Spatial distribution of heavy metals in the West Dongting Lake floodplain, China

Journal:	*Environmental Science: Processes & Impacts*
Manuscript ID	EM-ART-11-2019-000536.R1
Article Type:	Paper

Environmental Significance Statement

The study aims to understand heavy metal pollution in the West Dongting Lake (Ramsar Site) and to assess ecological hazards to humans, wildlife and even ecosystems. Comparing to the soil quality criteria in China, the concentration of total Hg and Cd were over the China's risk screening values for soil contamination of agricultural land of these metals by 103.9 and 2.1 times, respectively. According to this study, we found that West Dongting Lake is at high ecological risk of heavy metal pollution, and the major contaminant, mercury, may come from continuous pollutant anthropogenic activities such as regional industrial activities within Yuan River and Li River watershed.

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Abstract

The protection of Dongting Lake is important because it is an overwintering and migration route for many rare and endangered birds of East Asia and Australasia, but an assessment of heavy metal contamination in West Dongting Lake is lacking. A total of 75 sediment samples (five sites x three sediment depths x five repeats) were collected in West Dongting Lake in January 2017 to assess the spatial distribution and ecological risk of heavy metal in West Dongting Lake. Heavy metal values varied by sediment depth including As, Cd, Zn, and Cu, with depth giving an indication of recent vs. historical deposition. The major input of Hg, Cu, Ni may come from continued anthropogenic activities related to regional industrial activities within Yuan River and Li River whereas, the major sources of spread Cd pollution may be from agricultural fertilizers.

Key words

West Dongting Lake, Floodplain, Heavy metals, Spatial distribution

1. Introduction

West Dongting Lake it is a key biodiversity hotspot in China and designated as a Ramsar Key Wetland because of its unique aquatic ecosystem and rich biodiversity. It also is the main resource of industrial and agriculture water for millions of residents in the region (e.g., Changde City). Thus, poor water quality and potential effects on biota have received increased attention in this region during recent years (1-4). Heavy metal contamination exists in Dongting Lake, but studies did not explore the connection of the delta of the lake to the tributaries feeding it (Li and Yuan River). For example, Jiang et al. sampled the entire lake (Jiang et al. 2008), but not the tributaries flowing into the lake. Other studies have found higher levels of contamination coming from the Yuan vs. the Li River entering West Dongting Lake but do not sample in various places along these rivers, using the same methodology (5-7). One of the objectives of our research was to sample these river gradients from up to downstream into the delta area where these tributaries meet, to better track potential sources of heavy metals on the Dongting Lake floodplains (Figure 1).

Heavy metal pollution has toxic effects on the human body causing headaches, muscle and joint aches, confusion and other symptoms (8, 9). Arsenic can promote cancers and cadmium can attack kidney, liver, bone and the female reproduction system, also lead and mercury are neurotoxins, which can be consumed via seafood, vegetables and rice (8-10). Especially in countries with developing industries, industrial effluent, atmospheric deposition and sewage, polluted rivers are more likely to discharge heavy metals into the aquatic ecosystems (5, 11-16). Besides, heavy metals are persistent and have complex ecological effects on livestock, birds, and human beings (17-21). Various forms of heavy metals and their interactions can have complex ecological effects on organisms (22). These toxins are also carried by streams and influenced by the sedimentation condition, for example, in the middle-reach of the Yangtze River (4, 23, 24). Moreover, the remediation methods of soil heavy metal various might be accomplished using plant species that hyperaccumulate these toxins (25), burial by sediment,or remediation via the application of biochar (26, 27).

Our objective was to determine the contamination level of heavy metals in the soils of tributaries feeding the deltaic floodplains of Dongting Lake at various depths. This study is helpful for wildlife conservation, especially for migratory waterfowl, and environmental policies regarding fisheries in the lake.

2. Materials and methods

2.1 Study area

Dongting Lake is the largest freshwater lake of Hunan Province and the second largest in China. The western portion of Dongting Lake (West Dongting Lake, 30044 ha) connects the Yangtze River with South Dongting Lake and collects water from both the Yuan and Li Rivers. West Dongting Lake was designated as a Ramsar Wetland of International Importance in 2002 (https://rsis.ramsar.org/ris/1154). Therefore, this complex river system is crucial to the storage of flood water and the irrigation of farmland in the region (28). Yuan and Li River, which have mining industries and vast farmland along the river, are in the upper reaches of West Dongting Lake. Thus, many pollutants enter into the lake by the river. The sedimentation in the western part of the lake is the highest in Dongting Lake (24). The research sites including Taiyangcha (YnUp, upper reaches of Yuan River), Guanceta (YnMd, middle reaches of Yuan River), Liuzu (YnLiDelta, downstream reaches of Yuan and Li River) were placed in the flow direction of the Yuan River. Dabatai (LiUp, upper reaches of Yuan River), Dalianzhang (LiMd, middle reaches of Yuan River; in the delta) and Liuzu (YnLiDelta, downstream reaches of Yuan and Li River) were along the Li River; YnLiDelta near the intersection of the two rivers (Figure1).

