Study on heavy metal levels and its health risk assessment in some edible fishes from Nansi Lake, China

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Abstract Eight heavy metals, namely Cu, Zn, Fe, Mn, Cd, Ni, Pb, and As in the muscles of nine fish species collected from Nansi Lake, China. were determined, and the potential health risks to local residents via consumption of the fishes were estimated. The results of two-way ANOVA that showed the concentrations of heavy metals in the investigated fish samples were influenced significantly by fish species and sampling sites. Correlation analysis indicated that sampling sites had significant effects on the levels of correlation coefficients among different heavy metal concentrations. Interestingly, although none of the hazard quotient (HQ) values of any individual element was greater than 1 for the investigated exposure population through fish consumption, the hazard index (HI) values were more than 1 for local fishermen, suggesting that local fishermen may be experiencing some adverse health effects. Among the investigated nine fish species, *Cyprinus carpio* had the highest HQ and HI. As, Pb, and Cd were the most concerning heavy metals in the investigated fish samples due to their higher relative contributions to the HI values.

Keywords Fish · Heavy metals · Health risk · Nansi Lake

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Introduction

Fish is widely consumed by humans in the world due to their high protein supply and omega-3 fatty acids that help reduce the risk of certain types of cancer and cardiovascular diseases (Storelli 2008). However, fish has been reported to accumulate large amounts of some metals and is often at the top of the aquatic food chain (Mansour and Sidky 2002; Tüzen 2003; Bidar et al. 2009). High content of heavy metals leads to severe threat to fish and consequently results the health risks to people associated with fish consumption. On the other hand, fish is often used to monitor heavy metals and the other pollutions of aquatic ecosystems (Dorea 2008; Ahmad and Shuhaimi-Othman 2010; Rahman et al. 2012). The concentrations of heavy metals in the tissues and organs of fishes indicate the concentrations of heavy metals in water and their accumulation in food chains (Pintaeva et al. 2011). So, it is necessary to assess the levels of heavy metals in fishes and to report possible contamination that would represent a health hazard. Lately, numerous investigations and monitoring programs have been carried out on heavy metal concentrations in fishes (Tüzen and Soylak 2007; Uluozlu et al. 2007; Mendil et al. 2005; Reynders et al. 2008; Tüzen 2009; Tüzen et al. 2009; Yi et al. 2011).

Nansi Lake (34° 27′ N–35° 20′ N, 116° 34′ E–117° 21′ E) is the largest fresh water lake in Shandong Province, China with a surface area of 1266 km² and an average water depth of 1.46 m. It is composed of four lakes, namely Nanyang Lake, Dushan Lake, Zhaoyang Lake, and Weishan Lake. Nansi area is one of the most economically developed regions in China and has been polluted significantly by heavy metals originating from

anthropogenic sources, such as electronics, metalwork, and mining industries, putting thousands of people in this area into tremendous health hazard. Previous studies mostly focused on the sediments in Nansi Lake (An and Li 2009; Li et al. 2009; Liu et al. 2010). However, there is a lack of studies regarding metal levels in edible fishes from Nansi Lake and whether these levels represent a human health risk for local residents. Therefore, the objectives of the present study were to determine the concentrations of Cu, Zn, Fe, Mn, Cd, Ni, Pb, and As in the muscles of nine fish species collected from Nansi Lake and estimate the potential health risk of heavy metals to local residents through fish consumption.

Materials and methods

Sampling

A total of 288 fish samples belonging to ten fish species were collected from four lakes, Nanyang Lake, Dushan Lake, Zhaoyang Lake, and Weishan Lake (Fig. 1) during four seasons, from the spring to the winter of 2012. The species were *Ophiocephalus argus*, *Carassius auratus*, *Pseudobagrus fulvidraco*, *Parabramis pekinensis*, *Atractoscion nobilis*, *Ctenopharyngodon idellus*, *Scomberomorus niphonius*, *Silurus asotus*, and *Cyprinus carpio*. The fish samples collected were washed with clean water at the point of collection, separated by species, placed on ice, brought to the laboratory on the same day, and then frozen at −20 °C until dissection.

Sample preparation

Frozen fish samples were thawed at room temperature and dissected using stainless steel scalpels. One gram of accurately weighed epaxial muscle was dissected. One gram of accurately weighed epaxial muscle from each sample was dissected for analysis. They were washed with distilled water, dried in filter paper, weighed, packed in polyethylene bags, and stored at −20 °C until analysis.

