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Investigation on Metal Pollution in the Sediment of Chongqing Segment of Yangtse River

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Abstract Basing on experiment dada collected from 1995 to 2007 at Chongqing segment of Yangtse River, the pollution and the potential toxic effect of sediment were depicted and characterized by using the Index of Geoaccumulation (I_{geo}) method and the Logistic Regression model respectively. Results showed that the sediment had been slightly polluted by metals and had possible adverse effect on aquatic life. According to the I_{geo}, the order of the analyzed metals, arranging from highest to lowest pollution degree, was Cd > Hg > Pb > Cu > Zn > As. Meanwhile, sediment contamination level had been obviously decreasing before the storing water of Three Gorge Reservoir.

Keywords Yangtse river · Metals pollution · Logistic regression model · Index of geoaccumulation

A wide range of persistent chemicals, such as Pb, Hg etc, adsorb on sediment after depositing from surface water. These chemicals not only result in sediment contamination but also are harmful to aquatic life, which become a source of contaminants for bioaccumulation in the food chain (Yang et al. 1996; Yuan et al. 2000; Xie et al. 2007).

Although there are a lot of evidence to demonstrate that sediment contamination could result in severely adverse effect, both sediment quality standard and assessment criterion of freshwater are vacant in China. Most Chinese researchers used the Index of Geoaccumulation (I_{geo}) and the Index of Potential Ecological (RI) to assess their collected data. The Index of Geoaccumulation and the Index of Potential Ecological (RI) were put forward first by Müller (1969) and Swedish Hakanson respectively (Hakanson 1980). The former was used to assess the degree of accumulation and pollution of metal, the latter was used to evaluate the potential ecological risk of both single metal and integrated pollution of varied metals. Besides the concentration of specific chemicals, the key parameter of these two assessment models is background data. In fact, it is the bioavailability and bioreactivity of metals, which controls their potential to cause adverse effects (Yang et al. 1996), other than the sources of the contamination chemicals come from. Considering of this factor, it might be more valuable to have another method to estimating potential ecological risk. The Logistic Regression model, which was presented first by Field et al. (1999, 2002), is a suitable method to estimate the probability of observing sediment toxicity with no need to acquire background data or quality guidelines. The only variety of the Logistic Regression model is the concentration of compound. The concentrations of contamination chemicals in sediment are affected by lots of factors, such as, substrate particle sizes, content of organic matter, and hydraulics parameters of river etc.

Up to now, Three Gorge Reservoir engineering is the largest water conservancy project in this world. Accompanying the constructing of this project, researchers never stop arguing on it's influence on eco-environment. As a result of storing water in the Three Gorges Reservoir, the flowing velocity of Yangtse River of Chongqing segment became almost four times slower since 2008. It's reasonable that actions of suspended substances of Yangtse River, especially deposition, changed remarkably. In addition,

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Chongqing town where heavy industry is highly developed locates in the upstream of Yangtse River and it is the end of the backwater of Three Gorges Reservoir. It's possible that lots of nocuous substances could be input to Yangtse River and deposited on sediment unconsciously. Therefore, more attention should be paid to sediment in Chongqing town segment of Yangtse River. Based on sediment chemistry data collected from 1995 to 2007, this paper presented the evaluation results about sediment in Chongqing segment of Yangtse River, which became the part of the Three Gorges Reservoir in 2008. Our assessment results is a base of future research and would be helpful to assess potential trends in sediment contamination levels of Yangtse River after storing water of Three Gorges Reservoir. It is the first time to report the sediment contamination level at the Chongqing segment of Yangtse River before storing water of Three Gorges Reservoir by far.

Materials and Methods

From upstream to downstream of the Yangtse River, two sediment sampling stations of suspected contamination, Wang Longmen (locateing at middle of town) and Cuntan (locateing at edge of town), were selected to investigate the quality of sediment. By means of an Ekman dredge, sediment samples were collected at the two side of River beneath an aqueous layer at every year's spring from 1995 to 2007. After sampling, sediment was transferred to a clean sample container to airing, following the removing of unrelated components, such as cobble and dead leaves etc, then blending and grinding sample till the particle sizes of whole sample were little than 100 mesh.

"Modern analytical methods of soil elements" issued by Chinese Environmental Monitoring center (1992) was adopted as our analytical method source. Main equipments and reagents involved were: Temperature Adjustable Hot Plate, PE4100 and JENA Z700 Graphite Furnace Atomic Absorbance Spectrophotometer, PE3100 Flame Atomic Absorbance Spectrophotometer, HYDRA AA Atomic Fluorescence Cold Vapor System, Nitric acid (GR), Hydrochloric acid (GR), Sulfuric acid(GR), Reagent water (conductivity less than 0.06 µs/cm) et al. For Cu, Pb, Zn, Cd, Hg and As, laboratory detection limit was 0.1, 1.0, 0.14, 0.007, 0.0025 and 0.025 mg/kg respectively.