2.2 Sample Collection

A total of 75 sediment samples were collected in West Dongting Lake to evaluate the spatial distributions of heavy metals in January 2017. Each at 3 depths (0-10, 10-20, 20-30 cm were collected and marked as surface sediment, medium sediment and deep sediment, respectively, in all five sites with five samples within plots of 10 ×10 m (see in Table 1). Each of the 75 samples were collected with a spade (20×20×10 cm), and were packed in re-closable bags and transported to the laboratory at room temperature (0 ℃ to 8 ℃) within 24 hours.

2.3 Laboratory Analysis

The samples were air dried at room temperature (0 ℃ to 8 ℃) for five days in the laboratory. Air dried sediment samples were ground using a ceramic mortar and pestle, sieved through a 100-mesh nylon sieve (29), and placed into plastic bags at room temperature. Following this, every powdered samples (0.5 g) was digested by various acids (HNO_3, $HClO_4$, HF; analytical reagent grade, produced from Beijing Chemicals Factory, Beijing, China) and heated in a 100 ml polyfluoroethylene-crucible with lid at 220℃ *1h+280℃ until dry. All dry digestion products were dissolved by 5 ml 50% HNO_3 in a 50 ml volumetric flask. The digested solutions were stored in 25 ml centrifuge tubes (30, 31).

All elemental analysis work was done by Beijing Forestry University Public Analysis Center. Concentrations of total Hg, Pb, Cd, Ni, Zn and As were analyzed with Inductively Coupled Plasma Mass Spectrometry (ICP-MS, optima 8X00, USA). Cu was analyzed using an Atomic Absorption Spectrometer (AAS, SPECTRAA-220, Australia). Initial calibration verification and reagent blanks were used for quality control.

2.4 Statistical method

To assess the differences of heavy metals concentration at various sediment depths and sample sites, two-way ANOVA analysis was performed and data were appropriately log transformed to meet statistical assumptions. Two-way ANOVA were used to test treatment differences, using SNK to test differences in specific means (SPSS 19.0, 2018).

Principal Components Analysis was applied used to explore the relationships of heavy metals in floodplain sediments of the West Dongting Lake. Normally, a source of pollution contains various kinds of heavy metal contamination. For example, the waste water discharged by industry would have many different heavy metal pollutants. Principle Components Analysis (PCA) was used to assess if certain metals occurred together at the same sites to suggest if these may have come from a similar source using R (R 3.5.0, 2018).

3 Results

3.1 Metal concentrations in sediments

In West Dongting Lake, the concentrations of Ni, As, Cd, Hg, Pb, Zn, Cu varied from 13.23 to 71.55 mg/kg, not detected (ND) to 14.59 mg/kg, ND to 2.65 mg/kg, 149.00 mg/kg to 323.19 mg/kg, ND to 5.50 mg/kg, 28.85 to 118.40 mg/kg, 12.80 to 54.00 mg/kg, respectively, with mean concentrations of 26.95, 0.97, 0.64, 249.25, 0.14, 78.09, 41.55 mg/kg, respectively (Table 2).

3.2 Differences between sites and depths

Except Pb, the other heavy metals showed significant differences between sample sites (Table 3). Only As, Cd and Zn showed significant difference at different sediment depths. The concentration of As in difference depths from highest to lowest included: surface sediment > medium sediment > deep sediment; the concentration of Cd was ranked as: medium sediment > deep sediment > surface sediment. The concentration of Zn was ranked as: deep sediment > medium sediment > surface sediment. Sample sites locator and sediment depths did not interact ($p > 0.05$). The concentration of As in LiUp was higher than other sample sites. In addition, the concentration of Cd in YnMd and LiUp were higher than YnUp, LiMd and YnLiDelta.

