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RESEARCH PAPER

Metal Concentrations and Health Risk Assessment in the Muscle of Ten Commercial Fish Species from the Chishui River, China

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Abstract Concentrations of Cu, Zn, Pb, Cd, Fe, Cr, Mn, As, and Hg were analyzed in muscle of ten fish species collected from the Chishui River, China. The results showed that mean concentrations of Cu, Zn, Pb, Cd, Fe, Cr, Mn, As, and Hg in the ten fish species were 0.363 ± 0.106, 8.538 ± 3.877, 0.340 ± 0.233, 0.035 ± 0.036, 8.450 ± 4.959, 0.273 ± 0.088, 0.351 ± 0.110, 0.097 ± 0.035, 0.058 ± 0.033 mg/kg, respectively. There were no identical correlations between metal concentrations and fish length. The target hazard quotient (THQ) and hazard index (HI) exhibited higher potential risks in fishermen than that in general population. Compared with the maximum permissible levels according to China and European Commission, The results of metal concentrations in present study indicated that several kinds of fish from this study area could be not totally safe for human consumption.

Keywords Metal · Fish · Health risk · Chishui River

Introduction

The contamination of metals in aquatic ecosystems by anthropogenic activities such as agriculture, industry, and mining is of global concern in recent decades. It is a serious threat because of their persistence, toxicity, and bioaccumulation in organisms. Metals such as copper, zinc, iron, chromium, and manganese are essential for biological metabolism, whereas lead, cadmium, arsenic, and mercury have no known role in biological systems and can be toxic even at low concentrations (Jiang et al. 2016; Olmedo et al. 2013). The essential elements that exceed certain critical doses can also cause negative effects on aquatic organisms (Mutia et al. 2012). Fish is one of the most suitable indicators for aquatic environmental pollution monitoring (Van Ael et al. 2014). The uptake of metals in fish is directly from the water by gill and skin and indirectly from consuming food and non-edible particles (Hussain et al. 2014). The metals can be bioaccumulated in fish tissues through the food chain. Although the muscle of fish is not an active tissue in accumulating metals compared to other tissues, it could be very high in polluted water. The fish muscle is widely consumed by humans all over the world because it is an important source of protein and omega-3 polyunsaturated fatty acids which are known to contribute to good health (Copat et al. 2012). It could be a potential threat to public health if the metals exceed the permissible level. So, the metal concentrations in fish can be used not only to estimate metals pollution in aquatic ecosystems, but also to evaluate potential risk for human consumption.

The Chishui River is a tributary of the Yangtze River, originates from Wumeng Mountains, extends cross Yunnan, Sichuan, and Guizhou provinces, Southwest of China. It is famous as the “eco-river with a lot of endemic fishes” and “beauty river with natural scenic landscapes” (Qiu and Zhai 2014). It is also the important water source of Chinese famous Maotai liquors (Feng et al. 2016). Being the last undammed first tributary of the upper Yangtze River, the Chishui River is an important protection zone in the National Nature Reserve for rare and endemic fishes of the upper Yangtze River (NNRYR), which is established in 2006 to protect fish resources and aquatic ecological environment

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(Wu et al. 2011). There is potential risk of metal pollution in the Chishui River because of high background value (Chen et al. 1991; Zhang and Wong 2007), laxity in law enforcement, mismanagement, as well as indifferent consciousness to environment. A large number of people who living in the cities of Chishui River basin like consuming wild fish more than cultured fish because they think the wild fish are more delicious, uncommon, nutritious, and healthy. According to scientific investigation report on national natrue reserve for the rare and endemic fishes in the upper reaches of the Yangtze River (Pressed in Chinese), the annual catch of wild fish from the Chishui River was about 2.1 × 10^5 kg. However, there have been no reports on metal concentrations in commercial fishes from the Chishui River and whether these metals can cause human health risks for local residents. Therefore, the aims of the present study were to determine the concentrations of Cu, Zn, Pb, Cd, Fe, Cr, Mn, As, and Hg in the muscles of ten main economic and dominant fish species collected from the Chishui River and to assess the potential public health risks associated with consuming fish.