During our analysis, the calibration blank, the laboratory reagent blank, at least 10% of the samples spiked samples and duplicate samples were analyzed. Instrument performance check solution was analyzed periodically to verify instrument performance. The recovery of Cu, Pb, Zn, Cd, Hg and As was 73%–86.5%, 75%–89%, 78%–93%, 71.5%–86%, 81.3%–109% and 91.3%–108%.

The Index of Geoaccumulation (I_{geo}), derived by Müller (1969), is a popularly method which was used to evaluate the degree of enrichment and pollution of sediment quantificationally. The I_{geo} value was calculated by the following equation:

$$I_{\text{geo}} = \log_2^{C_n/(1.5\times B_n)}$$

where c_n is the concentration of chemical element in sediment particles, the unit of c_n is mg/kg;K is the changing coefficient of background data which is related to the difference of rock component, the value of k is 1.5; B_n is global geochemistry background data of the specific element in viscidity deposit rock. According to Muller's research conclusion, I_{geo} classed as seven grades as Table 1, which demonstrated the contamination levels of metal.

Normally, it is more appropriate to use the background data of just river than that of global to assess the contamination levels of metal. In fact, background data of element composition in sediment of Yangtse River have been collected (Zhang et al. 1996), and the results showed that the geologic composition of same element changed remarkably. For example, the concentration of copper fluctuated between 2.53 and 166.2 mg/kg. Other studies showed that the element background data of sediment is similar to fine particles which come from the ablation of mother terrene (Wang et al. 1992). In Chongqing city, our investigation results showed that element compositions of deep soil are similar to mother terrene. Therefore, this paper used the mean element concentration in deep soil of Chongqing town as evaluation's background data. For Cu, Pb, Zn, Cd, Hg and As, the background concentration was 23.8, 25.5, 75.8, 0.133, 0.053 and 5.82 mg/kg respectively.

Field et al. (1999, 2002) proposed an empirical method to evaluate sediment quality by using Logistic Regression

Table 1 Classification of index of geoaccumulation and metal contamination levels

Index of geoaccumulation	Classification of I_{geo}						
	0 <0	1 0–1	2 >1–2	3 >2–3	4 >3–4	5 >4–5	6 >5
Contamination level	Clean	Slight pollution	Partial middling pollution	Middling pollution	Partial heavy pollution	Heavy pollution	Sever heavy pollution

Table 2 Classification of *Y* and predicted toxic effect

Predicted proportion toxicity	Classification of *Y*		
	No indication of adverse effect	Adverse effect on aquatic life is possible	Adverse effect on aquatic life is probable
Y	≤0.25	>0.25–0.5	≧0.5

Table 3 Index of geoaccumulation and it's grade of sediment in Chongqing town segment of Yangtse river

Sampling site	Period of mean concentration	Assessment result											
		Cu		Pb		Zn		Cd		Hg		As	
		I_{geo}	Grade	I_{geo}	Grade	I_{geo}	Grade	I_{geo}	Grade	I_{geo}	Grade	I_{geo}	Grade
Left side of Wang Longmen	From 1995 to 2000	0.73	1	0.19	1	0.58	1	1.59	2	0.46	1	−0.54	0
	From 2000 to 2005	0.76	1	0.31	1	0.06	1	1.38	2	1.70	2	−0.32	0
	From 2006 to 2007	−0.02	0	0.06.	1	0.07	1	0.59	1	−0.20	0	−0.12	0
Right side of Wang Longmen	From 1995 to 2000	0.52	1	0.10	1	0.45	1	1.34	2	−0.16	0	−0.32	0
	From 2000 to 2005	0.72	1	0.69	1	−0.05	0	1.31	2	1.86	2	0	0
	From 2006 to 2007	0.20	1	0.42	1	0.25	1	0.50	1	−0.29	0	−0.24	0
Left side of Cuntan	From 1995 to 2000	0.34	1	−0.25	0	0.48	1	1.27	2	−0.34	0	−0.09	0
	From 2000 to 2005	0.85	1	0.39	1	0.01	1	1.42	2	1.82	2	−0.01	0
	From 2006 to 2007	−0.37	0	−0.19	0	−0.49	0	0.68	1	0.11	1	−0.40	0
Right side of Cuntan	From 1995 to 2000	0.13	1	−0.31	0	0.39	1	1.54	2	1.05	2	−0.07	0
	From 2000 to 2005	0.86	1	0.15	1	−0.03	0	1.32	2	1.62	2	0.03	1
	From 2006 to 2007	−0.39	0	0.18	1	−0.23	0	0.64	1	0.34	1	−0.38	0

model. The model can be used to predict the probability of observing specific toxic effects. For a single independent variable (x), the Logistic Regression model can be expressed with following formula:

$$P = \frac{\exp\left(B_0 + B_1 \log_{10}^{x}\right)}{1 + \exp\left(B_0 + B_1 \log_{10}^{x}\right)}$$

where p is probability of observing a toxic effect; B_0 is intercept parameter, for Cu, Pb, Zn, Cd, Hg and As,the value is −5.7878, −5.4523, −7.9834, −0.34, 0.8041 and −4.1407 respectively; B_1 is slope parameter, for Cu, Pb, Zn, Cd, Hg and As, the value is 2.9325, 2.7662, 3.342, 2.5073, 2.5461 and 3.1674 respectively; X is chemical concentration in log 10 units. Metal concentrations are expressed in parts per million (ppm) and organics concentrations are expressed in parts per billion (ppb) in the preceding equation.