3.3 Principal Component Analysis, PCA

Using three axes in the Principal Component Analysis, 70% of the data variance could be explained (Table 4, Figure 2). Hg, Cu, Ni, Zn and Pb were all related to the first principal component (RC1) (proportion variance = 0.28). Cd, Cn and As were related to the the second axis (RC2) (proportion variance = 0.25). Pb and As were related to the third axis (RC3) (proportion variance =0.16).

3.4 Spatial distribution analyze and sources identify of heavy metals

In general, Yuan River may carry more pollutants into the lake than the Li River (Figure 3). LiMd shows a lower concentration of Ni, Cd, Hg, Zn and Cu than LiUp, suggesting that deposition may be occurring upstream. In contrast, YnMd shows a higher concentration of Ni, Hg and Cu than YnUp. There was obvious pattern of soil heavy metal pollution along the two rivers. In YnMd, the flow and relative position of the river show a balance and then relatively high concentrations of Hg are found in the middle reaches of this river. The reason why LiMd shows a lower concentration of pollutant may be because is the site is not quite close to theoff the main channel of the river. And tThe concentration of As, Ni, Cd and Zn show highest value inare highest in the YnLiDelta. This may indicate that the pollutants carried by the two rivers have an additive effect on each other at the junction and the main pollutants were cameoriginated from upstream sources on the Yuan River (Figure 3).

Usually, the surface sediment contains more heavy metals of Cd and Zn, but, the highest level of As is the middle sediment (Figure 4). The significant differences of As, Cd and Zn along sediment depths suggested that As, Cd and Zn pollution may come from annual human activities or seasonal human activities such as fisheries aquaculture. Other heavy metal such as Hg pollution had no significant difference between sediment depth. So, its input came from continuous human activities and it may be more related to regional industrial activities, and could enter the wetlands via air or water (32, 33).

According to the PCA analysis, Hg, Cu, Ni contamination sources are related, and may enter the wetland from the same way. From 2008 to 2017, previous research suggested that the mercury concentration in Dongting Lake was stable and continuous (3, 34, 35) and usually the major input of these metals are related to human activities(36, 37). Thus, the major input of Hg, Cu, Ni may come from continued anthropogenic activities related to regional industrial activities within Yuan and Li River Watershed. The concentration of Cd is affected by sample location and sediment depths (Figure 3, 4). The natural occurred Cd levels are extremely low (9, 38) with the major source of spread Cd pollution are often from agricultural fertilizers (29, 39), therefore the PCA group related to Cd, Zn may come from agriculture activities. The irrigation and parent sediments or rock erosion are main sources of the contaminations of lead and arsenic (10, 40-42). In contrast, there was no groundwater irrigation going on in the region and there is little difference between the concentration of Pb and the early geochemical concentration of Pb, so Pb and As may come from sediment parental materials.

4 Discussion

Compared to the heavy metal pollution status in the other regional wetlands in China or elsewhere (Table 5), such high levels of contamination of Hg in West Dongting Lake is rare in other parts of the world. The concentration of Ni, As and Pb were significantly lower than other those of other lakes. The concentrations of several other metals (i.e., Cd, Zn and Cu) in West Dongting Lake areis similar to that of other wetlands exclude the high Cu pollution in Hindon River .The mercury pollution in West Dongting Lake is much higher than other wetlands including Poyang Lake, Dongping Lake, Yellow River, Yangtze River, Huludao Fresh River in China and Hindon River, Awash River Basin, Nemrut Bay, Candarli Gulf, Shur River, Tigris River in developing country and Esaro in developed country. Other heavy metals pollution is not as serious as Hindon River, Esaro river, Awash River Basin, Nemrut Bay and Tigris River.

Heavy metals contamination is a critical problem in the Yangtze River basin (6) and Dongting Lake (34). Dongting Lake is one of the most polluted lakes in China, possibly due to the nonferrous mining, metallurgy, and manufacturing industries in Hunan Province (43). In Dongting Lake, the background values(44) of Ni, As, Cd, Hg, Pb, Zn, Cu are 21.2 mg/kg, 12mg/kg, 0.33mg/kg, 0.047mg/kg, 23.3mg/kg, 83.3mg/kg, 33.3mg/kg, respectively. Other values were reported by Jiang et al. (34) for Ni, As, Cd, Hg, Pb, Zn, Cu and varied from 18.8-60.5mg/kg, 6.03-34.78mg/kg, 0.06-3.65mg/kg, 0.053-1.08mg/kg, 22.4-118.6mg/kg, 63-189mg/kg, 12.9-83.1mg/kg, respectively. China's Sediment Environmental Quality Risk Control Standard for sediment contamination of agricultural land (45) was updated by the Chinese government in 2018 to adopt the new regulation. The detail of the risk screening values and risk intervention values of the standard are given in