Materials and Methods

A total of 161 samples of ten fish species were collected with the help of local professional fisherman from the Chishui River in southwest of China during 2015–2016 (Fig. 1). All the fish samples were measured to the nearest 0.1 cm and weighed to the nearest 0.1 g (Table 1). Accurate weighed samples (0.50–0.80 g) of muscle were taken from each fish and stored in glass vials at −20 °C prior to analysis. Each sample was pre-digested overnight with 4 mL of digestion solution HNO_3-$HClO_4$ (9:1 v/v), then transferred in Teflon digestion vessel and rinsed the glass vial with 6 mL HNO_3. The digestion vessels with mixture were put into a microwave digestion system and set the temperature control procedure as follows: 10 min at 800 W, 5 min at 900 W, 5 min at 1000 W. After cooling and transfer into a 25 mL glass tube and rinsing with ultra pure water, samples underwent analysis.

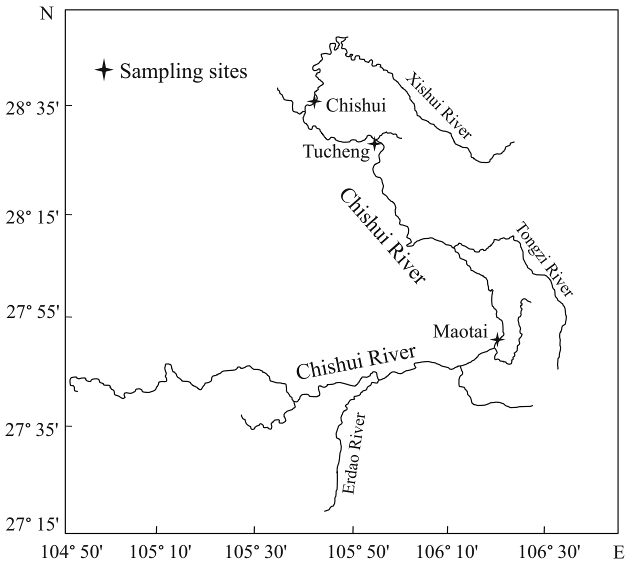

Fig. 1 Map of the sampling sites from the Chishui River

Concentrations of Cu, Zn, Pb, Cd, Fe, Cr, and Mn were carried out by inductively coupled plasma atom emission spectrometry (ICP-AES; Thermo ICAP6300-duo, USA). The concentrations of As and Hg were measured by the KCHG AFS-230E atomic fluorophotometer. The detection limits for Cu, Zn, Pb, Cd, Fe, Cr, Mn, As, and Hg were 2, 0.6, 4, 0.5, 2, 2, 0.5, 0.3, and 0.04 µg/L, respectively. Percentages of metal recovery based on standard reference material (GBW10050, standard samples of biological constituent, prawn, National Research Center for Certified Reference Materials of China) for samples were range from 94.3 to 105.8%. The blank and spiked fish samples were treated in triplicate using the same procedure.

The total metal accumulation of each fish species was examined using the metal pollution index (MPI), which was calculated using the following equation:

$$\mathrm{MPI} = (M_1 \times M_2 \times \ldots \times M_n)^{1/n}$$

M_n is the concentration of metal n (mg/kg; wet weight) in a sample.

In order to assess the human health risk from consuming the tested fishes, the target hazard quotient (THQ) and the hazard index (HI) were used in the risk assessment. THQ of metals (Cu, Zn, Pb, Cd, Fe, Cr, Mn, As, and Hg) for fish was calculated by the following equation:

$$\mathrm{THQ} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{FI} \times \mathrm{MC}}{\mathrm{OR_fD} \times \mathrm{BW} \times \mathrm{AT}} \times 10^{-3}$$

