SOIL HEAVY METAL CONTAMINATION IN RURAL LAND CONSOLIDATION AREAS IN THE YANGTZE RIVER DELTA, CHINA

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Abstract. Due to the rapid urbanization of the Yangtze River Delta in China, large numbers of formerly rural residents have migrated to the cities. To adjust the structure of rural land use, the government has performed extensive land consolidation. Previous studies indicated that the land consolidation has affected farmland quality to some extent. However, the effect of the land consolidation on farmland heavy metal concentrations has rarely been reported. In this study, the Jintan District was used as an example, and 40 sampling sites of various consolidation types in 4 representative areas of rural land consolidation were selected. Soil samples were collected from these sites, and the heavy metal concentrations were analyzed. We used multivariate methods of correlation analysis and principal component analysis to study the conditions and sources of the heavy metal contamination in the soil. The results indicate that the mean concentrations of Cd, Hg, Ni, Cu, and Zn in the soil all exceeded the background values. The mean concentration of Cd was 0.409 mg/kg, and the enrichment factor (EF) was 4.54, making Cd the most prevalent heavy metal soil contaminant in the study area. The enrichment of soil heavy metals varied among the various representative areas. Suburban areas surrounding the central cities were mainly enriched in Hg, with an EF of 6.20. The comprehensive development zone displayed enrichment in Cd, with an EF of 7.79. The heavy metal concentrations in the soil also differed depending on the type of land consolidation. The reclaimed soil of rural settlements contained high levels of Cd and Zn, with EFs of 7.25 and 2.52, respectively, which were related to the land use before the land consolidation. The soil heavy metals of the study area were affected by both human activity and natural background contamination.

Keywords: enrichment factor, land consolidation, potential ecology risk, reclamation of rural settlements, soil heavy metal, Yangtze River Delta.

Introduction

The Yangtze River Delta is currently the most rapidly developing region in China and has the largest GDP and greatest development potential (Chen 2007). With the rapid growth of the regional economy, urbanization in the Yangtze River Delta is also entering the middle and late stages of development (Gu *et al.* 2011; Wu *et al.* 2014). Rapid urbanization causes the migration of rural residents to cities. The government transforms rural regions via industrialization and agricultural intensification, which causes heavy rural farmland occupation and affects the rural land use structure and types (Long *et al.* 2007; Yan

et al. 2015). To promote harmonic development of the rural economy and society and to achieve a balance between farmland occupation and compensation, the government promotes numerous land consolidation projects (Tang *et al.* 2015), including a series of projects and measures for farmland consolidation, farmland merging, ditch and road construction, village relocation, and development and reclamation (Zhang *et al.* 2014; Zheng *et al.* 2016).

Researchers in China and abroad have studied the soil in land consolidation zones. Several studies of the soil properties in mining reclamation zones have revealed variations in the soil properties in these zones and their influencing factors (Esmaeili *et al.* 2014; Insam, Domsch

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1988; Ji *et al.* 2017; Mukhopadhyay *et al.* 2014). Mukhopadhyay *et al.* (2014) reported that the soil properties in a certain mining reclamation zone improved with time following the reclamation and that the soil could be remedied to some extent via long-term reclamation projects. Insam and Domsch (1988) showed that the ratio between soil microbial biomass carbon and soil organic carbon could be used as an index for evaluating the results of mining reclamation. The effects of human activity on soil properties during land consolidation have also drawn considerable attention (Mace, Amrhein. 2001; Wang *et al.* 2014). Previous studies evaluated the effects of fertilization and irrigation on the soil properties in these zones. Mace and Amrhein (2001) reported that irrigation water applied during the rainy season had a negative impact on the soil structure in land consolidation zones. In addition, numerous researchers have conducted systematic studies of land consolidation and reclamation measures and their benefits (Demetriou *et al.* 2012; Liu *et al.* 2013; Sheoran *et al.* 2010; Uyan 2016).

With rapid urbanization, industrialization, and agriculture intensification, the soil quality and health issues in the Yangtze River Delta have become more prominent and have limited the rapid development of the regional economy and severely affected the safety of agricultural products and human health (Zhong *et al.* 2011). Previous studies have shown that land consolidation projects can affect the soil in project zones to some extent (Fellet *et al.* 2011). However, studies of their effects on soil heavy metal concentrations are limited, and their specific effects and mechanisms remain unclear. The Jintan District is a representative densely populated region in the Yangtze River Delta. The urbanization rate exceeds 55%, and its natural conditions and economic development are representative of the Yangtze River Delta. The district recently promoted several land consolidation projects as part of the Ten Thousand Acres of Fertile Farmland project. Previous studies indicated that the soil in this region has been contaminated by heavy metals to some extent (Hao *et al.* 2009). Numerous studies have assessed the soil heavy metal contamination in this region (Zhao *et al.* 2010). However, studies of the soil heavy metal concentrations associated with various types of land consolidation are rare. Therefore, in this study, the Jintan District was selected as the study area, the soil heavy metal contamination associated with various land consolidation types in representative land consolidation zones was assessed, and its sources were analyzed. This study provides scientific data on the consolidation and development of farmland in the study area.