For the mixture of contaminants in a given sample, the maximum ($p_{\max}$ model) probabilities was used to estimate the probability of toxicity:

$$y = 0.11 + 0.33p_{\max} + 0.4p_{\max}^2$$

where $p_{\max}$ = maximum probability of observing a toxic effect; y = predicted proportion toxicity. The maximum value of the predicted proportion toxicity were list at Table 2.

Results and Discussion

Table 3 presented the Index of Geoaccumulation and it's grades of mean concentrations at Wang Longmen and Cuntan of Yangtse River from 1996 to 2007. According to these data, we can draw following conclusion: (a) Before storing water of Three Gorge Reservoir, the quality of sediment in Chongqing town was in slight pollution status, Hg and Cd had been slightly enriched, others hadn't been enriched or little. (b) The order of the analyzed metals, arranging from highest to lowest pollution value, was Cd > Hg > Pb > Cu > Zn > As. (c) Generally, there were no obvious differences between left and right side at the same stite of Chongqing town segment of Yangtse River, The sediment contamination level of the middle town was relatively more severe than that of edge. (d) The sediment contamination level had been aggravated since 1995 and reached up to maximum between 2000 and 2005. After that, pollution began to decrease. This result was somewhat different to that of the middle reaches of the Yangtze River, where sediment was also slightly polluted, but the dominant contaminants were Pb, Cu (Shi and Qin 2009).

Table 4 describe the *P* result and classification of *Y* at Wang Longmen and Cuntan of Yangtse River from 1996 to

Table 4 Sampling site *P* result and classification of *Y* of Yangtse river

Sampling site	Period of mean concentration	*P*						Assessment result	
		Cu	Pb	Zn	Cd	Hg	As	Y	Toxic grade
Left side of Wang Longmen	From 1995 to 2000	0.356	0.287	0.371	0.288	0.162	0.230	0.287	Possible
	From 2000 to 2005	0.362	0.306	0.259	0.258	0.334	0.186	0.282	Possible
	From 2006 to 2007	0.222	0.288	0.261	0.161	0.050	0.218	0.238	No indication
Right side of Wang Longmen	From 1995 to 2000	0.315	0.271	0.341	0.253	0.107	0.186	0.269	Possible
	From 2000 to 2005	0.356	0.377	0.239	0.248	0.361	0.238	0.291	Possible
	From 2006 to 2007	0.258	0.325	0.297	0.152	0.097	0.198	0.274	Possible
Left side of Cuntan	From 1995 to 2000	0.282	0.217	0.347	0.242	0.091	0.222	0.273	Possible
	From 2000 to 2005	0.381	0.321	0.250	0.264	0.354	0.235	0.294	Possible
	From 2006 to 2007	0.173	0.225	0.167	0.171	0.129	0.175	0.204	No indication
Right side of Cuntan	From 1995 to 2000	0.302	0.208	0.326	0.283	0.234	0.226	0.260	Possible
	From 2000 to 2005	0.383	0.279	0.242	0.250	0.320	0.242	0.295	Possible
	From 2006 to 2007	0.171	0.283	0.206	0.166	0.150	0.178	0.235	No indication

2007. As described in Table 4, we didn't found sediment contamination associated with probable adverse effects on aquatic life at all sampling sites; but contamination associated with possible adverse effects on aquatic life was found at all these sampling sites. Meanwhile, 3 of 4 stations were found no indication of adverse effects at 2006 which suggested that the sediment contamination of Chongqing town segment of Yangtse River had being decreased. Metals accumulated in sediment entered Yangtse River from a variety of sources, including plating factory, paint factory and cement factory etc. Fortunately, these factories have been moved to other places one after another by means of government regulations since 2001. Coincidently, the contamination levels in sediment of Chongqing town segment of Yangtse River had being decreased gradually since implementing the government regulations, these trends of decrease appear to be linked to the moving of various factories from 2001 to now.

In one word, every sampling site was classified as slight pollution and had possible adverse effect on aquatic life. At the same time, the assessment results demonstrated that potential tends in sediment contamination levels had being obviously decreased before the storing water of Three Gorge Reservoir. However, as mentioned above, building of Three Gorges Reservoir have changed hydraulics parameters of river greatly. Therefore, further investigation and evaluation on sediment contamination will be useful to predict the influence of Three Gorges Reservoir, which has important scientific and practical value.

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