Table 6. The pH of the sediments in West Dongtin Lake are between 6.5 and 7.5. The floodplain sediments of Dongting Lake show the following results: At first, levels of Ni, As, Pb, Zn, Cu in sediments were lower than the risk screening values for sediment contamination of agricultural land, and the minimum concentration of Cd, As, Pb were too low to detect. The mean concentrations of Cd were higher than its risk screening values for sediment contamination of agricultural land and the concentration of Hg was much higher than its risk intervention values for sediment contamination of agricultural land. Also, the mean concentrations of Cd and Hg exceeded 2.1 and 103.9 times their risk screening values for sediment contamination of agricultural; the mean concentration of Hg was as high as 62.3 times its risk intervention values for sediment contamination of agricultural land.

5 Conclusion

Surface sediment of the West Dongting Lake floodplain accumulates by sediment deposition during flooding. A change in heavy metal concentration at different sediment depths can reflect a change in heavy metal pollution over time. Also, the Yuan River and Li River show different pattern on heavy metal input which is Yuan River brings more pollutant to the main lake rather than Li River. Based on the sediment accumulation rate (in press) in the region, five sample sites were collected at three sediment depths to access the heavy metals (Ni, As, Cd, Hg, Pb, Zn, Cu), and In particular, the concentration of total Hg in West Dongting Lake is much higher than its risk intervention values for sediment contamination of agricultural land in the China's sediment quality criteria. These heavy metals enter the wetland ecosystem via industry, mines and domestic sewage discharged directly or by surface runoff into Yuan and Li River, which feed into West Dongting Lake. Additionally, the lower water levels in West Dongting Lake after the construction of the Three Gorges Dam may cause polluted sediments to become exposed to air and subsequently enter the food chain via plant absorption and the high concentration of heavy metals indicated that the high contamination exceed acceptable standards and show huge potential ecological risk. Therefore, the high heavy metals contamination in particular may seriously impact the health of humans and wildlife in this region, especially threats to the health of migratory birds in the area. The specific toxicity of high contamination mercury in sediment is unknown because mercury absorbed by the organism in the form of methyl mercury (33), which is we are going to do. Nevertheless, the control of the industrial emission discharged into aquatic ecosystem and use fertilizer properly may be helpful to reduce heavy metal contaminations input into West Dongting Lake.

Acknowledgments

We thank Peng Lingli, Chen Mingzhu, Staff of West Dongting Lake National Nature Reserve and my classmates in Beijing Forestry University for assistance with field and lab work. We thank anonymous reviewers for comments on earlier versions of the manuscript. Also thanks to the USGS Ecosystems Program.

Funding: This work was supported by the National Key R&D Program of China (No. 2018YFC0507200) and the National Training Program of Innovation and Entrepreneurship for Undergraduates (No. 201710022069), under the US-China EcoPartnership program and Beijing Forestry/U.S. Geological Survey Technical Agreement (TAA-15-3921).

Data Availability Statement (DAS)

The data used to support the findings of this study are available from the corresponding author upon request.

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Tables

Table 1 Locations and abbreviation names of sample sites and sampled at three depths (0-10, 10-20 and 20-30 cm) using three replications at each site.

	Site abbreviation	Latitude	Longitude
Taiyangcha	YnUp	28°54′8″N	112°8′54.64″E
Guanceta	YnMd	28°53′35.96"N	112°9′22.68″E
Dabatai	LiUp	28°55′10.63″N	112°12′56.45″E
Dalianzhang	LiMd	28°53′9.36″N	112°12′53.04″E
Liuzu	YnLiDelta	28°51′59.68″N	112°13′18.43″E

Table 2 General characteristics by depth of the heavy metal concentration in sediments of the West Dongting Lake floodplain.