EF is exposure frequency (365 days/year); ED is exposure duration (70 years for adults); FI is fish ingestion rate (g/person/day), 11.3 g/person/day for general population, 57.6 g/person/day for fishermen; MC is metal concentration in the muscle of fish (mg/kg, wet weight); $\mathrm{OR_fD}$ is the oral reference dose of the metal of concern (mg/kg/day), the $\mathrm{OR_fD}$ for Cu, Zn, Pb, Cd, Fe, Cr, Mn, As, and Hg were 0.04, 0.3, 0.004, 0.001, 0.7, 0.003, 0.14, 0.0003, and 0.0001 mg/kg/day, respectively (Cui et al. 2015; USEPA 2016); BW is the average adult body weight (60 kg for adults); AT is averaging time for non-carcinogens, set at 70 years × 365 days/year. The hazard index (HI) is then obtained by the sum of THQ for the different metals: $\mathrm{HI} = \mathrm{THQ}_1 + \mathrm{THQ}_2 + \ldots + \mathrm{THQ}_n$. A THQ below 1 means the exposed population is unlikely to experience obvious adverse effects, whereas a THQ above 1 means that adverse health effects might to occur (USEPA 1989).

Table 1 Number, length, and weight ranges of the ten fish species collected from the Chishui River

Fish species	Number	Length ranges (cm)	Weight ranges (g)
Procypris rabaudi	8	21.1–28.6	116.6–279.3
Glyptothorax sinense	11	7.8–12.6	5.2–22.3
Rhinogobio typus	22	11.1–17.5	13.9–54.5
Siniperca chuatsi	23	13.5–20.0	27.1–92.4
Leiocassis longirostris	11	12.6–30.3	19.0–313.2
Pseudobagrus truncatus	18	11.9–21.8	14.2–74.2
Silurus meriaionalis	21	13.9–64.0	15.7–414.6
Spinibarbus sinensis	17	14.4–45.6	40.8–1016.0
Hemibarbus labeo	10	9.8–30.5	8.6–206.3
Pelteobaggrus vachelli	20	8.3–25.2	6.6–165.0

Target cancer risk (TR) was used to indicate the carcinogenic risk. It was calculated by the following equation:

$$\mathrm{TR} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{FI} \times \mathrm{MC} \times \mathrm{CPSo}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-3}$$

where EF, ED, FI, MC, and BW were already explained above. CPSo is the carcinogenic potency slope, oral (mg/kg/day). AT is the averaging time for carcinogens, set at 70 years × 365 days/year. Since Cu, Zn, Pb, Cd, Fe, Cr, Mn, and Hg do not cause any carcinogenic effects as their CPSo have yet not been established (USEPA 2016), TR value for intake of only As was calculated to show the carcinogenic risk.

All statistical calculations were performed using SPSS 19.0 for Windows. One-way analysis of variance (ANOVA) and Duncan's multiple comparison test ($p = 0.05$) were used to access whether metal concentrations varied significantly between fish species when the data distribution normal and homogeneous. The Kruskal–Wallis test followed by stepwise step-down comparisons was used when the data distribution was skewed or not homogeneous. Pearson's correlation coefficient (r) was used to examine the relationship between metal concentrations and fish length. The metal concentrations in fish muscle were expressed as milligrams per kilogram (wet weight), as mean ± standard deviation (SD).

Results and Discussion

The metal concentrations in the muscle of *Procypris rabaudi*, *Glyptothorax sinense*, *Rhinogobio typus*, *Siniperca chuatsi*, *Leiocassis longirostris*, *Pseudobagrus truncates*, *Silurus meriaionalis*, *Spinibarbus sinensis*, *Hemiculter leucisculus*, and *Pelteobaggrus vachelli* are presented in Table 2. The mean concentrations of Cu, Zn, Pb, Cd, Fe, Cr, Mn, As, and Hg in the ten fish species were 0.363 ± 0.106, 8.538 ± 3.877, 0.340 ± 0.233, 0.035 ± 0.036, 8.450 ± 4.959, 0.273 ± 0.088, 0.351 ± 0.110, 0.097 ± 0.035, 0.058 ± 0.033 mg/kg, respectively. The concentrations of Zn and Fe were much higher than other metals in the examined fish species. It followed the decreasing order of $\mathrm{Zn} > \mathrm{Fe} > \mathrm{Cu} > \mathrm{Mn} > \mathrm{Pb} > \mathrm{Cr} > \mathrm{As} > \mathrm{Hg} > \mathrm{Cd}$. The most possible reason for that may be related to different capabilities of metal accumulation, as well as with the background values in the aquatic ecosystems.