1. Materials and methods

1.1. Study area

The Jintan District is located in southern Jiangsu Province, northwest of the Yangtze River Delta, at 31º33'42"-31º53'22" N, 119º17'45"-119º44'59"E. The northeastern

portion is a hilly region of high relief that transitions to the southeastern plain. The regional climate is characterized by the northern subtropical monsoon. The annual frost-free period spans 226 days, the annual mean temperature is 15.3 °C, and the annual mean precipitation is 1063.6 mm. The annual mean number of rainy days is 124.2, the mean wind velocity is 2.9 m/s, and the annual mean duration of sunshine is 2033.8 hours. Recently, the Jintan District performed numerous land consolidation projects, including two primary types, i.e., rural settlement reclamation and farmland consolidation, to increase the amount of farmland and to improve its quality.

To compare the soil heavy metal concentrations in representative land consolidation zones, soil sampling sites were selected in locations of various land consolidation types in four representative zones. We collected soil samples and analyzed the concentrations of Hg, As, Pb, Cd, Cr, Ni, Cu, and Zn (Figure 1). The four selected sampling zones are as follows. The village of Dongpu is located in Zhiqianzhen, Jintan District, and is characterized by flat topography and a dense network of waterways. The industrial and agricultural development and transportation conditions are regarded as adequate. This area is a key zone in the "Ten Thousand Acres of Fertile Farmland" project, and the land consolidation project is comprehensive and contains several land consolidation types. The village of Shangruan is located in Xuebuzhen, Jintan District in a hilly region in the suburbs of the Jintan District. It is a modern agricultural area, and land consolidation has been performed only in a few areas. The village of Xuxiang is located in Jinchengzhen, in the suburbs of the Jintan District. Land consolidation has been performed only in a few areas. The village of Xixi is located in Dengguan Village, Jintan District, and is characterized by flat topography, a dense network of waterways, and extensive agricultural development. This area features severe nonpoint agricultural pollution, and hosts several chemical plants, resulting in severe heavy metal soil contamination. Land
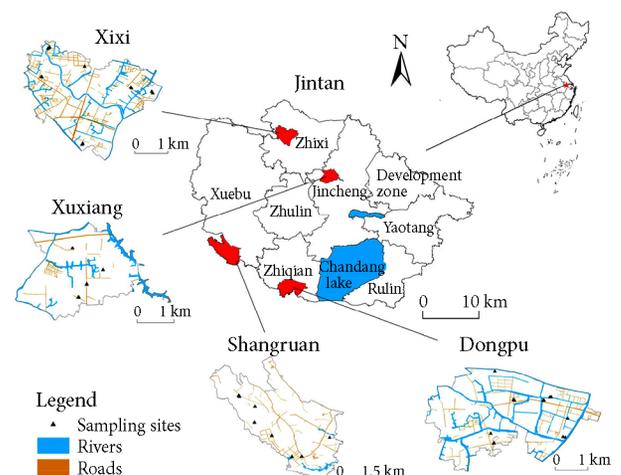
Figure 1. The study area and sampling sites

consolidation projects of rural settlement reclamation and farmland consolidation are comprehensively promoted in this area.

1.2. Soil sampling

We selected 40 representative land consolidation soil sampling sites in the Jintan District in Jiangsu Province. The sampling sites were selected based on administrative boundaries, soil types, land consolidation types, and regions to ensure that they were representative. We sampled 13 sites in the Dongpu comprehensive development zones, including 5 rural settlement reclamation sites, 4 farmland consolidation sites, and 4 farmland sites, as an external land consolidation control group. We sampled 9 sites in the village of Shangruan that were representative of modern agricultural parks, including 6 farmland consolidation sites and 3 farmland sites, as an internal land consolidation control group. We sampled 11 sites in Xixi that were representative of modern industrial parks, including 4 rural settlement reclamation sites, 4 farmland consolidation sites, and 3 farmland sites, as an external land consolidation control group. We sampled 7 sites in Xuxiang that were representative of suburbs of the central cities, including 5 farmland consolidation sites and 2 farmland sites, as an internal land consolidation control group. The soil type in the study area is mainly paddy soil, and it was mainly composed of clay. One soil sample spanning the depth interval of 0~20 cm was collected at each sampling location. We collected soil samples from 5 points in a quincunx pattern, composited them, and repeatedly split each composite by quartering until a sample weight of approximately 1 kg was achieved. We placed the samples in sample bags, labeled them, and shipped them to our laboratory for analysis. At each sampling location, the coordinates were recorded using GPS, and details of the surrounding environment were recorded.

