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Potential health risk assessment of metals in the muscle of seven wild fish species from the Wujiangdu reservoir, China

Shenwen Cai[1]*, Boping Zeng[2], Chuntao Li[2]

[1]*College of Resources and Environment, Zunyi Normal University, Zunyi, China;* [2]*College of Biology and Agriculture, Zunyi Normal University, Zunyi, China*

***Corresponding author:** Shenwen Cai, College of Resources and Environment, Zunyi Normal University, Zunyi, China. Email: swcai@zync.edu.cn

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RESEARCH ARTICLE

Abstract

Concentrations of Cu, Zn, Fe, Mn, Pb, Cd, As, and Hg were analyzed in the surface water and muscle of seven fish species (*Carassius auratus*, *Cyprinus carpio*, *Hemiculter leucisculus*, *Pelteobagrus fulvidraco*, *Silurus meriaionalis*, *Ctenopharyngodon idellus*, and *Parabramis pekinensis*) from the Wujiangdu reservoir, China. All metal concentrations in water were lower than grade one water quality values. Mean metal concentrations in the fish muscle decreased in the order: Zn (10.765 mg kg^{-1}) > Fe (8.908 mg kg^{-1}) > Mn (0.373 mg kg^{-1}) > Cu (0.369 mg kg^{-1}) > Pb (0.158 mg kg^{-1}) > As (0.102 mg kg^{-1}) > Hg (0.042 mg kg^{-1}) > Cd (0.024 mg kg^{-1}). Metal concentrations were higher in omnivorous and carnivorous fish than those in herbivorous fish. The bioconcentration factor (BCF) of Hg was much higher than that of other metals in all fish species. The values of target hazard quotient (THQ) and hazard index (HI) were lower than 1 for fishermen and the general population, indicating that there was no considerable noncarcinogenic risk. However, target cancer risk (TR) values were greater than 1.0×10^{-6}, indicating that the carcinogenic risk caused by fish consumption could not be ignored. Several kinds of fish species were not completely safe for human consumption according to the standard of the European Commission. The potential health risks in fishermen were much higher than that in the general population.

Keywords: fish; metal; muscle; risk assessment; Wujiangdu reservoir

Introduction

Metal pollution has been recognized as a serious global environmental issue because of the high toxicity, nonbiodegradability, and bioaccumulation of metals in living organisms. It can cause potential health risks for consumers due to ingestion of heavy metals through the consumption of contaminated food (Amiri *et al.*, 2021; Heshmati *et al.*, 2020; Su *et al.*, 2021). Metals can be discharged into aquatic systems through drainage, soil erosion, atmospheric deposition, and anthropogenic activities such as mining, agriculture, transportation, industry, etc. (Abadi *et al.*, 2015). Metals such as copper, zinc, iron, and manganese are essential for biological metabolism, but can also cause toxic effects on aquatic organisms at relatively high levels (Rezaei *et al.*, 2020; Rudovica and Bartkevics, 2015). Other metals like lead, cadmium, and mercury have no known role in living organisms and can be toxic even at low concentrations (Olmedo *et al.*, 2013). In general, the metal contamination in aquatic ecosystems is monitored by measuring the concentrations in water. Thereby, the degree of metal contamination can be assessed directly and clearly. However, the long-term effects of metal contamination in water cannot be adequately assessed by surface water sampling due to limited sampling times and points. Aquatic organisms are the inhabitants that cannot escape from the unfavorable effects of these metals and are therefore widely used to assess the health of aquatic ecosystems. Among aquatic organisms, fish is usually situated at the top of the food chain and is considered a suitable indicator for metal pollution monitoring in water (Plessl *et al.*, 2017). The uptake of metals in fish is not only directly from the water through the epithelia of gills and skin but also indirectly from the food consumption and intake of nonedible particles (Hussain *et al.*, 2014). Although the fish muscle is not an active tissue in accumulating metals, it can exhibit very high metal concentrations in polluted aquatic ecosystems (Avigliano *et al.*, 2015). The muscle of fish is widely consumed by humans worldwide because it has been widely recognized as a significant source of protein and omega-3 polyunsaturated fatty acids (PUFAs) (Storelli, 2008). However, if metal levels in fish exceed the permissible values, it could be a potential threat to general health and well-being. Therefore, the determination of metal concentrations in fish can be used to evaluate the metal pollution levels in aquatic ecosystems, and the potential health risks for human consumption (Lozano-Bilbao *et al.*, 2021; Renieri *et al.*, 2019; Shabani *et al.*, 2015).