Reagents and apparatus

All reagents were of analytical reagent grade unless otherwise stated. HNO_3 and H_2O_2 were of suprapure quality (Merck, Germany). Double deionized water

(Milli-Q Millipore; 18.2 M cm^{-1}) was used for all dilutions. The element standard solutions were prepared by dilution of 1000 mg l^{-1} certified standard solutions (Nssrc, China). XT-9912 model microwave system (Xintuo, China) equipped with advanced composite PTFE vessels was used for digestion of the samples. A Perkin Elmer Analyst 700 (CT, USA) atomic absorption spectrometer equipped with HGA graphite furnace (GF-AAS) was used to determine Cd, Ni, Pb, and As. For graphite furnace measurements, argon was used as inert gas. Pyrolytic-coated graphite tubes (Perkin Elmer part no. B3 001264) with a platform were used. Samples were injected into the graphite furnace using Perkin Elmer AS-800 autosampler. Optima 2100 DV model inductively coupled plasma atomic emission spectroscopy (ICP-AES) (PE, USA) was used for simultaneous multielement detection of Cu, Zn, Fe, and Mn. Detection limit values of elements as milligram per liter were found to be 0.018 for Cu, 0.010 for Zn, 0.016 for Fe, 0.020 for Mn, 0.09 for Cd, 0.35 for Ni, 0.18 for Pb, and 0.17 for As in this study. The operating conditions of ICP-AES and GF-AAS were listed in Table 1.

Microwave digestion

One gram muscle sample was digested with 5 ml of 65 % HNO_3 and 2 ml of 30 % H_2O_2 in microwave digestion system and finally diluted to 10 ml with double deionized water. A blank digest was carried out in the same way. All sample solutions were clear. Digestion conditions for microwave system were applied as 3 min for 400 W, 5 min for 600 W, 8 min for 900 W, 8 min for 1000 W, vent 8 min, respectively.

Quality assurance

All glasswares and equipments were carefully cleaned starting with 2 % HNO_3 and ending with repeated rinsing distilled deionized water to prevent contamination. Reagent blank determinations were used to correct the instrument readings. Detection limit is defined as the concentration corresponding to three times the standard deviation of ten blanks. Certified reference material (DORM-2 dogfish muscle) were used for accuracy evaluation, and the recovered values were given in Table 2.
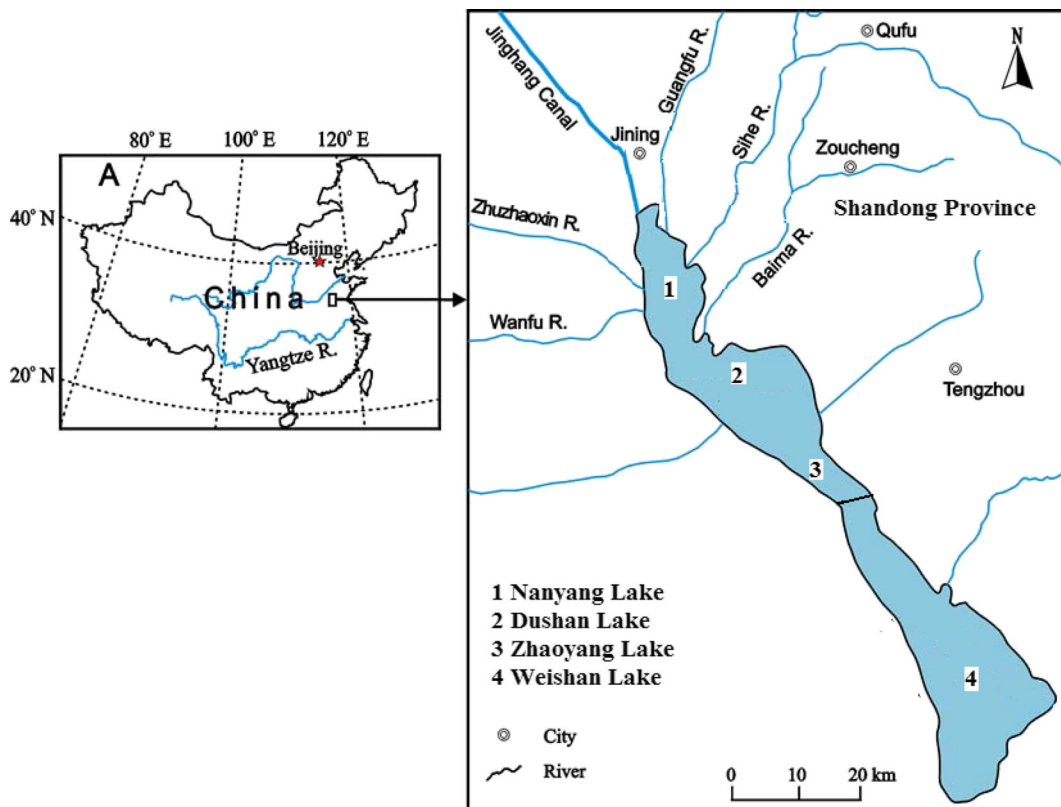
Fig. 1 Locating map of the study area (Nansi Lake, Shandong Province, China)

