

# Spatial distribution and ecological risk assessment of metals in sediments of Baiyangdian wetland ecosystem

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**Abstract** Although there are many studies of heavy metal contaminations of sediments, attention has seldom been paid to the problem in developing countries. The purpose of this article is to find the distribution and ecological risk of As, Hg, Cr, Cd, Pb, Cu, and Zn in surface sediment of Baiyangdian which is the biggest wetland in Northeast China. We apply three methodologies. The first is literature analysis comparing total concentrations of heavy metals with other water bodies around world. The second is Chinese Environmental Quality Standard for Soils (EQSS), National Environmental Protection Agency of China 1995, and the third is Soil and Aquatic Sediment Guidelines and Standards issued by New York Department of Environmental Conservation (NYSDEC). The results show that compared to other water bodies around the world, the seven heavy metals are low. However, Cd was found in the most polluting level of EQSS near a village and was second grade some distance from it. The village was also the most polluted site of Zn, which was in the second grade. When assessed by NYSDEC, Cu, Cr, and As contaminated the sediment and with moderate impacts on benthic life while Pb, Hg, and Zn were found at tolerable levels throughout Baiyangdian. The centre of Cu and Cr contamination was also near the village. As is the most polluting heavy metals with a major occurrence in the middle of the wetland. There were no heavy metals creating severe disturbance to

the benthic communities. Based on the assessment, this article proposes different options for more sustainable management.

**Keywords** Ecological risk assessment · Heavy metals · Sediment · Spatial distribution · Baiyangdian

## Introduction

The term ‘ecological risk assessment’, although barely used 25 years ago (Barnthouse 2008) is now fully developed and has become an important tool in watershed management. Ecological risk management provides policy makers and resource managers as well as the public with systematic methods that can inform decision making. A number of studies have applied ecological risk principles to different watersheds (Zandbergen 1998; Ohlson and Serveiss 2007; Serveiss 2002). Nevertheless, there remain many frustrations and much confusion among practitioners regarding the application of risk assessment procedures in actual projects (Kapustka 2008).

Among all the impacts threatening ecosystems, heavy metals play a decisive role. Several studies have evaluated the risk of heavy metals distribution in sediment (Monken 1997; Zheng et al. 2008; Álvarez-Iglesias and Rubio 2009; Hye-Sook et al. 2008). Heavy metals are normally discharged from waste water treatment plants, particularly where there is input of industrial waste (Madoni and Romeo 2006). Unlike organic contaminants which can be decomposed during natural processes, heavy metals in the river environment can be biomagnified or concentrated by organisms or build into organic complexes (Liu et al. 2009b). Accumulation of heavy metals in sediments, even when present in low concentrations in the overlying water

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column, is dependent on various factors such as the nature of the sediment particles, the properties of the adsorbed compounds, and the prevailing physiochemical conditions (Christophoridis et al. 2009).

Describing the spatial distribution of the pollutants as well as their ecological risk is the key point for environmental management and decision-making (Liu et al. 2006). Knowledge of the distribution and concentration of heavy metals provides rich information for management authorities, as it helps locate pollution sources and thus where to carry out proper treatment of effluents or other environmental management measures.

Heavy-metal distribution in water is often small and stochastic. It varies according to the differences in discharge and hydraulic conditions. But heavy metals often accumulate in much higher concentrations in sediment than in water. As the largest freshwater wetland in north China, Baiyangdian plays an important role in keeping the ecosystem balance, adjusting the regional climate, supplying underground water, regulating flooding, and protecting biodiversity within the watershed. Due to its amenity values and general importance it was once called the ‘pearl of northern China’. However, in recent years, the whole watershed has suffered from water scarcity due to overuse, sand sedimentation, environmental pollution, and also dysfunction in other wetland ecosystem services. Global climate change also triggers the warming that leads to increasing evaporation, drying up the wetland. Thus the Baiyangdian ecosystem will be under increasing pressure.

However the planning of the restoration is in need of support from scientific research. This article contributes to that by describing the contamination level compared to other water bodies around the world, comparing it with

other types of soils, and estimating the level of risk of contamination with heavy metals for the biology of the wetland, all factors that were still unknown. In order to meet the increasing need for an integrative approach which is both simple and can give a balanced view of the pressures on the ecosystem, this article takes Baiyangdian as a case study and carries out measurement of heavy metals and then assesses their impact by applying three different benchmark exercises methods to assess the ecological risk.