There are many Hg ore deposits in the Wujiang River basin, which are in the Circum-Pacific mercuriferous belt (Feng *et al.*, 2009). Because of this special geological background, Hg pollution in the Wujiang River has been of concern. In addition, the Wujiang River basin is rich in other mineral resources, such as coal, zinc, iron, manganese, and so on. The mineral exploitation and discharge of sewage could result in metal contamination of the Wujiang River. The highest heavy metal evaluation index values have been found in Wulong, which is in the downstream of Wujiang River, compared to other sites in the Three Gorges Reservoir (Ma *et al.*, 2016). So, besides Hg, pollution risk of other metals cannot be ignored in the Wujiang River. The Wujiangdu reservoir is located in the mainstream of the Wujiang River. It is the first large reservoir built during the Wujiang River cascade development, and plays an important role in determining the water quality of the Three Gorges Reservoir (Zhu *et al.*, 2017). Many residents in the Wujiang River basin prefer consuming wild fish that live in the natural environment more than cultured fish because they think the former is more delicious, uncommon, nutritious, and healthy. Yan *et al.* (2010) have reported that the concentration of Hg in wild fish from six reservoirs including the Wujiangdu reservoir was 0.066 ± 0.078 μg g^{-1} (n = 235), and six fish exceeded the maximum limit of Hg set by the US Environmental Protection Agency. However, there have been no reports of other metal concentrations in wild fish species from the Wujiangdu reservoir and whether these metals could cause health risks for the local residents. The purpose of the present study was not only to measure the levels of seven metals (Cu, Zn, Fe, Mn, Pb, Cd, and As) in the muscle of seven wild fish species caught from the Wujiangdu reservoir but also to assess whether the concentrations of selected metals in the fish muscle were within the permissible limits for human consumption.

Materials and Methods

Study area

The Wujiangdu reservoir is located on the Wujiang River, which is an upstream tributary of the Yangtze River, in central Guizhou province, southwestern China (Figure 1). It was the first large reservoir constructed in 1979 with a surface area of 47.8 km^2, a watershed area of 2.8×10^4 km^2, an average annual flow of 502 m^3 s^{-1}, a total water volume of 2.3×10^9 m^3, and a dam height of 165 m (Feng *et al.*, 2009).

Water quality characteristics

Water temperature, pH, DO, DO%, electronic conductivity (EC), NH_4-N, NO_3-N, Cl^-, and oxidation reduction potential (ORP) were measured in situ by using YSI Professional Plus (YSI Inc., Ohio, USA). Water samples were collected at a depth of 50 cm beneath the water surface and stored in 0.5 L precleaned polyethylene bottles. Samples were acidified immediately with 2 mL of nitric acid, and then stored at 4°C before analysis. A 100 mL of water sample with 5 mL concentrated HNO_3 was digested on a hotplate at 110°C in a fume hood. Heating and adding HNO_3 were continued until a colorless solution was obtained. The digested aliquot was

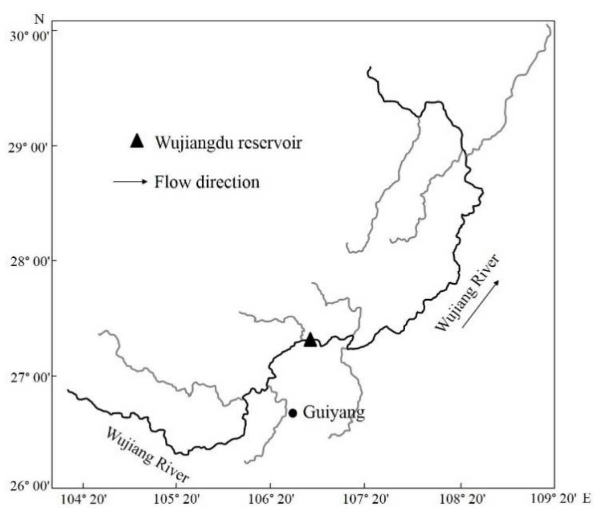

Figure 1. Map of study area.

cooled, filtered, and raised to 25 mL by adding ultrapure Milli-Q water. The concentrations of Ca and Mg were analyzed using a Shimadzu AA-6880 atomic absorption spectrophotometer.