The samples were processed individually. We crumbled and naturally dried the samples and removed rocks and visible plant residues. We then crushed the samples, passed them through 20-mesh, 60-mesh, and 100-mesh nylon sieves according to the requirements of the testing equipment, and bagged them. The concentrations of Hg and As were measured using reduction-gasification atomic fluorescence spectrometry. The concentrations of Cr, Cu, Ni, and Pb were measured using $HF-HNO_3-HClO_4$ digestion and inductively coupled plasma atomic emission spectrometry (Li *et al.* 2008). The total Cd content was measured using $HF-HNO_3-HClO_4$ digestion and graphite furnace atomic absorption spectrometry. The total Zn content was measured using $HF-HNO_3-HClO_4$ digestion and atomic absorption spectrophotometry (Wu *et al.* 2010).

1.3. Data analysis

The soil heavy metal contamination was assessed using the enrichment factor (EF) (Elias, Gbadegesin 2011; Kowalska *et al.* 2016; Mazurek *et al.* 2016) and the potential ecological risk index (RI) (Håkanson 1980; Kowalska *et al.* 2016). The EF is the ratio of the concentration of a contaminant in a medium to the background value of the contaminant (Table 1). The background value was based on the reference value of soil heavy metal concentrations in Jiangsu Province. The RI could comprehensively assess the ecological risk of soil heavy metal enrichment in an area, using the following formula:

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_r^i \times C_p^i , \qquad (1)$$

where n represents the number of studied heavy metals, E_r^i represents the single index of ecological risk factor, T_r^i represents the toxicity response coefficient of heavy metals (Håkanson 1980), and C_p^i represents the single pollution index of heavy metal using reference data from Liao *et al.* (2011). The RI classes are shown in Table 2.

The least significant difference method (LSD) was used to test the significance of the differences in the heavy metal concentrations. Principal component analysis (PCA) is a statistical method for analyzing primary information. PCA results can reflect the majority of the information of multiple original variables via data simplification (Pereira *et al.* 2016; Pouyat *et al.* 2007; Zhang 2006). In this study, PCA was used to reduce the dimensions of the variables (Ha *et al.* 2014) and to evaluate the correlations and differences among the soil heavy metal concentrations in the study area (Wang 2008). The data were rotated to obtain the principal vectors using the maximum variance method in the calculation, based on individual eigenvalue contributions of 10% and the accumulative eigenvalue contributions exceeding 70%, to further analyze the conditions of heavy metal soil contamination. The mean calculation, difference analysis, and PCA of the soil heavy metal concentrations were conducted using the statistical software SPSS 22.0. The figures were prepared using Excel 2013 and OriginPro.

Table 1. Classes of enrichment factor

EF_i	$EF_i \leq 2$	$2 < EF_i \leq 5$	$5 < EF_i \leq 20$	$20 < EF_i \leq 40$	$EF_i > 40$
Enrichment level	minimal	moderate	significant	very high	extremely high

Table 2. Classes of potential ecological risk

RI	$RI \leq 90$	$90 < RI \leq 180$	$180 < RI \leq 360$	$360 < RI \leq 720$	$RI > 720$
risk level	low	moderate	high	very high	extremely high

2. Results and discussions

2.1. Overall heavy metal concentrations in the soil

Table 3 shows that the mean concentrations of Hg, As, Pb, Cd, Cr, Ni, Cu, and Zn in the four representative land consolidation zones in the study area were 0.111 mg/kg, 9.4 mg/kg, 26.8 mg/kg, 0.409 mg/kg, 75.8 mg/kg, 31.3 mg/kg, 33.4 mg/kg, and 108.7 mg/kg, respectively. Compared with the background levels, the mean concentrations of Hg and Cd were significantly elevated, while those of Ni, Cu, and Zn were slightly elevated, indicating that the concentrations were significantly affected by human activity and external factors. The concentrations of Cd, Cu and Zn were 2.03, 1.51, and 1.34 times higher, respectively, than the mean concentrations of these elements in farmland soil in Yangtze River Delta (Shao *et al.* 2016). Compared with a reclaimed coastal area in Cixi, China, the study area featured similar concentrations of Pb and Zn but slightly higher concentrations of Ni and Cu (Wang *et al.* 2014). Compared with agricultural soils in the Argolida basin in the Mediterranean region, the study area featured concentrations of As, Pb and Zn that were 1.35, 1.36, and 1.45 times higher, respectively, but slightly lower concentrations of Cd, Cr and Ni (Kelepertzis 2014). Compared with agricultural soils in the Isfahan industrial zone in Iran, the study area featured similar concentrations of Cd, Cu and Zn but concentrations of Pb, Cr, Ni that were 22.5%, 11.8%, and 52.7% lower, respectively (Esmaeili *et al.* 2014). In general, the level of soil heavy metal contamination in the study area was mostly similar to that in the areas mentioned above, but the concentrations of Cd and Zn were relatively higher.