Risk assessment

A potential non-cancer risk for individual heavy metals is expressed as the hazard quotient (HQ) (US EPA 1992, 1999) and can be calculated as follows:

$$HQ = \frac{ADD}{RfD} \tag{1}$$

$$ADD = \frac{C \times IR}{BW} \tag{2}$$

where RfD is the daily intake reference dose ($\mu g\ kg^{-1}\ day^{-1}$); ADD is the average daily intake of heavy metals ($\mu g\ kg^{-1}\ day^{-1}$); C is the mean concentrations of heavy metals in fish ($\mu g\ kg^{-1}$); IR is the consumption rate of fish ($g\ person^{-1}\ day^{-1}$); and BW is the average adult body weight (kg). The RfD values were 40, 300, 700, 240, 1, 20, and 0.3 $\mu g\ kg^{-1}\ day^{-1}$ for copper, zinc, iron, manganese, cadmium, nickel, and arsenic, respectively (US EPA 2007). Because the RfD for Pb was not available, we used JECFA 3.57 $\mu g\ kg\ day^{-1}$ (JECFA 2003). If the HQ exceeds 1,

there may be concern for potential non-cancer effects. As a rule, the greater the value of HQ above 1, the higher the level of concern.

A hazard index (HI) approach was used to assess the overall potential non-carcinogenic health risk posed by more than one heavy metal. The HI is equal to the sum of the HQs, as described in Eq. (3) (US EPA 1989).

$$HI = HQ_1 + HQ_2 + \ldots + HQ_n \tag{3}$$

Statistical analysis

Two-way analysis of variance (ANOVA) was employed to test whether varied significantly between the heavy metal concentrations and three factors (species, sites, and seasons). The significance level was set at 0.05. Person correlation analysis was adopted to examine the inter-relationships among the investigated heavy metal concentrations in the fish samples. Data calculation and statistical analysis were performed with EXCEL and SPSS 19.0.

Table 1 The operating conditions of ICP-AES and GF-AAS

Conditions for ICP-AES				
RF power (W)	1200			
Auxiliary gas (ml min^{-1})	0.6			
Coolant gas (ml min^{-1})	18			
Nebulizer gas (ml min^{-1})	0.8			
Sample uptake (ml min^{-1})	1.5			
Torch	Axial			
Elements	Cu	Zn	Fe	Mn
Wavelength (nm)	327.4	206.2	238.2	257.6
Conditions for GF-AAS				
Elements	Cd	Ni	Pb	As
Wavelength (nm)	228.7	231.9	283.1	193.5
Argon flow (ml min^{-1})	250	250	250	250
Sample volume (μl)	20	20	20	20
Modifier (μl)	10	5	5	5
Drying 1	120 (5, 20)	100 (5, 20)	100 (5, 20)	100 (5, 20)
Drying 2	140 (15, 15)	140 (15, 15)	140 (15, 15)	140 (15, 15)
Ashing	800 (10, 20)	1000 (10, 20)	800 (10, 20)	1300 (10, 20)
Atomization	1800 (0, 5)	2200 (0, 5)	2000 (0, 5)	2200 (0, 5)
Cleaning	2500 (1, 3)	2500 (1, 3)	2500 (1, 3)	2500 (1, 3)

Results and discussion

The concentrations of heavy metals in fish

The concentrations of heavy metals in the studied nine fish species were given in Table 3. All metal concentrations were determined on a wet weight basis. The concentrations of copper, zinc, iron, manganese, cadmium, nickel, lead, and arsenic in fish samples were found to be 1.47–5.67, 11.43–28.23, 8.73–35.81, 1.48–4.62, 0.12–0.35, 0.84–3.12, 0.28–0.65, and 0.05–0.10 μg g^{-1}, respectively. Among all determined heavy metals, iron was found to be the dominant elemental ion followed by zinc and copper.

There was a great variation in zinc concentrations among the investigated fish muscles. Fishes are known to have a high threshold level of zinc. The minimum and maximum lead levels observed were 11.43 μg g^{-1} in *A. nobilis* and 28.23 μg g^{-1} in *C. auratus*. Zinc is known to be involved in most metabolic pathways in humans, and zinc deficiency can lead to loss of appetite, growth retardation, skin changes, and immunological abnormalities. The concentrations of zinc in all the fish samples were found to be lower than the standard of 30 μg g^{-1} (FAO 1983) and 50 μg g^{-1} (MAFF 1995).

Iron was found to be the dominant element as compared with other heavy metals in fish samples. The iron contents in the investigated fish samples ranged from 8.73 to 35.81 μg g^{-1}. *C. auratus* had the highest iron concentration whereas *P. fulvidraco* had the lowest. Iron is vital for almost all living organisms, participating in a wide variety of metabolic processes, such as oxygen transport, DNA synthesis, and electron transport. The

Table 2 Heavy metal concentrations in certified reference material (DORM-2 dogfish muscle) ($n=3$)

Element	Certified value (μg g^{-1})	Our value (μg g^{-1})	Recovery (%)
Cu	2.34±0.16	2.28±0.15	97
Zn	25.6±2.3	25.1±1.2	98
Fe	142±10	144±5.2	101
Mn	3.66±0.34	3.61±0.19	99
Cd	0.043±0.008	0.044±0.008	102
Ni	19.4±3.1	18.9±1.5	97
Pb	0.065±0.007	0.066±0.004	102
As	18±1.1	17.7±1.0	98

RDA of iron for 7–12 months infants and 51–70 years adults is 11 and 8 mg day^{-1}, respectively (Ikem and Egiebor 2005).