A large number of studies have shown that the metal concentrations in fish muscle are significantly correlated with fish species (Monroy et al. 2014). Statistically significant differences ($p < 0.05$) of metal concentrations were found among different fish species (Table 2). Dietary, trophic levels and lifestyle of fish are strongly related to interspecific differences of metal bioaccumulation (Canli and Atli 2003; Giri and Singh 2015). In general, *S. meriaionalis* and *S. chuatsi* are carnivorous fish, while others are omnivorous fish in present study. The highest concentrations of Cd, Cr, and Hg were detected in *S. meriaionalis*. The highest concentration of Pb was detected in *S. chuatsi*. It suggested that metal concentrations in carnivorous fish are higher than those in omnivorous, which in agreement with other studies (Li et al. 2015; Yi and Zhang 2012a). The highest concentrations of Cu, Zn, Fe, and Mn were detected in *G. sinense* which is bottom dweller. The concentrations of Cu, Zn, and Fe in *G. sinense* were significantly higher than those in other fish species ($p < 0.05$). Bottom sediment is a sink and source of metals in water system (Dalman et al. 2006; Liu et al. 2015). So, *G. sinense* could be easily exposed to higher metal concentrations. Higher metal concentrations were also demonstrated in benthic fish species by other studies (Hosseini et al. 2015; Yi et al. 2011). The concentrations of Hg in carnivorous fish (*S. meriaionalis* and *S. chuatsi*) were higher than those in omnivorous fish. The Hg can magnify thought the food web in aquatic ecosystems which results in higher Hg bioaccumulation in carnivorous top predator fish species relative to omnivorous fish species (Li and Xie 2016). The MPI was calculated to compare the total metal

Table 2 Concentrations of Cu, Zn, Pb, Cd, Fe, Cr, Mn, As, and Hg in the muscle of ten fish species from the Chishui River (mg/kg, wet weight, mean ± SD)

	Cu	Zn	Pb	Cd	Fe	Cr	Mn	As	Hg
Procypris rabaudi	0.309 ± 0.110^{c}	5.235 ± 1.141^{d}	0.159 ± 0.077^{c}	$0.013 \pm 0.004^{c,\ d}$	$7.036 \pm 1.346^{b,\ c}$	$0.217 \pm 0.078^{b,\ c}$	$0.359 \pm 0.043^{b,\ c}$	0.123 ± 0.030^{a}	0.032 ± 0.009^{b}
Glyptothorax sinense	0.544 ± 0.086^{a}	15.631 ± 4.941^{a}	$0.280 \pm 0.115^{b,\ c}$	$0.012 \pm 0.006^{c,\ d}$	20.010 ± 7.303^{a}	$0.297 \pm 0.037^{a,\ b}$	0.506 ± 0.115^{a}	$0.089 \pm 0.016^{b,\ c}$	$0.070 \pm 0.018^{a,\ b}$
Rhinogobio typus	0.233 ± 0.041^{d}	7.227 ± 2.589^{c}	0.191 ± 0.112^{c}	0.011 ± 0.013^{d}	5.528 ± 1.619^{d}	0.246 ± 0.056^{b}	$0.431 \pm 0.074^{a,\ b}$	0.097 ± 0.044^{b}	0.035 ± 0.014^{b}
Siniperca chuatsi	0.391 ± 0.105^{b}	$6.079 \pm 0.740^{c,\ d}$	0.592 ± 0.268^{a}	0.055 ± 0.042^{b}	8.359 ± 2.321^{b}	$0.242 \pm 0.067^{b,\ c}$	0.268 ± 0.057^{c}	0.079 ± 0.020^{c}	$0.073 \pm 0.028^{a,\ b}$
Leiocassis longirostris	0.337 ± 0.077^{b}	5.834 ± 2.703^{d}	$0.311 \pm 0.282^{b,\ c}$	0.024 ± 0.029^{c}	$7.855 \pm 3.067^{b,\ c}$	0.323 ± 0.054^{a}	$0.343 \pm 0.099^{b,\ c}$	$0.086 \pm 0.032^{b,\ c}$	$0.061 \pm 0.020^{a,\ b}$
Pseudobagrus truncatus	0.368 ± 0.074^{b}	$8.986 \pm 3.153^{b,\ c}$	$0.288 \pm 0.255^{b,\ c}$	0.023 ± 0.025^{c}	5.697 ± 1.629^{d}	$0.301 \pm 0.052^{a,\ b}$	0.288 ± 0.052^{c}	$0.085 \pm 0.014^{b,\ c}$	0.045 ± 0.029^{b}
Silurus meriaionalis	0.413 ± 0.062^{b}	12.313 ± 2.728^{b}	$0.457 \pm 0.214^{a,\ b}$	0.071 ± 0.036^{a}	6.891 ± 1.219^{c}	0.360 ± 0.104^{a}	0.306 ± 0.044^{c}	$0.102 \pm 0.038^{a,\ b}$	0.088 ± 0.051^{a}
Spinibarbus sinensis	0.360 ± 0.073^{b}	$8.467 \pm 2.732^{b,\ c}$	$0.255 \pm 0.069^{b,\ c}$	0.016 ± 0.007^{c}	8.369 ± 2.675^{b}	0.252 ± 0.086^{b}	0.380 ± 0.090^{b}	0.123 ± 0.037^{a}	$0.065 \pm 0.027^{a,\ b}$
Hemibarbus labeo	0.377 ± 0.091^{b}	9.909 ± 1.683^{b}	$0.276 \pm 0.083^{b,\ c}$	0.040 ± 0.031^{b}	$7.265 \pm 1.367^{b,\ c}$	0.149 ± 0.039^{c}	$0.374 \pm 0.137^{b,\ c}$	$0.079 \pm 0.021^{b,\ c}$	0.048 ± 0.023^{b}
Pelteobaggrus vachelli	0.348 ± 0.057^{b}	$6.724 \pm 2.496^{c,\ d}$	0.366 ± 0.182^{b}	0.053 ± 0.042^{b}	11.079 ± 6.463^{b}	0.284 ± 0.082^{b}	$0.346 \pm 0.136^{b,\ c}$	0.113 ± 0.037^{a}	0.048 ± 0.019^{b}