Previous studies indicated that Cd is associated with strong biological toxicity and the environmental risks (Ratha, Sahu 1993). In the study area, the EF value of Cd was higher than those of the other heavy metals. Therefore, controlling and mitigating Cd contamination should be an important objective of subsequent land consolidation in the study area. The coefficient of variation (CV) reflects the variation in a data set. According to the classification scheme of Wilding (1985), the levels of As, Pb, Cr, Ni, and Cu displayed intermediate levels of variation (15% < CV < 36%), and the levels of Hg, Cd, and Zn displayed high levels of variation (CV > 36%). The levels of Cd in particular yielded a CV much greater than those of the other heavy metals, indicating that the concentrations of Hg, Cd and Zn varied greatly within the study area. Thus, the distributions of Hg, Cd, and Zn in the study area were extremely heterogeneous, possibly due to anthropogenic point-source contamination.

Table 4 shows that some of the EF values in the representative land consolidation zones in the study area were larger than 1, indicating that the heavy metals were enriched in the soil to some extent in the study area. The EF values of Cd were higher than 5 (indicating significant enrichment levels) in the rural settlement reclamation and farmland consolidation zone in the comprehensive development area of Dongpu and in the rural settlement reclamation zone in Xixi modern industrial park. The EF values in the Xuxiang suburban area of the central cities were also higher than 5, indicating significant enrichment levels. The EF values of Zn in the rural settlement reclamation zones in Dongpu, Xixi and Xuxiang were higher than 2, i.e., moderate enrichment levels. Most of the RI values were higher than 180, indicating that a certain degree of potential ecological risk existed in the study area. The RI value of the control group soil in the Xuxiang suburban area of the central cities was the highest because the concentration of the highly toxic heavy metal Hg was significantly higher than the background level. The RI values of the rural settlement reclamation and farmland consolidation zones were also high, and the ecological risk mainly came from the significantly enriched Cd in the soil. In general, the potential ecology risk in the Dongpu comprehensive development zone and Xuxiang suburban area of the central cities was high, while the potential ecological risk in the Xixi modern industrial park and Shangruan modern agricultural park was relatively low.

Table 3. Statistical characteristics of heavy metal concentrations in the study area and comparisons with other similar areas

Element	Mean±SD (mg/kg)	CV (%)	Soil background (mg/kg)	EF	Mean concentrations (mg/kg) of heavy metals in agricultural soils from various areas around the world			
					Yangtze Delta, China	Cixi, China	Argolida, Greece	Isfahan, Iran
Hg	0.111±0.076	68.47	0.03	3.70	–	–	–	–
As	9.4±1.846	19.72	9.91	0.95	–	–	6.95	–
Pb	26.8±4.486	16.71	22.6	1.19	35.12	25.8	19.74	34.6
Cd	0.409±0.456	111.49	0.09	4.54	0.201	–	0.54	0.43
Cr	75.8±11.441	15.09	76.4	0.99	–	–	83.12	85.9
Ni	31.3±6.883	21.98	33.7	0.93	29.67	28.6	146.8	66.2
Cu	33.4±9.774	29.23	24.0	1.39	22.16	24.1	74.68	35.7
Zn	108.7±74.712	68.71	65.8	1.65	81.07	108	74.88	111.5

Table 4. Soil heavy metal contamination in the study areas

Administrative village	Land conso-lidation type*	EF_{Hg}	EF_{As}	EF_{Pb}	EF_{Cd}	EF_{Cr}	EF_{Ni}	EF_{Cu}	EF_{Zn}	RI
Dongpu comprehensive development zone	Reclamation	2.93	0.81	1.30	10.09	1.05	1.04	1.36	2.73	451.33
	Consolidation	3.20	0.71	1.29	8.14	1.16	1.16	1.61	1.82	403.74
	Control	4.60	0.87	1.25	3.89	1.05	1.03	1.53	1.16	331.71
Shangruan modern agricultural park	Consolidation	1.90	0.95	1.11	2.90	0.85	0.69	1.05	1.21	189.66
	Control	1.84	1.03	1.09	2.38	0.91	0.62	0.97	1.14	171.66
Xixi modern industrial park	Reclamation	3.57	1.01	1.18	5.50	0.97	0.93	1.45	2.31	339.95
	Consolidation	2.63	1.14	1.14	2.11	1.07	1.08	1.47	1.24	201.73
	Control	4.87	0.98	1.21	3.07	0.96	0.93	1.64	1.55	319.07
Xuxiang suburban area of the central cities	Consolidation	5.57	1.12	1.19	4.36	1.08	1.00	1.45	2.03	387.19
	Control	10.07	0.85	1.04	2.29	0.93	0.83	1.72	1.01	500.82

* "Reclamation" represents rural settlement reclamation, "consolidation" represents farmland consolidation, and "control" represents the farmland control group in the representative zones.