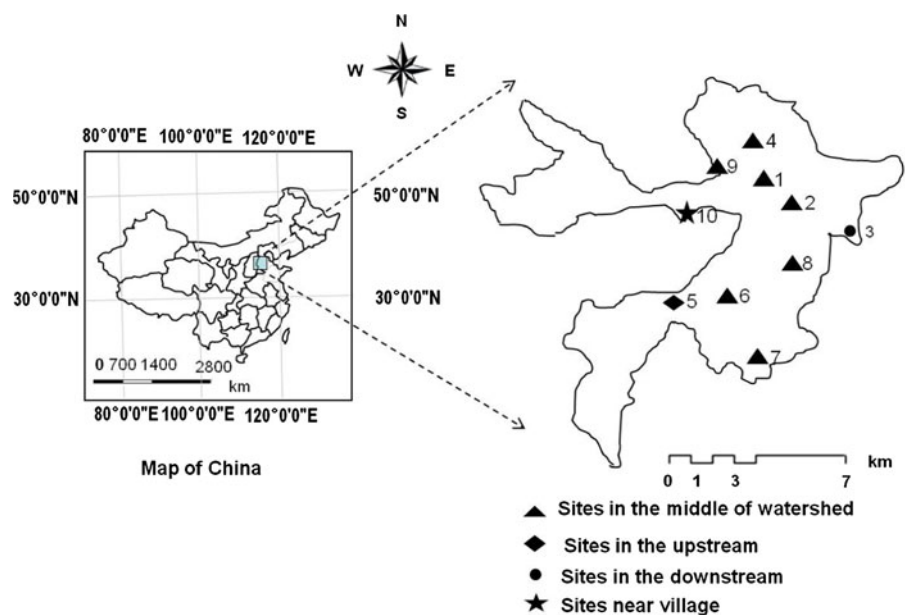
The purposes of this study are to determine the concentration of heavy metals in Baiyangdian surface sediment; to assess the ecological risks from heavy metals using different methodologies; to identify the sources of the heavy metals; to sketch the implications for decision-making and to provide suggestions for future watershed management.

## Materials and methodology

### Geology and field description

Baiyangdian is located in Hebei Province of China (Fig. 1). It is one of the state’s key tourist areas with its rich resources of lakes and lotus flowers. The lake consists of more than 100 small and shallow lakes that are linked by numerous ditches. The water area is 366 km<sup>2</sup> and the catchment is 31,200 km<sup>2</sup> (Xu et al. 1998). It’s the largest freshwater in North China and the average annual runoff of water is  $3.57 \times 10^9$  m<sup>3</sup>. The major types of land uses or land cover in Baiyangdian include water, arable land, construction land, forests, grassland, and urban areas.

**Fig. 1** Baiyangdian’s position in China and the location of the sampling sites in the wetland



The numerous lakes connected by gullies create a lot of small islands where there are villages and gardens. More than 3,700 ditches and reed areas divide the whole wetland into lakes of different sizes. The main method of transportation of the local people who live on these small islands is by boat.

The precipitation and water flow into Baiyangdian has decreased in recent years, causing the lake area and volume to continue to shrink. Human impact has also been the cause of a decrease in biodiversity. Sewage discharge, aquaculture, and industrial contamination from the nearby city of Baoding have generally been acknowledged as the sources of pollution. Compared with the situation 15 years ago, nine species have disappeared from Baiyangdian, the number of natural habitats has decreased from 16 to 13, and some predominant communities with large distribution areas, such as *Hydrilla verticillata* and *Najas major*, can no longer be found (Li et al. 2008). Furthermore the decrease in water supply and increase in water consumption intensifies the wetland degradation.

From 1981 to 2003, water from three reservoirs around Baiyangdian, Wangkuai, Xidayang and Angezhuang transferred  $5.02 \times 10^8 \text{ m}^3$  to Baiyangdian. In 2004, the same project implemented from Yuecheng reservoir and Yellow River transferred  $5.02 \times 10^8$  and  $1.0 \times 10^8 \text{ m}^3$  to Baiyangdian respectively (Yin et al. 2009). At present, the water from Fu River in the northeast enters into Baiyangdian and then distribute to the numerous ditches. The water being transferred from Yellow River enters from the southeast of Baiyangdian. But this only happens when the water is lower than the warning level (Su et al. 2010). Since it suffers from dry up in recent years, there seldom water flow out of the wetland. Thus the water velocity is quite low.