Copper is an essential part of several enzymes and is necessary for the synthesis of hemoglobin (Sivaperumal et al. 2007). However, high intake of Cu has been recognized to cause adverse health problem (Gorell et al. 1997). The lowest and highest Cu levels in fish species were found as 1.47 µg g^{-1} in *O. argus* and 5.67 µg g^{-1} in *A. nobilis*. The maximum copper level permitted is 30 µg g^{-1} (wet weight) for FAO (1983) and 20 µg g^{-1} for WHO (1996). The Australian Food Standard Code established the maximum concentration for Cu at 10 µg g^{-1} (wet weight) (Alam et al. 2002). The copper levels in analyzed fish samples were found to be lower than these limits.

Manganese, one of the essential trace elements, is a structure component of some enzymes and activates the actions of some enzymes. The deficiency of manganese can produce severe skeletal and reproductive abnormalities in mammals. High doses of manganese produce adverse effects primarily on the lungs and brain. In this study, the lowest iron content was 1.48 µg g^{-1}, for *C. auratus*, whereas the highest was 4.62 µg g^{-1}, for *C. carpio*. The US National Academy of Science recommends 2.5–5 mg manganese per day (National Academy of Sciences 1980), and the World Health Organization recommended 2–9 mg per day for an adult (WHO 1994).

In the present investigation, the lowest concentration of nickel was found in *C. auratus* (0.82 µg g^{-1}) and the highest in *C. idellus* (3.12 µg g^{-1}). Nickel normally occurs at very low levels in the environment, and it can cause variety of pulmonary adverse health effects, such as lung inflammation, fibrosis, emphysema, and tumors (Forti et al. 2011). The WHO recommends 100–300 µg nickel for daily intake (WHO 1994).

Cadmium is not a part of natural biochemical processes and is extremely hazardous. The cadmium concentrations were found in the range of 0.12–0.35 µg g^{-1}. *O. argus* had the lowest lead concentration whereas *C. carpio* had the highest. The concentrations of cadmium in all fish samples were far below the Western Australian authorities' proposed level of 5.5 µg g^{-1} (Plaskett and Potter 1979). But, the cadmium levels in some fish samples were higher than the standard of 2.0 µg g^{-1} (FAO 1983) and 50 µg g^{-1} (MAFF 1995).

The minimum and maximum lead levels observed were 0.28 µg g^{-1} in *S. asotus* and 0.65 µg g^{-1} in *O. argus*. Lead is similar to cadmium that has no beneficial role in human metabolism, producing progressive toxicity. Lead creates health disorders such as sleeplessness, tiredness, and hear and weight loss. The maximum permitted lead level is 2.0 µg g^{-1} set by MAFF (1995) and WHO (1996). The maximum permitted concentration of Pb proposed by Australian National Health and Medical Research Council is 2.0 µg g^{-1} (wet weight) (Plaskett and Potter 1979). The lead levels in the investigated fish samples were found to be lower than the standard.

Inorganic arsenic is considered to be the most toxic to human health. Arsenic at low doses over a long period of time is known to cause skin changes that may lead to skin cancer. The lowest and highest arsenic content in fish species were found as 0.05 µg g^{-1} in *S. niphonius* and 0.10 µg g^{-1} in *P. fulvidraco*. The maximum arsenic level permitted for fishes is 1.0 µg g^{-1} according to Australia standard (Australia New Zealand Food Authority 1998). US Environmental Protection Agency (EPA) has set arsenic tissue residues of 1.3 µg g^{-1} in freshwater fish (wet weight) as the criterion for human health protection (Burger and Gochfeld 2005). The arsenic concentrations in the studied fish samples were far below these standards.

Two-way ANOVA analysis

The results of two-way ANOVA presented in Table 3 indicating the concentrations of each heavy metal in the investigated fish samples changed significantly among different fish species. This might be a result of different ecological needs, metabolism, and feeding patterns for different species. The results clearly showed that sites had significant effects on the levels of Zn, Cd, Ni, Pb, and As in fish samples. Season variation, however, did not bring out significant content changes of heavy metals except Cu and Cd. The effects of the interaction between species and sites suggested that the significant variations were only found in Fe and Pb concentrations. It is also observed that only Cu level was influenced significantly by interaction of species×seasons. On the whole, the concentrations of heavy metals in the investigated fish samples were mainly influenced by fish species and sites. The fishes collected from Nanyang Lake had the highest concentrations of Cu, Fe, Mn, Cd, Pb, and As, while fishes from Weishan Lake had the lowest concentrations of Zn, Fe, Mn, Ni, Cd, Pb, and As. The metal contents in fishes of other two lakes were

Table 3 Heavy metal concentrations in fish samples ($\mu g\ g^{-1}$)