2.2. Differences in heavy metal concentrations between representative land consolidation zones

Based on the significance tests of the differences in soil heavy metal concentrations in the representative land consolidation zones (Table 5), many differences among the soil heavy metal concentrations of the four representative zones were significant (P < 0.05). Therefore, the differences among the four selected representative zones accurately reflect the soil characteristics of the representative zones. The Hg concentration in the village of Xuxiang, representing an area of rapid urbanization, differed significantly from that in the other three representative zones. The concentrations of Cr, Ni, and Cu in the soil in the village of Shangruan, representing modern agricultural parks, differed significantly from those in the other three representative zones.

Figure 2 shows that the Hg concentration in the village of Xuxiang was far higher than that in the other three representative zones, and its EF was 6.20, representing significant enrichment. Previous studies indicated that there is a high probability that suburban areas display anomalous Hg distributions due to anthropogenic emissions, particularly coal burning (Guédron *et al.* 2016). The soil Cd concentration in the village of Dongpu was significantly higher than that in the other three representative zones,

and had an EF of 7.79, representing significant enrichment. The concentrations of Cr, Ni, and Cu in the village of Shangruan were lower than those in the other three representative zones. The heavy metal concentrations were relatively high in the villages of Dongpu and Xixi, where the degree of land consolidation was high. The heavy metal concentrations were relatively low in the villages of Shangruan and Xuxiang, where the degree of land consolidation was low. In the village of Dongpu, the concentrations of Cd and Zn were far higher than the mean levels in the four representative zones. The mean Cd concentration was 0.653 mg/kg and had a CV of 95.893%. The mean Zn concentration was 126.055 mg/kg, and had a CV of 78.364%. These data indicate that the concentrations of Cd and Zn in the soil in the village of Dongpu varied significantly. In Xixi, the mean concentrations of Ni, Cu, and Zn in the soil exceeded the mean levels in the four representative zones. Furthermore, the CV of Zn was high, with a value of 59.589%. Although the mean concentration of Cd (0.312 mg/kg) was lower than the mean, the CV was high, with a value of 86.420%. In Shangruan, the mean concentrations of As and Pb in the soil exceeded the means in the four representative zones, but the CV values were small. Therefore, these high concentrations might be widely distributed in this village. Although the concentrations of Cd

Table 5. Significance tests of soil heavy metal concentrations in representative areas

	Hg	As	Pb	Cd	Cr	Ni	Cu	Zn
Dongpu-Xixi	−0.008	−2.199*	2.264	0.340	6.704	3.156	−1.334	15.961
Dongpu-Shangruan	0.054	−1.303	4.524*	0.407*	18.184*	12.926*	10.996*	48.759
Dongpu-Xuxiang	−0.064*	−2.386*	2.458	0.305	1.854	3.240	−0.365	8.015
Xixi-Shangruan	0.062	0.896	2.260	0.066	11.481*	9.770*	12.330*	32.799
Xixi-Xuxiang	−0.056*	−0.187	0.194	−0.035	−4.849	0.084	0.969	−7.945
Shangruan-Xuxiang	−0.118*	−1.083	−2.065	−0.102	−16.330*	−9.686*	−11.362*	−40.744

* Significant levels, P < 0.05
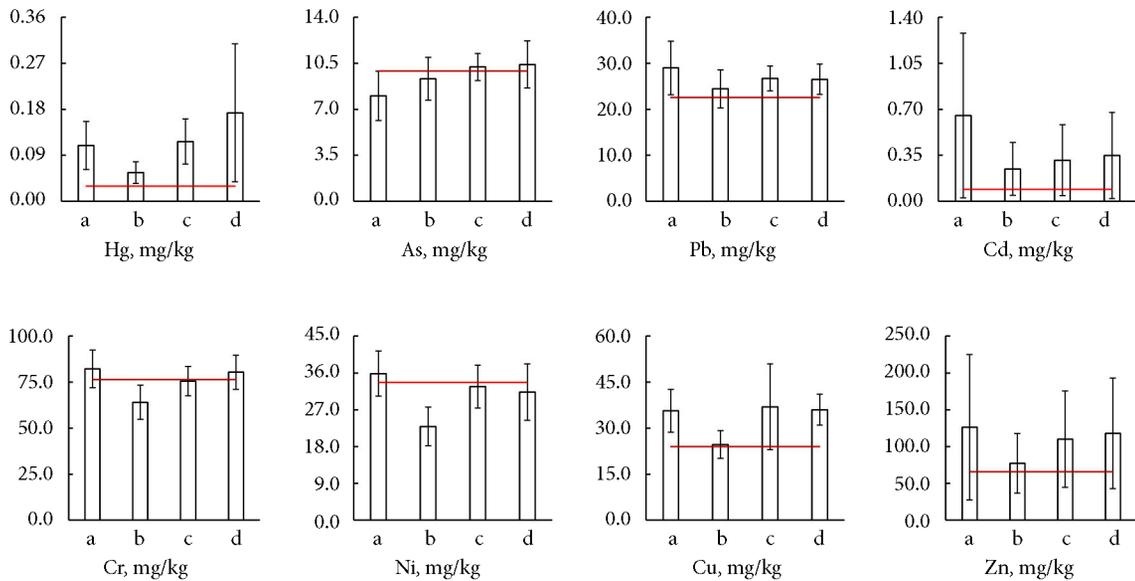
Figure 2. Heavy metal concentrations in representative areas
(a: Dongpu; b: Shangruan; c: Xixi; d: Xuxiang; red lines denote background values)