#### Sampling sites

In April 2008, we carried out an environmental surveillance programme in Baiyangdian. The concentrations of seven metals in the sediment were measured in the 10 samples collected in Baiyangdian. There were state monitoring stations at the first nine sites (Fig. 1) and they cover the key nodes of Baiyangdian. The sampling sites were located by a global positioning system. We added the last site because it was next to the living area of local people and neighboring to one of the main water flows into Baiyangdian. The distribution of sampling sites was mainly chosen to reflect the different land uses and the important tributaries flowing into and out of Baiyangdian. As they are influenced by the city and industries, all parts of Baiyangdian are under heavy impact from people, although to different degrees.

The samples were taken at Duancun on the upper river (Site 5), Wangjiazhai (Site 1), Guangdianzhangzhuang (Site 2), Guolikou (Site 4), Datianzhuang (Site 6), Caiputai (Site 7), Quantou (Site 8), and Dazhangzhuang (Site 9) in the middle of the wetland, Nanliuzhuang (Site 10) next to the village, and Zaolinzhuang (Site 3) downstream of the Baiyangdian.

In each sampling site, the top 5 cm of sediment samples were collected. The sediment core sampler was homemade. Compared to the sediment core samplers sold on the market, it is much easier to carry and efficient in field work. It has an inner diameter of 6 cm and length of 50 cm. After collection, the samples were sealed in polyethylene bags and kept in a cooled box. When the cooled samples were brought back to the laboratory, they were air dried. The collection, preservation, and laboratory work all followed 'The Technical Specification for Soil Environmental Monitoring' (National Environmental Protection Agency of China 2004).

#### Chemical analysis

The samples from the 10 locations were examined for seven heavy metals (As, Hg, Cr, Cd, Pb, Cu, and Zn). For total metal analysis, each sample was dissolved by a 5:1 mixture of hydrofluoric and perchloric acids (Tessier et al. 1979). The five-step method was used to analyze the metal forms, including exchangeable and bound to carbonate, bound to Fe/Me oxide, bound to organic matter and sulfide, and residual forms (Tessier et al. 1979). To determine the concentrations of As and Hg, atomic fluorescence spectrometry (AFS) was used. Inductively coupled plasma mass spectrometry (ICP-MS, Perkin Elmer Elan 6000) was used for testing the concentrations of Cd, Cr, Cu, and Pb, and ICP-OES was used to determine the concentration of Zn. All samples were analyzed in duplicate experiments as well as blank experiments. In the duplicate experimentations, the standard analysis of the material accuracy was 100%, which shows a very good reproducibility of the equipment. The detection limits were: 1 µg/g for As, 0.002 µg/g for Hg, 0.03 µg/g for Cd, 5 µg/g for Cr, 2 µg/g for Pb, 1 µg/g for Cu, and 2 µg/g for Zn.

This study made use of the following reference material: As: GBW (E) 080390; Hg: GBW (E) 080392; Cr: GBW (E) 080403; Cd: GBW (E) 080401; Pb: GBW (E) 080399; Cu: GBW (E) 080396; and Zn: GBW (E) 080400.

#### Ecological risk assessments

To assess the impacts of heavy metals in Baiyangdian, this study applied three different benchmark methods.

The first one was literature analysis that compared the maximum concentration of total heavy metals with those of other water bodies around the world, with the aim of establishing a crude picture of the status of Baiyangdian compared to other water bodies. The cases in China are the main water bodies known of sediment contamination and the other cases outside China are the ones we know of and come from various countries.

The second method was the Environmental Quality Standard for Soils (EQSS), National Environmental Protection Agency of China 1995 (Table 1). It proposes three grades for the soil quality according to different functions and protection objectives. The grade defined by the standard is the maximum allowable contaminants of each heavy metal in the soil. For example, if the soil has an As concentration of 13 mg/kg, this means its concentration is less than the natural background value which is 15 mg/kg and thus in the first grade soil quality. And this soil could be suitable for purpose of nature reserves, drinking water resource areas, tea gardens, and pastures.