Different letter superscripts in each column indicate the significant difference between different fish species ($p < 0.05$)

concentrations in muscle of ten different fish species (Fig. 2). It was in the following order: *S. meriaionalis* (0.471) > *G. sinense* (0.433) > *P. vachelli* (0.401) > *S. chuatsi* (0.396) > *S. sinensis* (0.349) > *L. longirostris* (0.344) > *H. labeo* (0.342) > *P. truncates* (0.326) > *R. typus* (0.269) > *P. rabaudi* (0.268). The results indicated that the carnivorous fish and benthic fish accumulated higher metals than other fish species, which in agreement with the pattern of metal concentrations. Some other studies have also reported that the MPI of metals in fish muscle is significantly correlated with fish species (Idris et al. 2015; Li et al. 2015).

The relationships between metal concentrations and fish length in muscle of ten fish species are shown in Table 3. Significant negative correlations were found between fish length and Cu in *G. sinense* ($p < 0.05$), Fe in *G. sinense* ($p < 0.05$), Cr in *G. sinense* ($p < 0.01$) and *R. typus* ($p < 0.05$), Mn in *P. truncatus* ($p < 0.05$) and *P. vachelli* ($p < 0.01$), As in *G. sinense* ($p < 0.05$), Hg in *S. sinensis* ($p < 0.01$). Significant positive correlations were found between fish length and Pb in *P. truncatus* ($p < 0.01$) and *P. vachelli* ($p < 0.05$), Cd in *P. truncatus* ($p < 0.01$), Fe in *Procypris rabaudi*($p < 0.01$), *S. chuatsi* ($p < 0.05$), and *S. meriaionalis* ($p < 0.05$). Hg in *R. typus* ($p < 0.01$), *L. longirostris* ($p < 0.01$), and *P. truncatus* ($p < 0.05$). There were no significant relationships between fish length and metal concentrations in *H. labeo* ($p > 0.05$). The results showed that there were no identical correlations between metal concentrations and fish length. Similar pattern was showed in other literatures (Agah et al. 2009; Jonathan et al. 2015; Liu et al. 2015). There were significant positive correlations between Hg concentrations and the length of *R. typus*, *L. longirostris*, and *P. truncatus*. In most cases, the Hg concentrations were found to be positively correlated with fish length (Storelli et al. 2005; Kojadinovic et al. 2006; Jiang et al. 2016). However, there was significant negative correlation between Hg concentration and the length of *S. sinensis*. Significant negative relationships between Hg concentrations and fish length were also found in other studies (Yi and Zhang 2012a). The negative correlation between metal concentrations and fish length might be explained by the fact that the metabolic activities of younger fish are higher than those of older fish (Pourang et al. 2005). Besides, more energy for growth, less energy might be available for detoxification in young fish (Merciai et al. 2014). The positive correlation between metal concentrations and fish length could be attributed to the differences in feeding habits at different life history stage of fish (Monikh et al. 2013). Moreover, higher metal concentrations in water could result in continued metal accumulation in fish (Yi and Zhang 2012b). The relationship between metal concentration and fish length dependents on many factors such as specific metal, degree of pollution in