and Zn were low, the CV values were high, i.e., 79.314% and 53.540%, respectively. In Xuxiang, the concentrations of the eight heavy metals in the soil were all low, indicating that the contamination in this village was low. However, the CV values of the concentrations of Hg, Cd, and Zn were high. In the four representative zones, the CV values of the concentrations of Cd and Zn were high, suggesting that the farmland contamination originated from point sources of Cd and Zn.

2.3. Differences in soil heavy metal concentrations among different land consolidation types

Based on the significant tests, the differences among the soil heavy metal concentrations associated with different land consolidation types (Table 6) were not significant ($P < 0.05$) except for those of Hg, Cu, and Zn. The concentrations of Hg and Cu in the farmland control group were high overall. The Zn concentration in the rural settlement reclamation soil was far higher than that in the farmland consolidation soil and the control group. The Zn concentration in the rural settlement reclamation soil differed significantly from that in the farmland consolidation soil and the control group, indicating that the Zn concentrations in the study area might be related to the type of land use.

Figure 3 shows that the soil heavy metal concentrations associated with the different land consolidation types varied along a clear gradient. The mean concentrations of Pb, Cd, Cr, Ni, and Zn ranked in the order of rural settlement reclamation > farmland consolidation > farmland control group. The EF values of Cd and Zn in the rural settlement reclamation soil were 7.25 and 2.52, respectively, which exceeded the background levels and were significantly higher than those of the farmland consolidation soil and control group. Although the levels of Pb, Cr, and Ni also conformed to this pattern, the differences between the land consolidation types were small. The EF values of Hg in the land consolidation types in the study area all exceeded 2, and the EF of the control group was 5.32, which was higher than that in the other areas. The concentrations of As and Cu did not vary distinctly among the different types of land consolidation.

Based on the data in Table 6 and Figure 3, the soil heavy mental concentrations associated with the different land consolidation types generally followed the pattern of rural settlement reclamation > farmland consolidation > farmland control group. The differences among Hg, Cd, and Zn were significant. The concentrations of Zn and Cd in the rural settlement reclamation soil were higher than the background value and differed significantly from those of the farmland consolidation soil and control group, indicating that these elevated concentrations might have been due to human activity. Previous studies indicated that

Table 6. Significance tests for soil heavy metal concentrations associated with soil reclamation areas

	Hg	As	Pb	Cd	Cr	Ni	Cu	Zn
Reclamation-consolidation	−0.001	−1.089	2.377	0.349	2.606	3.463	3.336	59.880*
Reclamation-control	−0.063	−0.400	0.905	0.390	1.277	0.766	−4.210	71.756*
Consolidation-control	−0.062*	0.689	−1.47	0.041	−1.328	−2.697	−7.547*	11.876

elevated Zn and Cd concentrations were present in the old residential zones (Zhang *et al.* 2015). Thus the Zn and Cd enrichment in the rural settlement reclamation soil in the study area might have been due to human activity predating the land consolidation projects. The soil Hg concentration in the study area was far higher than the background value, probably due to atmospheric dust fall. Atmospheric Hg emissions from coal burning in Jiangsu Province are high, exceeding 10 t/a (Jiang *et al.* 2005); thus, coal burning emissions might be a cause of the widespread elevated Hg concentrations in the study area.