This limit describes the natural background of soil quality and defines the level to protect the natural ecology. If the soil has an As concentration of 27 mg/kg with pH 6.4, then it is second grade. This soil is suitable for farm land, vegetable fields, tea gardens, orchards, and pastures but could not be used as drinking water resource area. The limit value for second grade guarantees a sound agriculture and safety for human health. Thus there is also a third grade which is only for forest, contaminated soil, and

farmland near mine guaranteeing safe agriculture and growth of vegetables.

The third benchmark method used in this study is the Soil and Aquatic Sediment Guidelines and Standards issued by the New York State Department of Environmental Conservation (NYSDEC) (1999), often called the sediment quality guidelines (SQGs).

The total heavy metal concentrations are compared with the two benchmarks of lowest effect level (LEL) and severe effect level (SEL), which signifies chronic, long-term impacts of contamination to benthic organisms (Table 2). Macro benthic communities are considered good indicators of ecosystem health (Dauer et al. 2000) as benthos shows the real effects of pollution on the communities, being an integrator of the recent pollution history in the sediment and of different kinds of pollutants, which can be synergistic (Occhipinti-Ambrogi and Forni 2004).

If the heavy metal concentration in the sediment is lower than LEL, it would be tolerated by the majority of benthic organisms. If the concentration is more than the LEL but lower than the SEL concentration, the sediment is considered to be contaminated, but with moderate impacts on benthic life. If SEL is exceeded; this indicates a clear disturbance to the sediment-dwelling benthic communities and would be detrimental to the majority of them. If all the heavy metal concentrations are higher than SEL it could severely impact health of this biota (Graney and Eriksen 2004).

**Table 1** Environmental Quality Standard for Soils (National Environmental Protection Agency of China 1995). All numbers represents each metal's concentration and in mg/kg

Element	First grade		Second grade		Third grade
	Natural background	< 6.5	6.5–7.5	> 7.5	> 6.5
pH of soil					
Metals					
As					
Paddy field ≤	15	30	25	20	30
Dry land ≤	15	40	30	25	40
Hg ≤	0.15	0.3	0.5	1.0	1.5
Cr					
Paddy field ≤	90	250	300	350	400
Dry land ≤	90	150	200	250	300
Cd ≤	0.2	0.30	0.30	0.60	1.0
Pb ≤	35	250	300	350	500
Cu					
Paddy field ≤	35	50	100	100	400
Dry land ≤	–	150	200	200	400
Zn ≤	100	200	250	300	500

**Table 2** NYSDEC (1999) guidelines for metal concentrations in sediment

Element	LEL (mg/kg)	SEL (mg/kg)
As	6.0	33.0
Hg	0.15	1.3
Cr	26.0	110.0
Cd	0.6	9.0
Pb	31.0	110.0
Cu	16.0	110.0
Zn	120.0	270.0

**Table 3** Concentration of heavy metals in sediments of Baiyangdian (mg/kg)

Site	As	Hg	Cr	Cd	Pb	Cu	Zn
1	9.5	0.04	69	0.30	25	23	68
2	10.5	0.03	69	0.20	25	22	61
3	10.3	0.05	64	0.12	22	20	52
4	24.8	0.04	59	0.13	23	21	56
5	7.9	0.04	58	0.12	20	19	53
6	12.3	0.04	69	0.27	24	25	80
7	4.7	0.06	64	0.12	21	20	58
8	10.8	0.03	84	0.26	26	29	85
9	10.8	0.05	67	0.18	22	23	67
10	9.3	0.06	83	0.90	30	35	112

## Results and discussion

### Heavy metals concentration found in Baiyangdian

The concentrations of the seven investigated heavy metals in the sediments from different parts of Baiyangdian are presented in Table 3. It can be seen that the concentrations are lower at Sites 5 and 7 than at other sites. The highest metal concentrations in sediment were observed at Site 10, which was next to a village. This indicates that most of the pollution is highly related to human impact, where sewage is discharged or washed into Baiyangdian by runoff. Besides the large amount of waste water, sampling Site 10 was on a narrow river way. The particles settle in the river when the river widens out and the water velocity is reduced. This increases the heavy metal pollution downstream of the living area.