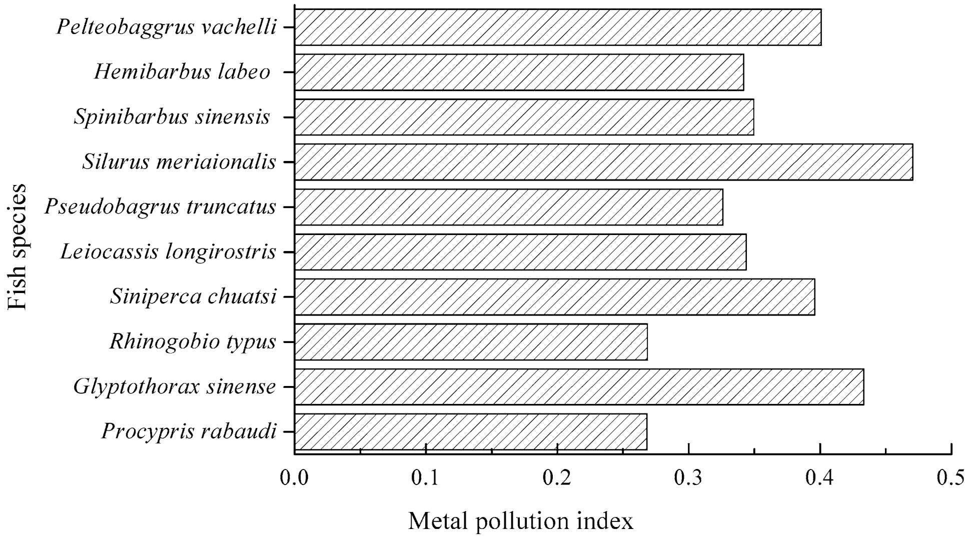

Fig. 2 Metal pollution indices for the muscle of ten fish species from the Chishui River, China

Table 3 Correlation coefficients between metal concentrations and fish length

	Cu	Zn	Pb	Cd	Fe	Cr	Mn	As	Hg
Procypris rabaudi	0.218	−0.326	0.488	−0.016	0.841**	0.433	−0.033	−0.277	−0.189
Glyptothorax sinense	−0.709*	−0.266	−0.180	−0.158	−0.693*	−0.738**	−0.572	−0.729*	−0.517
Rhinogobio typus	−0.394	−0.383	−0.175	0.042	0.102	−0.459*	0.285	−0.122	0.558**
Siniperca chuatsi	−0.088	−0.007	0.299	−0.203	0.415*	0.229	−0.084	−0.013	−0.109
Leiocassis longirostris	−0.329	0.431	0.404	0.342	−0.379	−0.322	−0.468	0.549	0.754**
Pseudobagrus truncatus	0.217	0.157	0.723**	0.641**	−0.141	−0.45	−0.512*	0.179	0.490*
Silurus meriaionalis	0.380	0.352	−0.288	−0.426	0.501*	−0.051	−0.119	−0.283	0.367
Spinibarbus sinensis	0.406	−0.392	−0.338	−0.433	−0.226	0.389	−0.383	0.011	−0.646**
Hemibarbus labeo	0.096	0.295	−0.618	−0.281	−0.131	0.609	−0.048	−0.291	−0.048
Pelteobaggrus vachelli	−0.355	−0.381	0.536*	0.351	−0.405	0.120	−0.573**	0.059	0.036

*$p < 0.05$, **$p < 0.01$

water, fish species, stage of fish life, as well as physiological condition of fish.