Element		Species									ANOVA	
		C. auratus	P. fulvidraco	O. argus	P. pekinensis	C. carpio	C. idellus	S. asotus	S. niphonius	A. nobilis	Factor	p value
Zn	Average	28.23±1.41	13.35±1.16	12.61±0.87	11.54±0.82	21.78±1.35	15.88±1.23	25.49±1.57	15.92±1.21	11.43±0.85	Specie	5.88E-46
	Range	22.66–35.17	11.83–17.25	7.41–18.58	6.82–14.19	18.44–27.61	9.57–17.62	19.35–28.26	13.51–18.39	9.75–15.53	Site	0.021
											Season	0.004
											Specie×site	0.227
											Specie×season	0.415
Fe	Average	35.81±1.74	8.73±0.68	19.56±1.33	31.62±2.15	28.35±1.74	16.52±1.16	25.31±1.53	28.12±1.83	16.46±1.17	Specie	1.16E-61
	Range	31.26–37.83	6.52–9.94	15.71–21.85	28.37–36.43	24.16–29.62	15.28–19.81	18.44–28.71	26.54–34.39	11.83–18.56	Site	0.851
											Season	0.527
											Specie×site	0.005
											Specie×season	0.449
Cu	Average	2.64±0.18	3.31±0.21	1.47±0.11	4.35±0.27	5.56±0.28	2.26±0.18	1.58±0.13	3.46±0.25	5.67±0.38	Specie	3.69E-54
	Range	1.93–2.86	2.54–3.75	0.97–1.93	3.58–4.86	4.37–6.91	1.75–2.82	1.14–1.88	2.72–3.97	4.34–6.51	Site	0.191
											Season	0.038
											Specie×site	0.951
											Specie×season	0.028
Mn	Average	1.48±0.11	1.77±0.15	2.81±0.23	2.86±0.23	4.62±0.31	2.73±0.22	3.55±0.28	3.21±0.26	1.96±0.15	Specie	1.71E-60
	Range	1.15–1.93	1.46–2.54	2.27–3.38	2.45–3.14	4.11–5.52	2.28–3.48	2.89–4.34	2.64–3.78	1.68–2.47	Site	0.247
											Season	0.363
											Specie×site	0.024
											Specie×season	0.241
Cd	Average	0.23±0.02	0.19±0.02	0.12±0.01	0.28±0.02	0.35±0.03	0.17±0.01	0.21±0.02	0.31±0.03	0.18±0.02	Specie	2.18E-45
	Range	0.15–0.27	0.14–0.23	0.06–0.15	0.22–0.37	0.28–0.41	0.13–0.24	0.15–0.28	0.24–0.36	0.13–0.23	Site	0.005
											Season	0.068
											Specie×site	0.605
											Specie×season	0.956
Ni	Average	0.84±0.06	1.28±0.09	2.65±0.17	1.81±0.12	2.76±0.17	3.12±0.19	1.63±0.10	2.06±0.14	1.14±0.09	Specie	2.83E-68
	Range	0.62–0.97	0.93–1.46	2.13–2.95	1.44–2.38	2.17–3.28	2.75–3.46	1.28–1.89	1.51–2.53	0.83–1.47	Site	0.001
											Season	0.453
											Specie×site	0.078
											Specie×season	0.095

Table 3 (continued)

Element	Species	C. auratus	P. fulvidraco	O. argus	P. pekinensis	C. carpio	C. idellus	S. asotus	S. niphonius	A. nobilis	ANOVA Factor	p value
Pb	Average	0.31±0.02	0.46±0.03	0.65±0.05	0.34±0.03	0.42±0.03	0.53±0.04	0.28±0.02	0.37±0.03	0.43±0.03	Specie	5.01E-59
											Site	1.87E-5
											Season	0.950
											Specie×site	0.004
											Specie×season	0.669
	Range	0.24–0.39	0.37–0.51	0.48–0.76	0.25–0.39	0.37–0.51	0.44–0.65	0.21–0.36	0.32–0.47	0.36–0.52		
As	Average	0.08±0.02	0.10±0.02	0.07±0.01	0.08±0.01	0.07±0.01	0.06±0.02	0.08±0.02	0.05±0.01	0.09±0.02	Specie	6.57E-56
											Site	0.008
											Season	0.062
											Specie×site	0.816
											Specie×season	0.825
	Range	0.05–0.11	0.07–0.12	0.04–0.12	0.05–0.12	0.05–0.09	0.04–0.10	0.06–0.11	0.03–0.09	0.07–0.13		

found in between. This might suggest that heavy metal pollution in Nanyang Lake was more serious than the other three lakes. The previous study showed that the concentrations of heavy metals in fishes were seriously affected by river input to the lake (Yu et al. 2012). In fact, the Nanyang Lake receives a large amount of wastewater containing heavy metals as several main river branches flow across the important industrial cities such as Jining, Yunzhou, and Hezhe, resulting the increase of heavy metal concentrations in the water and sediment environment of Nanyang Lake. Consequently, the metal concentrations in fishes living in this lake area increase.