### Comparison of heavy metal concentrations from Baiyangdian with other water bodies around the world

Compared to other rivers, lakes, lagoons, creeks, bays, gulfs, wetlands, and seas around the world (Table 4), the

concentrations of the seven metals found in the sediment of Baiyangdian were lower. The reason for this is probably that Baiyangdian has only recently undergone industrial development and was previously dominated by agriculture and fisheries. Recent pollution probably owes its existence to the upstream factories. Compared to other regions that have had industries for longer time spans, Baiyangdian is not heavily polluted. But this fact also underlines the need to pay much attention to heavy metals control in the coming years. Thus, more effective management of heavy metals discharges should be encouraged in order to preserve this watershed at its present level in order to preserve the biological integrity of this valuable natural habitat.

### Assessment of the heavy metal pollution in Baiyangdian using the Environmental Quality Standard for Soils in China

When compared with the grading defined in Table 2 it shows that the Cd concentrations were in the second grade in Site 1 and Site 8 and in the third grade that in Site 10. Zn was in the second grade in Site 10 and all these heavy metals were under the value for natural background. Cd found in the middle of the wetland was above the limit value that indicates 'natural background' but it would be safe for human health and farming would be possible. Cd and Zn in Site 10 were unsafe for agriculture and growth of vegetables. From the profile of Baiyangdian and the sites' locations in Fig. 2, it can be seen that the most polluted place is the one near to the village situated close to Site 10. The Cd content shows a tendency to decrease along the water flow being highest upstream, thus concentrating the heavy metals upstream so they are not yet disseminated to the whole wetland. In addition to the Cd pollution, Site 10 also showed a value for Zn (100 mg/kg) that was higher than the natural background value.

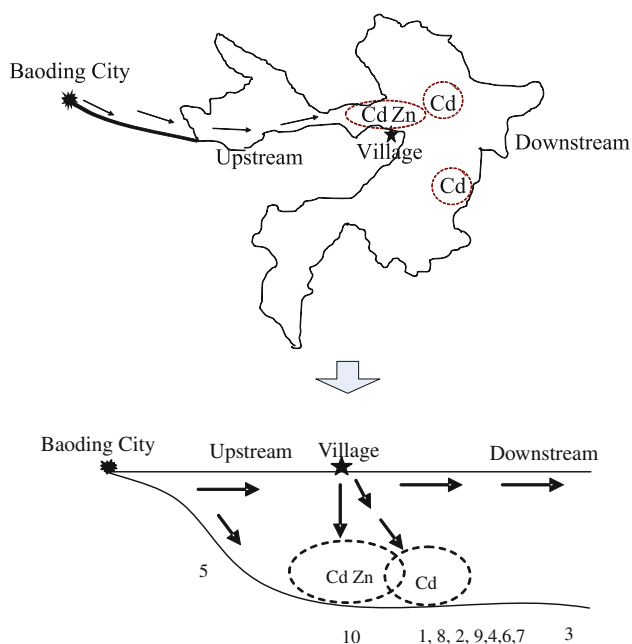
### Assessment of the heavy metal pollution in Baiyangdian by using the NYSDEC (1999) guideline

Assessment result of the heavy metal pollution in Baiyangdian using the NYSDEC method is shown in Fig. 3. The most polluting heavy metal is now arsenic (As). Total As concentration was lower than LEL only in Site 7 (4.7 mg/kg); in all other sampling sites, concentrations were higher than LEL. For all sites the concentrations of As were lower than SEL, which indicates that the sediment has been impacted by human activities but not yet severely contaminated. The tendency is for the As concentration to decrease with distance from Site 4. Therefore Site 4 is the centre of As contamination. The main contamination of heavy metals assessed by NYSDEC is shown in Fig. 4.