Fish sampling and preparation

The fish species (*Carassius auratus*, *Cyprinus carpio*, *Hemiculter leucisculus*, *Pelteobagrus fulvidraco*, *Silurus meriaionalis*, *Ctenopharyngodon idellus*, and *Parabramis pekinensis*) were caught using fishing nets by the local professional fisherman from the Wujiangdu reservoir in January 2019 (Figure 1). Ten samples of each fish species were selected randomly to analyze the metal concentrations. The body lengths and weights of fish samples were recorded to the nearest 0.1 cm and 0.1 g before dissection (Table 1). Accurate weighed samples (0.40–0.65 g) of dorsal muscle without skin were taken from each fish and stored in 10 mL glass bottles at –20°C prior to analysis. Each fish sample was pre-digested for 12 h with 4 mL HNO_3, then transferred into the teflon digestion vessel and rinsed in the glass bottle with 6 mL HNO_3. The digested mixture was then transferred into a microwave digestion system and the temperature control procedure was set as shown in Table 2. After cooling to 25°C, the samples were diluted with ultrapure Milli-Q water to a final volume of 25 mL.

Table 1. Number, length, and weight ranges of the seven fish species from the Wujiangdu reservoir.

Fish species	Number	Length ranges (average)/cm	Weight ranges (average)/g
Carassius auratus	10	11.8–24.5 (16.8)	56.4–611.3 (191.2)
Cyprinus carpio	10	20.1–37.1 (29.3)	130.5–1151.2 (670.6)
Hemiculter leucisculus	10	11.0–11.7 (11.6)	11.4–17.3 (14.3)
Pelteobagrus fulvidraco	10	12.5–22.0 (16.5)	33.9–120.0 (69.3)
Silurus meriaionalis	10	14.4–27.3 (22.0)	25.1–313.0 (127.0)
Ctenopharyngodon idellus	10	18.8–31.0 (27.1)	69.5–715.2 (442.2)
Parabramis pekinensis	10	22.1–25.6 (23.4)	252.8–412.6 (329.0)

Table 2. The control procedure of microwave digestion.

Step	Power (W)	Temperature (°C)	Time (min)	Stable time (min)
1	800	120	10	5
2	1000	150	5	3
3	1000	180	5	3

Determination of metal concentrations in water and fish

Concentrations of Cu, Zn, Fe, Mn, Pb, and Cd were measured by inductively coupled plasma atomic emission spectrometry (ICP-AES; Thermo ICAP6300-duo, USA). Concentrations of As and Hg were measured with a KCHG AFS-230E atomic fluorophotometer. The detection limits for Cu, Zn, Fe, Mn, Pb, Cd, As, and Hg were 2 μg L^{-1}, 0.6 μg L^{-1}, 2 μg L^{-1}, 0.5 μg L^{-1}, 4 μg L^{-1}, 0.5 μg L^{-1}, 0.3 μg L^{-1}, and 0.04 μg L^{-1}, respectively. Percentages of metal recovery based on standard reference materials (GBW10050 and GBW10051, National Research Center for Certified Reference Materials of China) for samples ranged from 92.3 to 108.1%. Blank and spiked samples were treated in triplicate using the same procedure.

Contamination and risk assessment

The total metal accumulation of fish species was examined using the metal pollution index (MPI), which was calculated according to Equation 1 (Usero *et al*., 1996).

$$\mathrm{MPI} = (C_1 \times C_2 \times \ldots \times C_n)^{1/n} \tag{1}$$

where C_n is the concentration of metal n (mg kg^{-1}; wet weight) in a sample. A higher value of MPI indicates greater accumulation of metals in the sample (Islam *et al*., 2017).

Bio-concentration factor (BCF) was used to evaluate bioaccumulation of metals in fish tissues after exposure via water. It was calculated according to Equation 2 (Sujitha *et al*., 2019).

$$\mathrm{BCF} = \frac{C_{fish}}{C_{water}} \tag{2}$$

where C_{fish} is the concentration of metal in the muscle of fish (expressed as mg kg^{-1}); C_{water} is the concentration of metal in water (expressed as mg L^{-1}).

The target hazard quotient (THQ) and the hazard index (HI) were applied to assess the human health risk from consuming the tested fishes. The THQ values were calculated on the base of the metals' (Cu, Zn, Fe, Mn, Pb, Cd, As, and Hg) concentrations recorded in the muscle of fish. It was calculated according to Equation 3 (Chary *et al*., 2008).