Correlation analysis

Inter-element relationships can provide important information on the sources and pathways of the heavy metals. The correlation coefficients between different heavy metal concentrations in the investigated fish samples were given in Table 4. The results clearly showed that correlation coefficients were influenced significantly by the sampling sites. For Nanyang Lake, there were good correlations between Cu and Zn, Fe and Cd, Fe and Pb, and Ni and As for the investigated fish species. For Dushan Lake, significant correlations were found between Fe and Cd, Mn and Ni, As and Ni, and As and Pb. For Zhaoyang Lake, between Zn and Mn, Fe and Mn, Fe and Cd, Fe and Pb, Mn and Cd, Mn and Pb, and Cd and Pb were found to have significant correlations. For Weishan Lake, Cu–Pb, Mn–Pb, Cd–Pb, and Ni–As were significantly correlated. These significant correlations might indicate that the distributions of these pairs of metals were regulated by common local inputs and similar dispersion processes in the study area.

Comparison of metal levels in fish from Nansi Lake with reported values

In order to determine the degree of contamination in the studied area, the concentrations of heavy metals in the investigated fish samples collected from Nansi Lake were compared with the reported values in other lakes (Table 5). Reported results in the literatures showed that metal concentrations in the fish muscles varied widely depending on where and which species were caught. Considering the conversion factor 4.8 from wet weight to dry weight, the heavy metal levels in fish from Nansi

Table 4 Correlation coefficients between different heavy metals in the fish samples from different sampling sites

Nanyang Lake

	Zn	Fe	Cu	Mn	Cd	Ni	Pb	As
Zn	1							
Fe	0.032	1						
Cu	0.912**	0.166	1					
Mn	0.166	0.111	0.166	1				
Cd	0.595	0.685*	0.595	0.093	1			
Ni	−0.050	−0.095	−0.048	0.400	0.033	1		
Pb	−0.120	−0.668*	−0.119	0.006	−0.585	0.605	1	
As	−0.061	−0.399	−0.059	0.246	−0.186	0.733*	0.544	1

Dushan Lake

	Zn	Fe	Cu	Mn	Cd	Ni	Pb	As
Zn	1							
Fe	0.355	1						
Cu	−0.171	0.124	1					
Mn	0.202	0.509	0.144	1				
Cd	0.083	0.737*	0.584	0.491	1			
Ni	−0.169	0.163	−0.086	0.812**	0.233	1		
Pb	−0.471	−0.599	−0.144	0.09	−0.481	0.489	1	
As	0.036	−0.428	−0.181	0.441	−0.363	0.674*	0.691*	1

Zhaoyang Lake

	Zn	Fe	Cu	Mn	Cd	Ni	Pb	As
Zn	1							
Fe	0.432	1						
Cu	0.070	0.246	1					
Mn	0.852**	0.671*	0.174	1				
Cd	0.618	0.857**	0.506	0.791*	1			
Ni	0.210	−0.067	−0.253	0.400	0.086	1		
Pb	0.479	0.813**	0.486	0.782*	0.930**	0.209	1	
As	0.564	0.556	0.213	0.433	0.582	−0.349	0.445	1

Weishan Lake

	Zn	Fe	Cu	Mn	Cd	Ni	Pb	As
Zn	1							
Fe	0.462	1						
Cu	−0.319	0.143	1					
Mn	0.145	0.280	0.096	1				
Cd	0.106	0.604	0.576	0.586	1			
Ni	−0.365	−0.145	−0.249	0.523	0.005	1		
Pb	−0.299	0.189	0.693*	0.745*	0.834**	0.464	1	
As	−0.028	−0.384	−0.26	0.428	−0.208	0.772*	0.314	1

*Correlation is significant at 0.05 level

**Correlation is significant at 0.01 level

Table 5 Comparison of heavy metal accumulation in fish muscles with the reported values in other lakes ($\mu g\ g^{-1}$)