**Table 4** Maximum As, Hg, Cr, Cd, Pb, Cu, and Zn in sediments of Baiyangdian and other water bodies around the world

Site	Maximum concentration(mg/kg)							Reference
	As	Hg	Cr	Cd	Pb	Cu	Zn	
<b>Domestic</b>								
1. Baiyangdian, China	24.8	0.06	84	0.90	30	35	112	This study
2. Luan River, China	12.90	1.39	152.73	0.37	38.29	178.61	25.66	Liu et al. (2009b)
3. Hengshuihu Wetland, China	51.30	0.21	85.98	0.023	38.90	41.72	270.3	Zhang et al. (2009)
4. Yellow River, China	50.0	–	130.0	–	80.0	110.0	210.0	Liu et al. (2009a)
5. Moshui Lake, China	–	–	1,779.00	–	220.00	1,249.00	1,337.00	Liu et al. (2008)
6. Yangtze River, China	29.90	1.43	205.00	3.40	98.00	129.00	1,142.00	Yang et al. (2009)
7. Huaihe River, China	–	–	73.70	0.33	113.00	54.60	83.10	Zhang and Shan (2008)
8. Taihu Lake, China	–	–	–	–	35.17	20.33	26.77	Shen et al. (2007)
<b>Overseas</b>								
9. Mississippi River, US	–	0.7	50.0	8.0	67.0	–	–	Balogh et al. (2009)
10. Southern Baltic sea	–	–	58.7	2.19	55.9	34.8	190.0	Szefer et al. (1996)
11. Thermaikos Gulf, N. Greece	–	–	172	–	218	165	358	Christophoridis et al. (2009)
12. Vembanad Wetland, India	–	–	2.36	0.73	54.42	49.43	211.3	Harikumar et al. (2009)
13. Izmit Bay, Turkey	26.8	–	116.1	8.9	178	139.0	1190	Pekey (2006)
14. French Guiana	–	0.514	72.8	–	55.89	39.04	386.1	Calculated from Marchand et al. (2006)
15. Gulf of Lions, Mediterranean Sea	–	–	117.3	0.82	69.7	45.8	144.9	Roussiez et al. (2006)

Note: All results are given in terms of the dry weight of material analyze



**Fig. 2** The distribution and position of the most important heavy metals in Baiyangdian as described by the EQSS standard

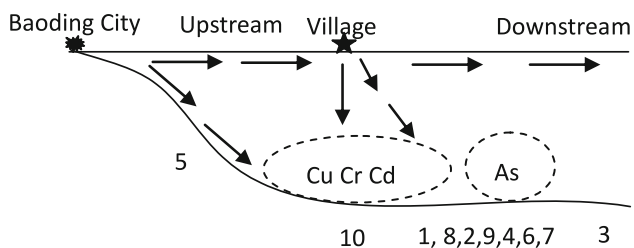
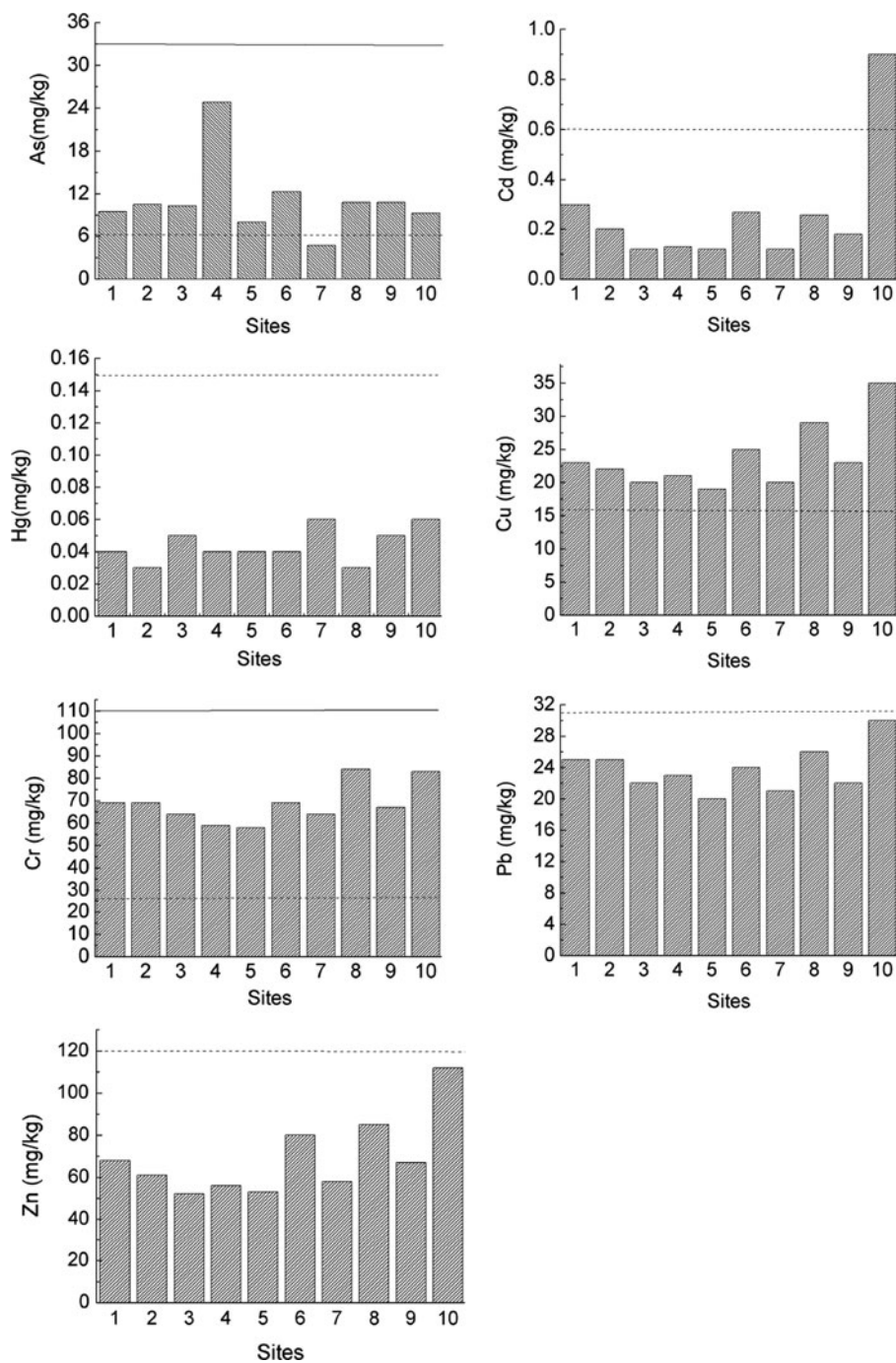
As which was the most polluting heavy metal in Baiyangdian according to the NYSDEC was not revealed by the EQSS. The same basic data thus show different results. This suggests that different pictures are painted of the heavy metal situation with different methods. One method