2.4. Sources of the soil heavy metals in the study area

Based on Table 5, the soil heavy metal concentrations associated with the representative land consolidation zones differed significantly. Therefore, we used the representative zones as division units and used SPSS to conduct a PCA of the soil heavy metal concentrations in the study area (Table 7). The resulting eigenvectors (Figure 4) were then used to further analyze the sources of the soil heavy metal contamination.
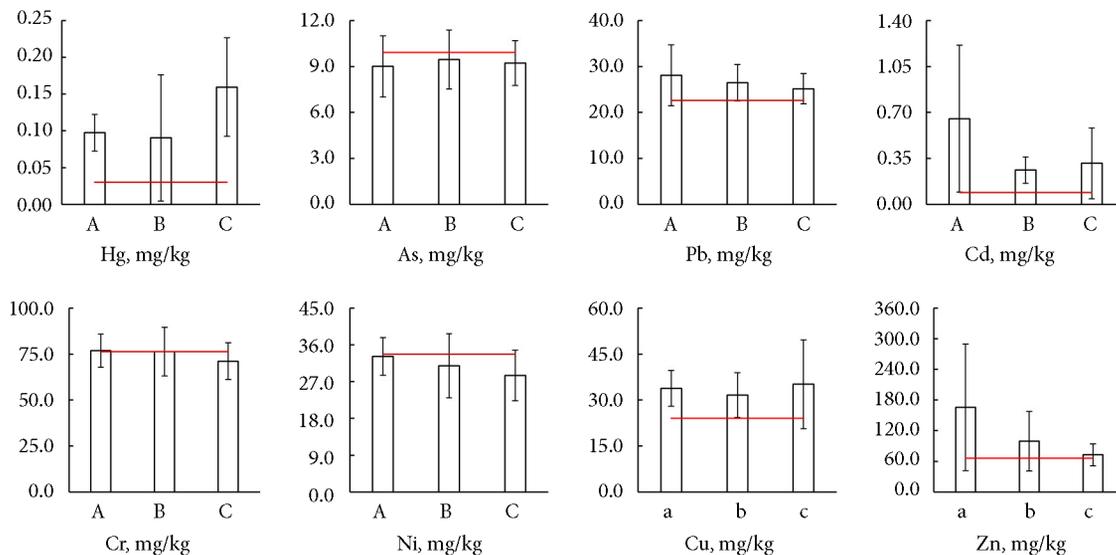
Figure 3. Heavy metal concentrations associated with various types of land reclamation
(A: Reclamation; B: Consolidation; C: Control; red lines denote background values)
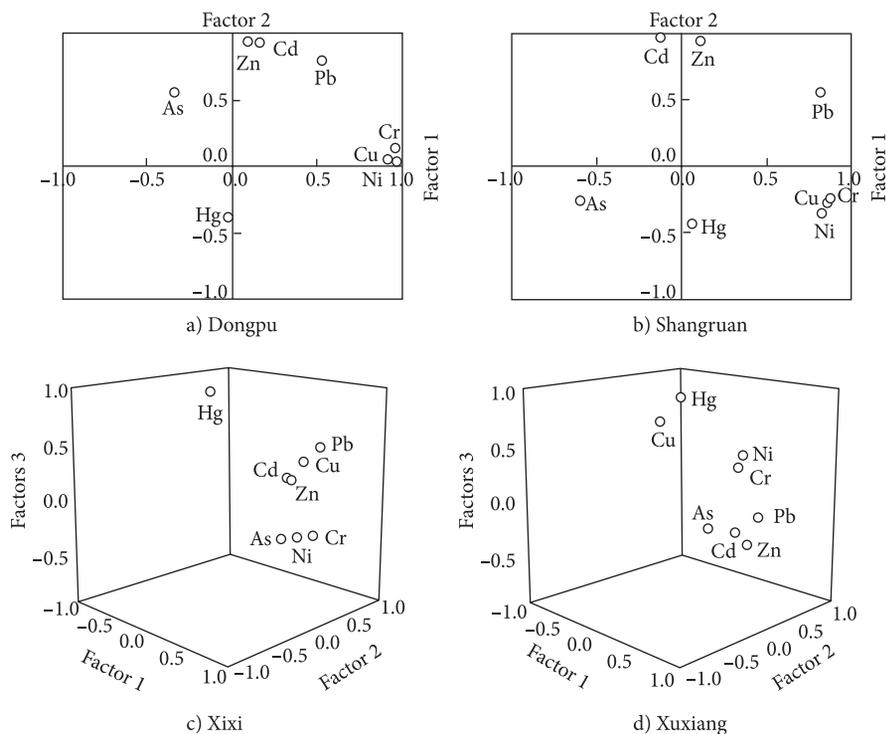
Figure 4. PCA results for the heavy metals in the soils of the four representative areas

Table 7. Sources of soil heavy metal concentration in the different representative areas