The muscle of fish is the main edible part that can directly affect human health if carries metals beyond standards (Diop et al. 2016). The consumption of wild fish from the Chishui River is an important source of income in the past years. Individuals living in the Chishui River basin like consuming wild fish than cultured fish because the former is more rare and delicious. In order to evaluate the health risk to people living in the Chishui River basin through consumption of wild fish, the target hazard quotient (THQ), hazard index (HI), and target cancer risk (TR) of metals were calculated and listed in Table 4. According to our questionnaire of 200 adults living in the Chishui River basin, the average ingestion rate of fish from the Chishui River for the general population and fishermen were 11.3 and 57.6 g/day, respectively. Assuming that inorganic As and methyl Hg contents accounted for 10% of total As and 75% of total Hg in fish (Buchet et al. 1996). All the THQs of metal were below 1 for all fish species, suggesting intake of metals by consuming these fish do not result in an appreciable hazard risk on human health. However, the THQ exhibited different potential risks for different exposure groups, which consistent with other studies (Yu et al. 2012; Zhu et al. 2015). There were differences for THQ values among different metals. The THQs of Hg were the highest, ranging from 0.045 to 0.635. The THQs of Mn were the lowest, ranging from 0 to 0.003. *S. meriaionalis* had the highest THQs whereas *P. rabaudi* had the lowest. Although no single metal exposure is higher than its OR$_f$D, potential risk must be pay attention to the fishermen because of the relatively higher combined effects of all metals through fish consumption. The HI of *S. meriaionalis* for fishermen was above 1, indicating that the fishermen from the study area may experience adverse health effects. The health protection standard of lifetime risk for TR is 1.0×10^{-6} (USEPA 2016). TR values of ten fish species for As in general population and fishermen

Table 4 Target hazard quotient (THQ), hazard index (HI), and target cancer risk (TR) of metals for different exposure groups by consuming different fish species from the Chishui River, China

Exposure group	Fish species	THQ									HI	TR
		Cu	Zn	Pb	Cd	Fe	Cr	Mn	As	Hg		
General population	*P. rabaudi*	0.001	0.003	0.007	0.002	0.002	0.014	0.000	0.008	0.045	0.084	3.5×10^{-6}
	G. sinense	0.003	0.010	0.013	0.002	0.005	0.019	0.001	0.006	0.099	0.157	2.5×10^{-6}
	R. typus	0.001	0.005	0.009	0.002	0.001	0.015	0.001	0.006	0.050	0.090	2.7×10^{-6}
	S. chuatsi	0.002	0.004	0.028	0.010	0.002	0.015	0.000	0.005	0.103	0.169	2.2×10^{-6}
	L. longirostris	0.002	0.004	0.015	0.005	0.002	0.020	0.000	0.005	0.086	0.138	2.4×10^{-6}
	P. truncatus	0.002	0.006	0.014	0.004	0.002	0.019	0.000	0.005	0.064	0.115	2.4×10^{-6}
	S. meriaionalis	0.002	0.008	0.022	0.013	0.002	0.023	0.000	0.006	0.125	0.200	2.9×10^{-6}
	S. sinensis	0.002	0.005	0.012	0.003	0.002	0.016	0.001	0.008	0.092	0.141	3.5×10^{-6}
	H. labeo	0.002	0.006	0.013	0.008	0.002	0.009	0.001	0.005	0.068	0.114	2.2×10^{-6}
	P. vachelli	0.002	0.004	0.017	0.010	0.003	0.018	0.000	0.007	0.067	0.129	3.2×10^{-6}
Fishermen	*P. rabaudi*	0.007	0.017	0.038	0.012	0.010	0.069	0.002	0.039	0.231	0.427	1.8×10^{-5}
	G. sinense	0.013	0.050	0.067	0.012	0.027	0.095	0.003	0.028	0.503	0.799	1.3×10^{-5}
	R. typus	0.006	0.023	0.046	0.011	0.008	0.078	0.003	0.031	0.255	0.461	1.4×10^{-5}
	S. chuatsi	0.009	0.019	0.142	0.052	0.011	0.078	0.002	0.025	0.523	0.862	1.1×10^{-5}
	L. longirostris	0.008	0.019	0.075	0.023	0.011	0.103	0.002	0.028	0.437	0.705	1.2×10^{-5}
	P. truncatus	0.009	0.029	0.069	0.022	0.008	0.096	0.002	0.027	0.324	0.586	1.2×10^{-5}
	S. meriaionalis	0.010	0.039	0.110	0.068	0.009	0.115	0.002	0.033	0.635	1.022	1.5×10^{-5}
	S. sinensis	0.009	0.027	0.061	0.015	0.011	0.081	0.003	0.039	0.470	0.716	1.8×10^{-5}
	H. labeo	0.009	0.032	0.066	0.039	0.010	0.048	0.003	0.025	0.348	0.579	1.1×10^{-5}
	P. vachelli	0.008	0.022	0.088	0.051	0.015	0.091	0.002	0.036	0.343	0.657	1.6×10^{-5}