	Depth (cm)	**Maximum (mg/kg)**	**Minimum (mg/kg)**	**Mean of all depths (mg/kg)**	**S.D. (depth)**	**Mean of all depths (mg/kg)**	**S.D.**	**Background value (mg/kg)**
Ni	0-10	33.58	16.77	27.22^{a}	4.09	26.95	7.41	21.2
	10-20	34.23	14.75	26.46^{a}	5.03			
	20-30	71.55	13.23	27.18^{a}	11.06			
As	0-10	7.64	ND	0.47^{a}	1.59	0.97	2.48	12
	10-20	14.59	ND	2.02^{b}	3.67			
	20-30	2.71	ND	0.43^{a}	0.86			
Cd	0-10	2.49	ND	1.16^{a}	0.79	0.64	0.77	0.33
	10-20	2.65	ND	0.60^{b}	0.74			
	20-30	1.05	ND	0.16^{b}	0.32			
Hg	0-10	295.71	180.17	252.37^{a}	31.34	249.25	46.26	0.047
	10-20	323.19	149.10	250.38^{a}	51.23			
	20-30	316.95	149.00	244.99^{a}	52.76			
Pb	0-10	1.20	ND	0.05^{a}	0.23	0.14	0.71	23.3
	10-20	2.25	ND	0.16^{a}	0.51			
	20-30	5.50	ND	0.22^{a}	1.08			
Zn	0-10	112.50	48.15	94.68^{a}	17.00	78.09	23.81	83.3
	10-20	111.00	44.50	76.33^{b}	20.70			
	20-30	118.40	28.85	63.27^{c}	22.01			
Cu	0-10	54.00	12.80	44.28^{a}	10.00	41.55	9.88	33.3
	10-20	52.00	22.40	40.39^{a}	8.94			
	20-30	51.20	21.80	39.97^{a}	10.08			

The a, b, c in the table means different group by ANOVA.

ND means concentrations below the detection limit.

Table 3 Two-way ANOVA comparison of sample sites, soil depths, and the interaction of site × soil depth.

Variable		**Sample sites**	YnUp	LiUp	YnLiDelta	YnMd	LiMd	**Soil Depths**	0-10cm	10-20cm	20-30cm	**Sites × Depths**
Ni	**df**	4						2				8
	F	7.92						0.403				0.491
	Sig.	<0.001**						0.67				0.858
	Mean±S.E.		1.454±0.026b	1.376±0.026ab	1.477±0.026b	1.471±0.026b	1.310±0.026a		1.431±0.020a	1.416±0.020a	1.406±0.020a	
As	**df**	4						2				8
	F	7.83						4.826				1.707
	Sig.	<0.001**						0.011*				0.115
	Mean±S.E.		0.163±0.056ab	-4.163E-17±0.056a	0.380±0.056b	0.015±0.056a	0.072±0.056a		0.067±0.043a	0.235±0.043b	0.076±0.043a	
Cd	**df**	4						2				8
	F	6.029						15.344				1.356
	Sig.	<0.001**						<0.001**				0.235
	Mean±S.E.		0.073±0.025ab	0.179±0.025c	0.160±0.025bc	0.039±0.025a	0.076±0.025ab		0.189±0.019a	0.081±0.019b	0.045±0.019b	
Hg	**df**	4						2				8
	F	29.481						0.709				1.805
	Sig.	<0.001**						0.579				0.32
	Mean±S.E.		2.407±0.014bc	2.369±0.014b	2.437±0.014cd	2.468±0.014d	2.266±0.014a		2.399±0.011a	2.390±0.011a	2.380±0.011a	
Pb	**df**	4						2				8
	F	0.684						0.551				1.191
	Sig.	0.606						0.579				0.32
	Mean±S.E.		0.023±0.025a	0.025±0.025a	0.049±0.025a	-2.082E-17±0.025a	2.776E-17±0.025a		0.003±0.015a	0.026±0.015a	0.030±0.015a	
Zn	**df**	4						2				8
	F	6.425						19.012				0.924
	Sig.	<0.001**						<0.001**				0.503
	Mean±S.E.		1.865±0.03a	1.893±0.03ab	1.987±0.03b	1.860±0.03a	1.777±0.03a		1.979±0.023a	1.871±0.023b	1.779±0.023c	
Cu	**df**	4						2				8
	F	30.302						2.16				0.897
	Sig.	<0.001**						0.124				0.525
	Mean±S.E.		1.655±0.02a	1.618±0.02a	1.646±0.02a	1.690±0.02a	1.409±0.02b		1.630±0.016a	1.594±0.016a	1.586±0.016a	

** means significant differences.

Table 4 Rotated component matrix for PCA loadings of heavy metals in West Dongting Lake.

Elements	**Component loadings**		
	RC1	***RC2***	***RC3***
Ni	0.54	0.00	0.17
As	-0.18	0.41	0.60
Cd	0.06	0.92	-0.10
Hg	0.83	0.21	0.10
Pb	0.21	-0.13	0.80
Zn	0.39	0.83	0.19
Cu	0.88	0.15	-0.22
SS loading	1.99	1.78	1.13
Proportion Var	0.28	0.25	0.16
Cumulative Var	0.28	0.54	0.70

Table 5 Summaries of heavy metal concentration in sediments from lakes in China.