	Dongpu		Shangruan		Xixi			Xuxiang		
	PC1	PC2	PC1	PC2	PC1	PC2	PC3	PC1	PC2	PC3
Hg (mg/kg)	−0.02	−0.38	0.06	−0.43	−0.27	0.03	0.94	−0.06	0.06	0.93
As (mg/kg)	−0.34	0.56	−0.60	−0.26	0.77	−0.13	−0.19	−0.32	0.73	−0.51
Pb (mg/kg)	0.53	0.80	0.81	0.55	0.43	0.76	0.44	0.99	−0.06	0.05
Cd (mg/kg)	0.16	0.94	−0.13	0.98	−0.14	0.98	−0.01	0.94	−0.30	−0.06
Cr (mg/kg)	0.97	0.15	0.86	−0.24	0.96	0.10	−0.17	−0.12	0.94	0.12
Ni (mg/kg)	0.97	0.03	0.82	−0.35	0.93	−0.12	−0.14	−0.10	0.97	0.21
Cu (mg/kg)	0.92	0.05	0.85	−0.26	0.79	0.10	0.46	−0.52	0.25	0.61
Zn(mg/kg)	0.10	0.95	−0.01	0.92	−0.11	0.98	−0.02	0.89	−0.07	−0.22
Contribution (%)	46.87	28.91	41.11	31.17	41.30	33.39	15.43	48.65	22.67	18.16

The cumulative variance contributions of the principal components of the four representative land consolidation zones were 76%, 73%, 90%, and 89%, indicating that the principal components were sufficient to explain the soil heavy metal concentration data in the study area. The heavy metals in the Dongpu comprehensive development zone were divided into two components. The first principal component consisted of Cr, Ni, and Cu, and the second principal component consisted of Zn, Pb, and Cd. The heavy metals in the Shangruan modern agricultural park were divided into two components. The first principal component consisted of Pb, Cr, Ni, and Cu, and the second principal component consisted of Cd and Zn. The heavy metals in the Xixi modern industrial park were divided into three components. As, Cr, Ni, and Cu were assigned to the first principal component; Pb, Cd, and Zn were assigned to the second principal component; and Hg was assigned to the third principal component. The heavy metals associated with urbanization in Xuxiang were divided into three components. Pb, Cd, and Zn were assigned to the first principal component; As, Cr, and Ni were assigned to the second principal component; and Hg and Cu were assigned to the third principal component.

After combining these data with those in Table 3, we noted that the concentrations of As, Cr, and Ni in the study area approximated the soil background values and were therefore little affected by human activity. The distribution depended primarily on the soil characteristics, which is a natural factor. The Pb and Cu concentrations were elevated slightly above the background values, indicating that the concentrations of these two heavy metals were affected by human activity to some extent. The Hg, Cd, and Zn concentrations differed significantly from the background values and were therefore affected by human activity. The first principal component in the analysis of the Dongpu comprehensive development zone and the Shangruan modern agricultural park was associated primarily with natural factors. The second principal component was associated primarily with human factors. Thus, the soil characteristics were an important factor controlling the concentrations in these areas. The first principal

component in the analysis of the Xixi modern industrial park was associated primarily with natural factors. The second and third principal components were associated primarily with human factors. The contribution of natural factors to the soil heavy metals in Xixi was 41.30%, whereas human factors contributed 48.82%. These two contributions are approximately equal. The first and third principal components in the analysis of Xuxiang in the suburbs of the central cities were associated primarily with human factors, which contributed 66.81%, indicating that the effects of human activity were significant. In addition, the soil heavy metal concentration in the study area often showed correlations among Cr, Ni, and Cu and among Pb, Cd, and Zn. In contrast, the correlations among Hg and As and the other heavy metals were low. Therefore, the Cr, Ni, and Cu concentrations in the soil in the study area might be related to the soil characteristics, whereas the Pb, Cd, and Zn concentrations might be related to human activity, i.e., land use. The sources of the Hg possibly include local land use and atmospheric dust fall. The contributions of various sources to the heavy metal concentrations in the study area require further study.

Conclusions

The concentrations of Hg and Cd in the soils of the four representative land consolidation zones were significantly elevated above the corresponding background values, and the concentrations of Ni, Cu, and Zn were also enriched to some extent. Therefore, the concentrations of these elements were significantly affected by human activity and external factors.

The heavy metal concentrations in the Shangruan modern agricultural park were the lowest. The environmental quality of the soil in Shangruan was generally good. The soil heavy metals in the Xuxiang suburbs of the central cities were most severely affected by human factors, based on the Hg enrichment. The concentrations of the heavy metals in the soils of the Xixi modern industrial park were affected by human and natural factors and the concentrations of Cd and Zn were high. The heavy metal

concentrations in the Dongpu comprehensive development zone were controlled primarily by the soil characteristics. However, the concentrations of Cd and Zn were elevated.

Widespread Cd and Zn enrichment existed in the rural settlement reclamation soil due to human activity in this zone prior to reclamation.

The soil heavy metal concentrations in the study area were controlled by both human activity and natural background effects. Therefore, it is important to control background contamination, improve the soil background quality, and reduce anthropogenic heavy metal emissions during efforts to mitigate soil heavy metal contamination and improve farmland quality in consolidation zones during land consolidation.

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Disclosure statement

The authors declare no conflict of interest.

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