) I_{geo} (between 0 and 2) and (b) E_r (between 20 and 160) of heavy metals

less impact on soil heavy metal enrichment. Studies have shown that the use of fertilizers and livestock waste are commonly used to increase crop yields and improve economic efficiency in Northeast China (Khoshgoftarmanesh et al. 2010), meaning that these methods may have enriched the Cd concentration. Cd is closely related to the use of pesticides and fertilizers and is often used as an indicator of agricultural activities (Liu et al. 2018). According to the experimental analysis, the concentration of Cd in organic fertilizers was relatively high, with an average value of 4.78 mg/kg (Chen et al. 2009). The application of organic fertilizer resulted in the increase of Cd concentration in lakeside soil. In addition, the main source of heavy metals in soil of the study area was lake water irrigation. Studies have shown that the average concentration of Cd in the water of Nansi Lake is 0.03 μg/L (Wang et al. 2014). Therefore, it can be inferred that moderate Cd ecological risk in the lakeside region was mainly due to organic fertilizer use and lake water irrigation.

Combined with the above two evaluation methods, the risk status of typical heavy metal pollution in the study area was analyzed. The results showed that As, Pb, and Zn concentration in the study area exceeded the background values, but only had slight ecological risk. The degree of enrichment for elemental Cd was greater, and 20% of the sampled sites had reached a moderate ecological hazard level. These results show that the environmental quality of the soil west of Nansi Lake was in good condition on the whole, and the study region is conducive to establishing production bases for agriculture, and guaranteeing the safe production and effective supply of agricultural products.

Conclusion

This study analyzed the spatial distribution and ecological risks from heavy metals including As, Cd, Cu, and Zn in soil from the western area of Nansi Lake, China. The average concentrations of As, Cd, Pb, and Zn were 13.208 mg/kg, 0.196 mg/kg, 23.935 mg/kg, and 79.946 mg/kg, respectively. The spatial distribution characteristics of heavy metals in the study area were similar, with concentrations gradually decreasing from east to west, showing a step-function distribution. There were significant negative correlations between SiO_2 and the heavy metal concentrations, with significant positive correlations between OrgC, Al_2O_3, Fe_2O_3, and the heavy metals. Based on the results of the I_{geo} and E_r quantification, the As, Pb, and Zn concentrations showed a slight ecological risk, while Cd showed medium ecological harm. Overall, Cd was the main heavy metal pollutant in farmland soil in the research area and should be specifically monitored and addressed during future agricultural development.

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