might conceal what is exposed in another with different benchmarks. Total Hg, Pb, and Zn concentrations were lower than LEL at all sampling sites and could thus be tolerated by the majority of benthic communities. For both Pb and Zn, the highest concentrations were found in Site 10 and this illustrates that the village is the main source of heavy metals. This is consistent with the results shown by EQSS. Total Cr and Cu concentrations were all above LEL and lower than SEL at all sites and indicated that the sediment was contaminated. They also both showed highest concentrations close to the village (Site 10). Total Cd was also above LEL and lower than SEL only at Site 10 and the closest concentrations to those at Site 10 were at Sites 1 and 8. This is also consistent with the results obtained using EQSS.

## Discussion and conclusion

Compared to other rivers, lakes, and marine areas around the world, the concentrations of the seven heavy metals examined in the sediment of Baiyangdian were low. Nevertheless, some of these heavy metals can cause a potential risk depending on the assessment method. When using EQSS to assess the situation in Baiyangdian, it was shown that Cd at some sites constitutes a potential risk. Cd was found to be in the third grade, the most polluting level, near the village of Site 10, but in the second grade at some

**Fig. 3** Assessment results using the NYSDEC guideline (*dash* is LEL and *dot* line is SEL)



**Fig. 4** The distribution of the most important heavy metals in Baiyangdian using the NYSDEC methodology

distance from the village, although it had not yet been disseminated to the whole wetland. The village was also the most polluted site with regard to Zn, which was found to be in the second grade.

When assessed by NYSDEC method, it was shown that Cu, Cr, and As were found in moderate concentrations (above LEL but under SEL), while Pb, Hg, and Zn were found at tolerable levels throughout the Baiyangdian. Only at one point was Cd found to be above the LEL; this was near the village of Nanliuzhuang (Site 10). The centre of Cu and

Cr contamination was also near the village. According to this method, As is the most polluting among the seven heavy metals (but still below SEL levels), with a major occurrence in the middle of the wetland. There were no heavy metals creating severe disturbance to the benthic communities according to the definition of the methodology.