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

EF is the exposure frequency (365 days/year); *ED* is the exposure duration (70 years); *FI* is the wild fish ingestion (17.9 and 75.0 for general population and fishermen, respectively, according to the questionnaire of 200 adults who live nearby the Wujiangdu reservoir, g/person/day); *MC* is the metal concentration in the fish muscle (mg kg^{-1}, wet weight), the concentrations of inorganic As (10% total As) and methyl Hg (75% total Hg) in the fish muscle were used in the present study (Buchet *et al.*, 1996); OR_fD is the oral reference dose of the metal of concern in mg/kg/day (0.04 for Cu, 0.3 for Zn, 0.7 for Fe, 0.14 for Mn, 0.0036 for Pb, 0.001 for Cd, 0.0003 for As, and 0.0001 for Hg) (Cui *et al.*, 2015; USEPA); *BW* is the average body weight for adult consumer (set as 60 kg); *AT* is the average exposure time, set as 365 days/year × 70 years. The hazard index (HI) was then obtained by the sum of THQ for all selected metals: HI = $THQ_{Cu} + THQ_{Zn} + THQ_{Fe} + THQ_{Mn} + THQ_{Pb} + THQ_{Cd} + THQ_{As} + THQ_{Hg}$ (Ullah *et al.*, 2017).

Target cancer risk (TR) was used to assess the carcinogenic risk. It was calculated according to Equation 4.

$$\mathrm{TR} = \frac{EF \times ED \times FI \times MC \times CPSo}{BW \times AT} \times 10^{-3} \tag{4}$$

where *EF*, *ED*, *FI*, *MC*, *BW*, and *AT* were as explained before. *CPSo* is the carcinogenic potency slope, oral (mg kg^{-1} day^{-1}). The TR As was calculated to show the carcinogenic risk because the *CPSo* of other metals have not been established (USEPA).

Statistical analysis

Statistical analysis was carried out using SPSS 19.0 for Windows. One-way ANOVA and Duncan's Multiple Comparison Test (P = 0.05) were used to access whether metal concentrations varied significantly between different fish species. Pearson's correlation coefficient was used to examine the relationship between metal concentrations in the fish muscle. The metal concentrations in fish were expressed as milligrams per kilogram (wet weight).

Results and Discussion

Physicochemical parameters in water

The characteristics of water temperature, pH, DO, DO%, electronic conductivity (EC), NH_4^+-N, NO_3^--N, Cl^-, oxidation reduction potential (ORP), Ca, Mg, Cu, Zn, Fe, Mn, Pb, Cd, and As from surface water of the Wujiangdu reservoir are shown in Table 3. Water quality was classified into five levels according to the Environment Quality Standard for Surface Water of China (GB 3838-2002) (SEPA, 2002). The NH_4-N was higher than the cutoff value for grade one (set as 0.15 mg L^{-1}). The average metal levels in water of the Wujiangdu reservoir were generally low. All metal concentrations were much lower than the values for grade one water quality. The concentrations of Zn, Pb, and As in water found in the present study were lower than those reported from the Three Gorges Reservoir (Zhao *et al.*, 2017a), whereas the concentrations of Cu, Zn, Mn, and Pb were higher than those from the downstream of the Wujiang river (Ma *et al.* 2016).

Table 3. Values of physicochemical characteristics and metals concentration in water samples from the Wujiangdu reservoir (n = 3).

Parameters	Values (Mean ± SD)
Temperature (°C)	13.47 ± 0.05
pH	8.28 ± 0.04
DO %	94.23 ± 0.12
DO (mg L^{-1})	9.83 ± 0.03
EC (μS cm^{-1})	284.8 ± 10.69
NH_4^+-N (mg L^{-1})	0.39 ± 0.05
NO_3^--N (mg L^{-1})	10.13 ± 0.29
Cl^- (mg L^{-1})	29.82 ± 1.19
ORP (mv)	448.37 ± 2.25
Ca (mg L^{-1})	71.80 ± 8.49
Mg (mg L^{-1})	12.45 ± 0.15
Cu (μg L^{-1})	3.41 ± 0.00
Zn (μg L^{-1})	14.33 ± 1.32
Fe (μg L^{-1})	241.15 ± 20.63
Mn (μg L^{-1})	25.78 ± 0.92
Pb (μg L^{-1})	0.28 ± 0.02
Cd (μg L^{-1})	0.12 ± 0.03
As (μg L^{-1})	0.91 ± 0.04
Hg (μg L^{-1})	0.02 ± 0.00