Name of the Wetlands	Explain	Metal concentration （mg/kg）							Data from
		Ni	As	Cd	Hg	Pb	Zn	Cu	
West Dongting Lake, China	Lake	26.95	0.97	0.64	249.25	0.14	78.09	41.55	This study
Dongting Lake, China	Lake	NA	29.71	4.65	0.157	60.99	185.25	47.48	(35)
East Dongting Lake, China	Lake	NA	4.5	0.82	NA	34.11	121.6	30.21	(3)
Poyang Lake, China	Lake	NA	NA	0.7	NA	50.4	132.9	62	(46)
Dongping Lake, China	Lake	NA	25.3	0.285	0.055	35.5	100.5	52	(29)
Yellow River Riverbed, China	River	28.5	NA	NA	NA	NA	50.19	22.95	(19)
Yangtze River catchment of Wuhan, China	Mainstream	40.91	15.85	1.53	0.15	45.18	140.27	51.64	(47)
	Tributaries	43.31	14.82	115.56	0.3	47.13	255	57.06	
	Lakes	40.44	16.03	0.57	0.32	57.78	296.78	75.56	
Yangtze River intertidal zone, China	Coastal Wetland	31.8	NA	0.261	NA	27.3	94.3	30.7	(7)
Huludao Freshwater Rivers	River	28.50 ± 8.01	NA	NA	NA	NA	50.19 ± 19.26	22.95 ± 7.67	(11)
Hindon River, India	River	13.90–57.66	NA	0.29–6.29	NA	27.56–313.57	22.22.50–288.29	21.70–280.33	(48)
Awash River Basin, Ethiopia	River	89.46	15.87	2.6	0.17	13.53	382.73	79.43	(49)
Esaro, Italy	River	NA	20.9	0.22	0.044	13.1	NA	NA	(50)
Nemrut Bay, Turkey	Coastal Wetland	18.1–63.4	14.4–20.2	0.005–0.25	1.70–9.60	22.3–89.4	75–271	9.6–43.7	(51)
Candarli Gulf, Turkey	Coastal Wetland	7.6–100.3	11–35	NA	0.23–1.4	14.5–137.8	55–358	2.7–34.8	(52)
Shur River, Iran	River	NA	NA	0.55	NA	32	187	26.2	(53)
Maden of Tigris River Turkey	River	216.8	8.9	2.4	NA	393.9	530.5	1941.9	(54)

NA: not available

Table 6 The risk screening values and risk intervention values of China's Sediment Environmental Quality Risk Control Standard for sediment contamination of agricultural land, mg/kg

	Type	pH≤5.5	5.5<pH≤6.5	6.5<pH≤7.5	pH>7.5
Cd	risk screening value	0.3	0.3	0.3	0.6
	risk intervention value	1.5	2.0	3.0	4.0
Hg	risk screening value	1.3	1.8	2.4	3.4
	risk intervention value	2.0	2.5	4.0	6.0
As	risk screening value	40	40	30	25
	risk intervention value	200	150	120	100
Pb	risk screening value	70	90	120	170
	risk intervention value	400	500	700	1000
Cu	risk screening value	50	50	100	100
	risk intervention value	-	-	-	-
Ni	risk screening value	60	70	100	190
	risk intervention value	-	-	-	-
Zn	risk screening value	200	200	250	300
	risk intervention value	-	-	-	-

Figure caption

Figure 1 Locations of sample sites in West Dongting Lake in China (A) Dongting Lake in China, (B) West Dongting Lake with Dongting Lake and Yangtze River, (C) Yuan River and Li River flow into Dongting Lake including Taiyangcha (YnUp), Guanceta (YnMd), and Liuzu (YnLiDelta) along the Yuan River and Dabatai (LiUp), Dalianzhang (LiMd) and Liuzu (YnLiDelta) along the Li River. The arrows indicate the flow direction of the rivers. Surrounding cities have many industries including auto parts and manufacturing. Areas directly adjacent to the river include farming and forestry activities.