Sample area	Countries	Unit	Cu	Zn	Fe	Mn	Cd	Ni	Pb	As	References
Nansi Lake	China	ww	1.47–5.67	11.43–28.23	8.73–35.81	1.48–4.62	0.12–0.35	0.84–3.12	0.28–0.65	0.05–0.10	Present study
Taihu Lake	China	dw	0.25–0.97	8.82–17.58			0.08–0.43	0.06–0.18	0.06–0.26		Yu et al. 2012
Taihu Lake	China	dw	14.59–98.08	0.77–2.72		0.32–16.24	0.01–0.05	0.04–1.01	0.02–0.34		Zeng et al. 2012
Taihu Lake	China	dw	1.06–83.88	63.33–367.39			0.47–1.76	1.89–6.35	6.63–27.18	1.04–3.99	Fu et al. 2013
Nam Co Lake	China	ww	2	6.9		0.61	0.025	0.094	0.047		Yang et al. 2007
Yamdro Lake	China	ww	1.1	4.4		0.24	0.024	0.12	0.079		Yang et al. 2007
Macquarie Lake	Australia	dw	0.38–3.16	14.0–75.4			<0.211		<1.036		Roach et al. 2008
Ataturk Dam Lake	Turkey	ww	0.81–2.41		3.64–20.70	0.13–1.76	ND	ND	ND	5.32–17.96	Karadede and Ünlü 2000
Manzala Lake	Egypt	dw	3.430–5.490	12.980–35.450			0.810–1.610		1.410–2.660		Mohamed et al. 2011
George Lake	Uganda	dw	0.2–2.5	8.3–64.4				<2.5			Lwanga et al. 2003
Chascomus Lake	Argentina	dw	0.95–1.35	20.8–23.1	25.5–52.1	0.84–1.58	<0.01	0.84–1.04	0.37–1.3	0.13–0.27	Schenone et al. 2014
Awassa Lake	Ethiopia	ww	0.54–0.65	3.67–5.30			ND	0.002–0.01	0.003–0.004		Yohannes et al. 2013
Tanganyika Lake	Africa	dw	3.6–4.04	16–101		0.59–7.81	0.25–0.38		4.64–5.03		Chale 2002
Šalek Lake	Slovenia	ww		6.71–16.5			<0.01		0.01–0.04	0.02–0.08	Petkovšek et al. 2012
Itezhi-tezhi Lake	Zambia	dw	2–33	21–78				0.28–0.82	0.04–1.36		Nakayama et al. 2010
Kariba Lake											
Plitvice Lakes	Croatia	dw	115	258			10.9		11.7		Vukosav et al. 2010
Budi Lake	Chile	dw		0.48–39.04		0.02–12.17	<0.26		<1.88		Tapia et al. 2012
Rawal Lake	Pakistan	ww	0.199–1.293	8.491–24.23	1.811–9.835	0.487–2.336	0.449–0.745		5.038–8.796		Iqbal and Shah 2014

ww wet weight, *dw* dry weight, *ND* not detectable

Table 6 HQ and HI values for different exposure groups due to consumption of different fish species

Fish species	Exposure group	HQ								HI
		Zn	Fe	Cu	Mn	Cd	Ni	Pb	As	
C. auratus	General population	0.058	0.031	0.040	0.004	0.141	0.026	0.053	0.163	0.516
	Fishermen	0.148	0.080	0.104	0.010	0.361	0.066	0.136	0.418	1.323
P. fulvidraco	General population	0.027	0.008	0.051	0.005	0.116	0.039	0.079	0.204	0.529
	Fishermen	0.070	0.020	0.130	0.012	0.298	0.100	0.202	0.333	1.165
O. argus	General population	0.026	0.017	0.022	0.007	0.073	0.081	0.111	0.143	0.480
	Fishermen	0.066	0.044	0.058	0.018	0.188	0.208	0.286	0.366	1.234
P. pekinensis	General population	0.024	0.028	0.066	0.007	0.171	0.055	0.058	0.163	0.572
	Fishermen	0.060	0.071	0.171	0.019	0.439	0.142	0.149	0.418	1.469
C. carpio	General population	0.044	0.025	0.085	0.012	0.214	0.084	0.072	0.143	0.679
	Fishermen	0.114	0.064	0.218	0.030	0.549	0.216	0.185	0.366	1.742
C. idellus	General population	0.032	0.014	0.035	0.007	0.104	0.095	0.091	0.122	0.500
	Fishermen	0.083	0.037	0.089	0.018	0.267	0.245	0.233	0.314	1.286
S. asotus	General population	0.052	0.022	0.024	0.009	0.128	0.050	0.048	0.163	0.496
	Fishermen	0.133	0.057	0.062	0.023	0.329	0.128	0.123	0.418	1.273
S. niphonius	General population	0.032	0.025	0.053	0.008	0.190	0.063	0.063	0.102	0.536
	Fishermen	0.083	0.063	0.136	0.021	0.486	0.162	0.163	0.261	1.375
A. nobilis	General population	0.023	0.014	0.087	0.005	0.110	0.035	0.074	0.183	0.531
	Fishermen	0.060	0.037	0.222	0.013	0.282	0.089	0.189	0.471	1.350

Lake were mostly in the high levels compared with the other lakes. For all collected fresh water fish species considered collectively, Zn, Mn, and Cd concentrations were around the 90th percentile ($n=15$ for Zn, $n=9$ for Mn, $n=14$ for Cd) and Pb, Cu, and As around the 75th percentile of the collected worldwide results ($n=15$ for Pb, $n=14$ for Cu, $n=4$ for As). Fe and Ni concentrations in fishes from Nansi Lake were found to be higher than the reported values in other lakes. The above results may indicate that Nansi Lake has been suffering more severe pollution.

Potential health risk to local residents via consumption of fish

Fish from Nansi Lake is an important daily food resource for local residents. Therefore, it is necessary to assess the potential health risks caused by the consumption of local fishes. A total of 1450 adult volunteers who have been told the objectives of this study before the face-to-face survey were randomly recruited from local villages in 2012. The results of our questionnaires showed that the average body weight is 62.8 kg, and

the average consumption rates of fresh fish were 38.4 and 98.5 g per day for general population and fishermen, respectively.