From the methodological perspective it was found that the three different methods delivered different results. With all three methods, it is an obvious conclusion that Baiyangdian is not heavily polluted. However, the first comparison could give a crude idea of the whole contamination level, clearly showing that Baiyangdian is less polluted compared with many other water bodies. The second method, EQSS, was initially established to compare heavy metals from different soil types and land uses in order to make sure that the concentration of heavy metals could not jeopardize the environment, the farmland, and especially the growing of vegetables. This method showed that only Cd was a potential risk. In contrast, the third method, from NYSDEC, was established on the basis of assessing potential chronic, long-term impacts of contamination to benthic organisms with a clear focus on the ecological risk. This method showed that especially As is a problem, but many of the other heavy metals were also above the lower level (LEL), thus causing a moderate risk to the ecosystem.

From the perspective of distribution, the influence of heavy metals to the different soil types was shown as 'point pollution'. However the ecological risk to the benthic communities spread to the whole water body. When looking at specific metals, Cd and Zn were the first influence to different soil types but Cu, As and Cr were the main contributors to threaten the benthic communities. This means land use for humans react differently to the benthic communities. For example, in Site 1 and 8, there were no disturbances to the benthic communities, but it was unsafe for agriculture, human health and vegetables. This could also imply the soil type for agriculture; human health and vegetables had less tolerance than the benthic communities.

The NYSDEC method should of course be favored in an overall assessment of Baiyangdian as it concentrates on potential risk for benthic communities. The conclusion drawn on this background is that Baiyangdian is moderately polluted.

The question of why we supplement the NYSDEC methodology with two others remains. The results presented clearly show that they also validate the fact that Baiyangdian is fairly unpolluted, but they add new dimensions to the picture regarding which heavy metals are the worst in this case, as it points to Cd. Though there are many research studies on developing sediment guidelines and quality criteria for heavy metals in China (Dong and Chen 1997; Chen et al. 2001), no specific guidelines for

heavy metals in sediment have been issued. There are normally two kinds of quality criteria (Wang and Chen 2003). One is an empirical method which is based on the biological effects database for sediment. Countries such as Canada, Florida in America, Australia, New Zealand and Hong Kong adopted it. The other is an equilibrium partitioning approach which was being used by the Netherlands and England. Some countries use water quality criteria for sediment (Wang and Chen 2003). In China some research studies choose the soil standard EQSS (Liu et al. 2009b; Hua 2006; Li et al. 2007) as applied in this study.

This investigation clearly demonstrates that this standard should be supplemented with others like the NYSDEC. The NYSDEC or other more advanced risk based methods should always be used as long as a specific Chinese standard covering more specific sediments is not developed. In this investigation the EQSS contributed knowledge of the risk of other heavy metals but also confirmed the spatial distribution of the risk, thus validating the overall picture of the pollution by heavy metals in Baiyangdian.

Thus it is strongly recommended that NYSDEC methodology should be used as it gives a more precise picture of the potential risk facing the benthic communities. In that case, is there any benefit from using the two other methods? The answer is yes, there is in the sense that they give a complementary picture, not least of when it comes to identifying where in the Baiyangdian the pollution is worst. All three methods point to the sediments close to the village of Nanliuzhuang (Site 10) as the most polluted spot. Here it becomes very important, as a uniform picture develops, that management measures should be devoted to solving this local problem near Site 10 and then in general to making sure that the whole of Baiyangdian is protected from heavy metals pollution in the future. This is to make sure that this potentially pristine area can be restored for the enjoyment of future generations.

From the results presented, the whole process of the heavy metals transfer may also be deduced: most of the heavy metals come from the city situated in the upper wetland and are carried by the water flow into Baiyangdian. They are deposited in the middle of the Baiyangdian because of the slowing down of the water velocity and the lower terrain. This heavy metal flow together with the contribution from the villages into Baiyangdian is partly deposited but also becomes a source for the downstream part of the lake. No matter where the heavy metals come from, whether from the cities in the upper part of the wetland or from the villages in the middle of the area, human impacts are the cause of the disturbance to the ecosystem.

However, this research is only based on the total concentration of metals. The toxic effect of heavy metals is



determined by various conditions and a decrease in the stable fraction could result in increasing the mobile fraction. Thus the bioavailability analysis which could provide a meaningful insight to the ecological risk of the metals is needed in the future research.

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