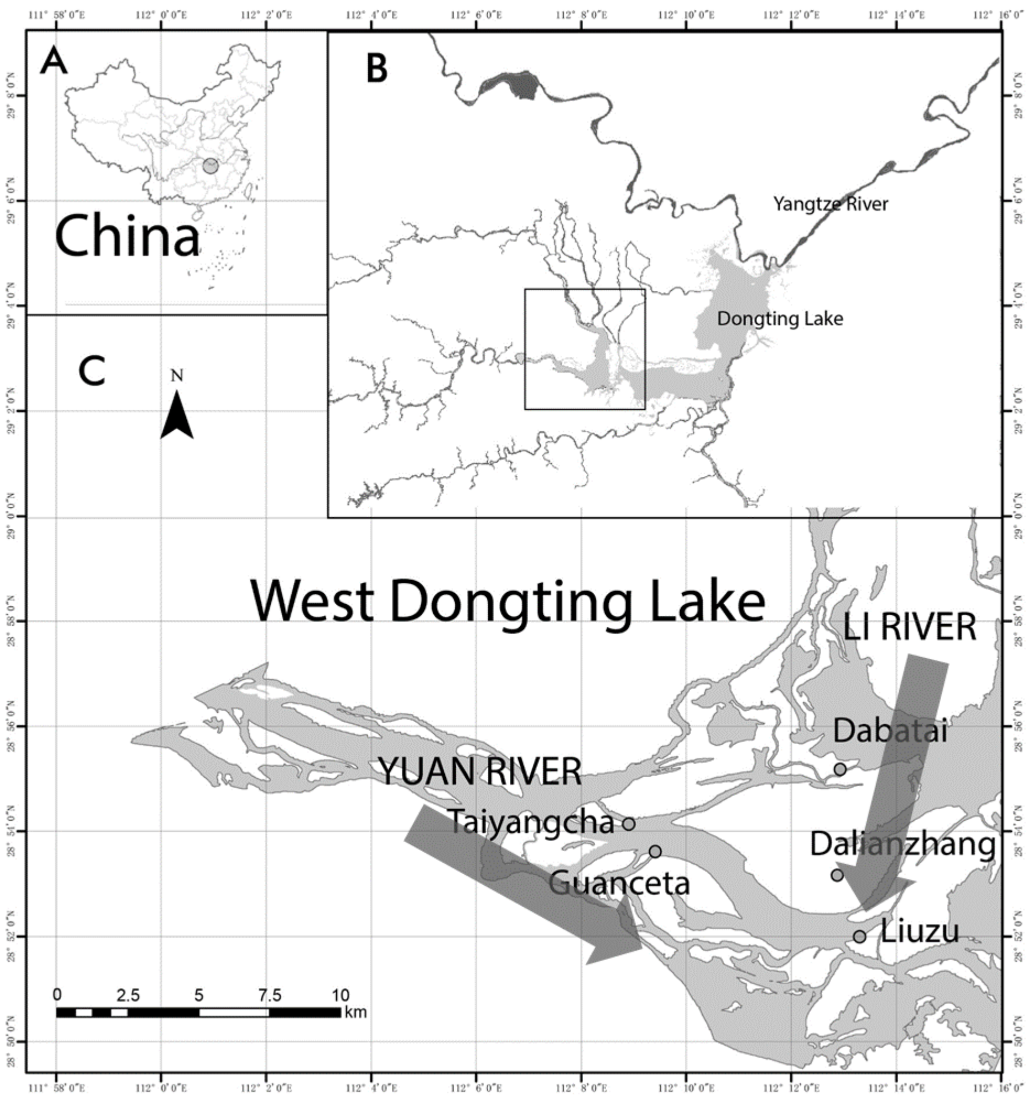

Figure 2 Principal Component Analysis loading plot showing heavy metal relationships in West Dongting Lake.