The HQ values of individual metal through fish consumption were calculated and listed in Table 6. For different exposure population, HQs of individual metal were all below 1, which means that the daily intake of individual metal through the consumption of fish would be unlikely to cause adverse health effects for local residents. However, for different exposure groups, HQ values exhibited different potential risks. The HQ of every metal for fishermen was higher than for general population, which is a coincidence with those found in previous report (Yu et al. 2012). There was a big discrepancy of HQ among different metals. HQs of As and Cr were the biggest, ranging from 0.102 to 0.471 and 0.073 to 0.549. HQ of Cr was the lowest, having concentrations between 0.004 and 0.030. On the whole, *A. nobilis* had the highest HQs whereas *S. niphonius* had the lowest.

It is very interesting that there is no single metal exposure that exceeds its RfD, but the potential risk due to the combined effects of all heavy metals through

fish consumption is significant for fishermen other than general population. As shown in Table 6, the HI values were observed in the range of 0.480–0.679 for general population, suggesting that general population were not likely to be hurt by heavy metals through fish consumption. However, the HI values ranged from 1.165 to 1.742 for fishermen, indicating that local fishermen may experience some adverse health effects. Generally, *C. carpio* consumption had the highest health risk for the investigated exposure groups, while *P. fulvidraco* consumption had the lowest. The results indicated that the consumption of the fishes from Nanyang Lake had the highest health risk for local residents, while the consumption of the fishes from Weishan Lake had the lowest. The data listed in Table 6 and Fig. 2 showed that As, Pb, and Cd were the key elements contributing to the HI values, and the sum of the three components was more than 50 %, with Cu and Ni being secondary and Zn, Mn, and Fe the least important. High potential risk due to As, Pb, and Cd may be related to wastewater released from metallurgy and chemical plants in this area.

It is worth mentioning that the exposure risk estimates in this study were only for fish, without accounting for any other sources. Many studies showed that human beings are significantly exposed to heavy metals through other foods such as rice, wheat, and vegetable (Zheng et al. 2007; Huang et al. 2008; Hang et al. 2009). If potential health risks of heavy metals through these exposure routs were considered, total heavy metals would be likely to pose higher health risks to local residents.

Conclusions

The heavy metal concentrations found in the fish muscles sampled from Nansi Lake decreased in the order of Fe>Zn>Cu>Mn>Ni>Pb>Cd>As. In general, the levels of Zn, Cu, Ni, Pb, and As in the investigated fish samples were found to be lower than the legal limits. However, the cadmium levels in some fish samples were higher than the standards set by FAO and MAFF. The results of two-way ANOVA showed that the concentrations of heavy metals in the investigated fish samples were affected significantly by fish species and sampling sites. The HQ values for any individual heavy metal were below 1, which means that the daily intake of individual metal through fish consumption would be unlikely to cause health risk for local residents. It should be noted, however, that the aggregate effects of eight heavy metals were more than 1 for local fishermen, indicating that the fishermen were more likely to experience adverse health effects. As, Pb, and Cd are the key elements contributing to the potential health risk of non-carcinogenic effects for general population and fishermen. Furthermore, considerable

Fig. 2 HI values to local residents via consumption of fishes from different lakes. *1* General population, *2* fishermen
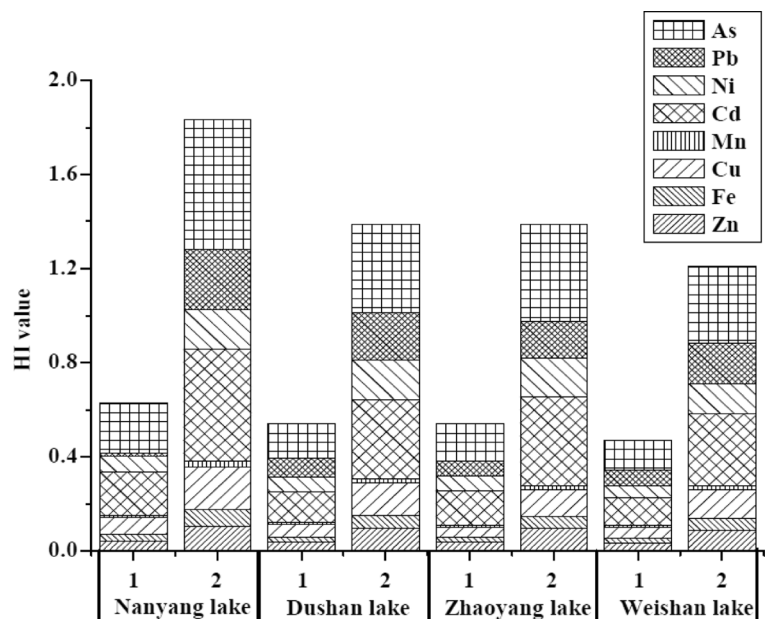
attention should also be paid to the potential health risks of heavy metals through other exposure pathways.

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