ranged from 2.2×10^{-6} to 3.5×10^{-6}, 1.1×10^{-5} to 1.8×10^{-5}, respectively, which were above 1.0×10^{-6}. It indicated that cancer risk of As caused by fish consumption cannot be ignored.

The maximum acceptable metal concentrations recommended by the food safety Criterion of China for Pb, Cd, Cr, inorganic As, and methyl Hg were 0.5, 0.1, 2.0, 0.1, and 0.5 mg/kg, respectively (GB 2762-2012). Cu, Zn, Fe, and Mn were not listed in this new national standard. Metal concentrations in fish muscles were all lower than the permissible levels except for Pb in *S. chuatsi*. The concentrations of Pb in *L. longirostris*, *S. meriaionalis*, and *P. vachelli*, Cd in *S. chuatsi*, *S. meriaionalis*, and *P. vachelli* were also above the maximum permissible levels according to European Commission (0.3 mg/kg for Pb and 0.05 mg/kg for Cd) (EC 2006). It showed that some of these fish species from this study area could be not totally safe for human consumption.

The concentrations of Cu, Cd, and Fe in muscle of *L. longirostris* in present study were lower than those in the middle and lower reaches of the Yangtze River, whereas the concentrations of Zn, Pb, Cr, As, and Hg were higher than those in the middle and lower reaches of the Yangtze River (Yi et al. 2008). The concentrations of Cu, As, and Hg in *P. vachelli* from present study were lower than those from the upper reach of the Yangtze River (Cai et al. 2012). The concentrations of Pb, Cd, Cr, As, and Hg in *P. vachelli* were higher than those in the same fish from the Three Gorges Reservoir (Li and Xie 2016). The concentrations of Hg in *R. typus*, *P. vachelli*, *G. sinense*, and *S. sinensis* in present study were all lower than those from the Wujiang River, which is another tributary nearby the Chishui River on the southern bank of Yangtze River (Li et al. 2008). The present study provided the basic data of metal concentrations in different fish species from the Chishui River, an important protection area for rare and endemic fish in the upper reach of the Yangtze River. Strict protection and long-term monitoring of metal pollution in this area are recommended.

Conclusions

Based on the results of the present study, the mean metal concentrations in the muscle of ten fish species from the Chishui River followed the decreasing order of Zn > Fe > Cu > Mn > Pb > Cr > As > Hg > Cd. There were no identical correlations between metal concentrations and fish length. The target hazard quotient (THQ) exhibited different potential risks for different exposure groups. The hazard index (HI) of *S. meriaionalis* for fishermen was above 1, indicating that the fishermen from the study area may experience adverse health effects. The results of metal concentrations compared to the maximum permissible levels according to China and European Commission also indicated that some of these fish species from this study area could be not totally safe for human consumption. Strict protection and long-term monitoring of metal pollution will be helpful for protecting the rare and endemic fish living in this area.

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