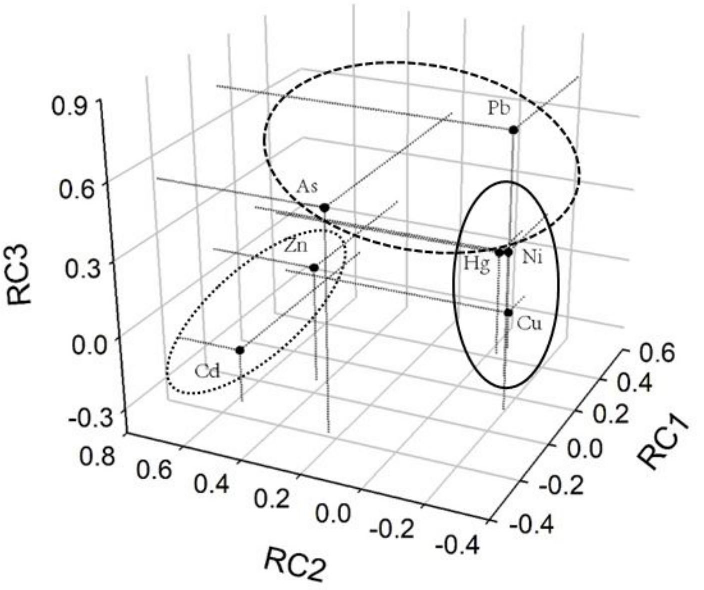

Figure 3 Two-way ANOVA comparison of sample sites

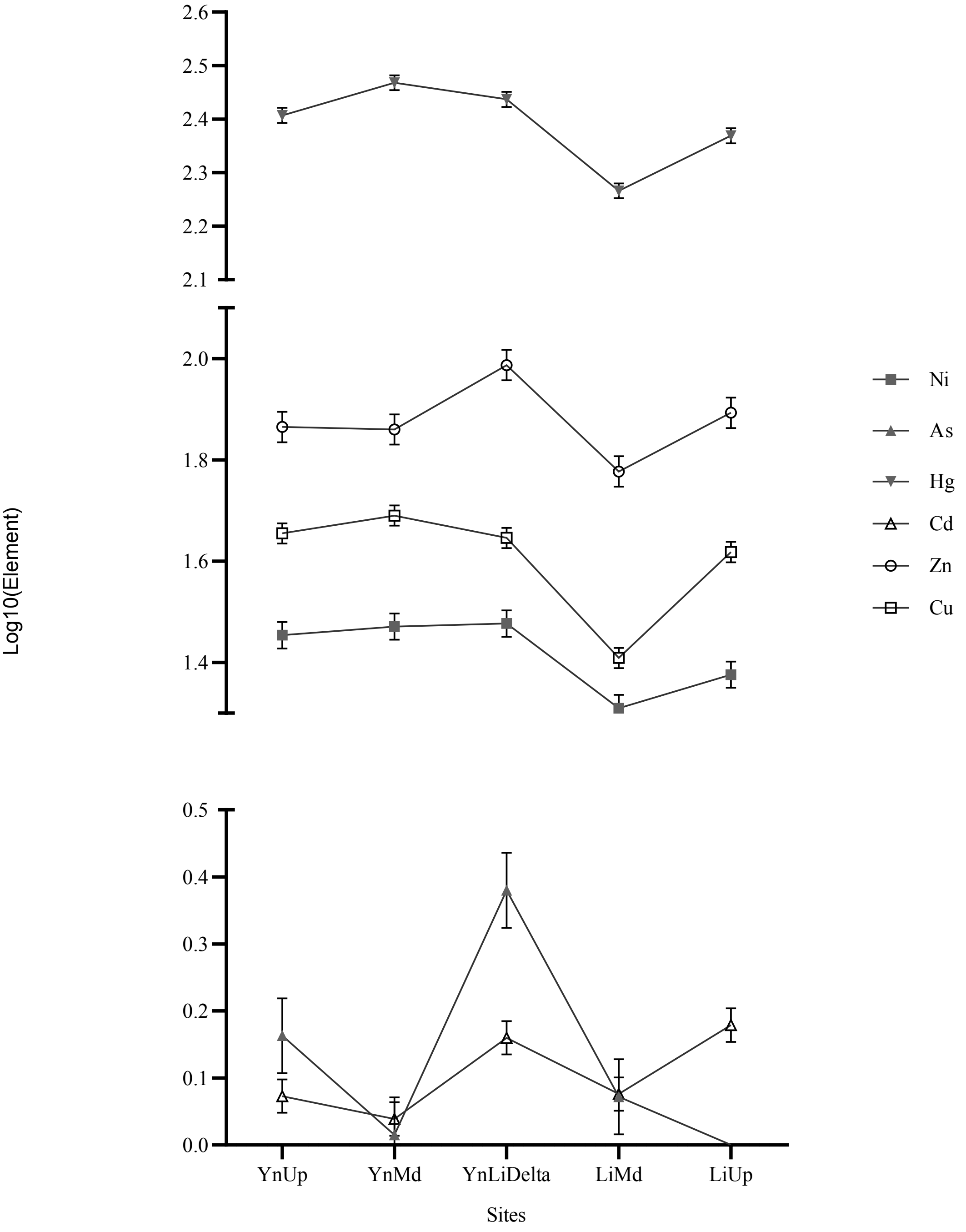

Figure 4 Two-way ANOVA comparison of sample depths