Metal concentrations in the fish muscle

Metal bioaccumulation in the muscle of *Carassius auratus*, *Cyprinus carpio*, *Hemiculter leucisculus*, *Pelteobagrus fulvidraco*, *Silurus meriaionalis*, *Ctenopharyngodon idellus*, and *Parabramis pekinensis* are listed in Table 4. Regardless of fish species, the median concentrations of Cu, Zn, Fe, Mn, Pb, Cd, As, and Hg in the muscle were 0.348, 6.518, 6.879, 0.288, 0.122, 0.008, 0.090, and 0.039 mg kg^{-1}, respectively. It manifested that metals could be accumulated in the fish muscle. Although the metal concentrations in water were relatively lower, the high bioavailability of metals cannot be ignored (Liu *et al.*, 2018). There were differences in the muscle of the different fish species. The results were in the range of 0.273–0.515, 5.870–26.709, 6.629–16.170, 0.149–0.813, 0.113–0.278,

Table 4. Concentrations of Cu, Zn, Fe, Mn, Pb, Cd, As, and Hg in the muscle of seven fish species from the Wujiangdu reservoir (mg kg^{-1}, wet weight, mean ± SD).

Fish species	Cu	Zn	Fe	Mn	Pb	Cd	As	Hg
Carassius auratus	0.515 ± 0.240^{a}	16.268 ± 8.212^{b}	8.728 ± 2.763^{b}	0.403 ± 0.232^{b}	0.131 ± 0.078^{b}	0.014 ± 0.011^{b}	0.058 ± 0.048^{d}	0.053 ± 0.037^{a}
Cyprinus carpio	0.394 ± 0.153^{ab}	6.209 ± 1.893^{c}	9.369 ± 5.835^{b}	0.303 ± 0.113^{bc}	0.152 ± 0.090^{b}	0.007 ± 0.002^{b}	0.092 ± 0.038^{bcd}	0.032 ± 0.018^{bc}
Hemiculter leuciscuIus	0.273 ± 0.232^{b}	26.709 ± 10.004^{a}	16.170 ± 3.753^{a}	0.813 ± 0.414^{a}	0.133 ± 0.037^{b}	0.009 ± 0.006^{b}	0.129 ± 0.014^{ab}	0.048 ± 0.013^{ab}
Pelteobagrus fulvidraco	0.375 ± 0.090^{ab}	6.474 ± 2.680^{c}	6.656 ± 1.537^{b}	0.341 ± 0.155^{bc}	0.278 ± 0.232^{a}	0.068 ± 0.069^{a}	0.135 ± 0.048^{a}	0.052 ± 0.014^{a}
Silurus meriaionalis	0.278 ± 0.102^{b}	7.790 ± 3.237^{c}	7.984 ± 5.299^{b}	0.286 ± 0.075^{bc}	0.181 ± 0.057^{b}	0.057 ± 0.062^{a}	0.128 ± 0.082^{abc}	0.056 ± 0.018^{a}
Ctenopharyngodon idellus	0.464 ± 0.258^{a}	5.870 ± 1.744^{c}	6.820 ± 1.291^{b}	0.317 ± 0.367^{bc}	0.117 ± 0.043^{b}	0.006 ± 0.002^{b}	0.089 ± 0.015^{cd}	0.030 ± 0.012^{c}
Parabramis pekinensis	0.281 ± 0.250^{b}	6.037 ± 3.503^{c}	6.629 ± 2.558^{b}	0.149 ± 0.096^{c}	0.113 ± 0.042^{b}	0.009 ± 0.002^{b}	0.081 ± 0.009^{d}	0.024 ± 0.011^{c}

Different superscript letters in each column denote the significant difference between different fish species ($P < 0.05$).

0.006–0.068, 0.058–0.135, 0.024–0.056 mg kg^{-1} for Cu, Zn, Fe, Mn, Pb, Cd, As, and Hg, respectively. The order of mean concentrations of metals in the fish muscle were as follows: Zn (10.765) > Fe (8.908) > Mn (0.373) > Cu (0.369) > Pb (0.158) > As (0.102) > Hg (0.042) > Cd (0.024). Rather *et al.* (2019) also found Zn in maximum and Cd in minimum concentration in fish. It might be associated with the background values, as well as different capabilities of metal accumulation in the aquatic ecosystems. The Cu concentrations in the muscle of *C. carpio*, *H. leucisculus*, *P. fulvidraco*, *C. idellus*, and *P. pekinensis* in the present study area were lower, while the concentrations of Fe, Pb, As, and Hg were higher than those in the middle and lower reaches of the Yangtze River (Yi *et al.*, 2008). The concentrations of Pb and As in *C. auratus*, C. carpio, and *S. meriaionalis* were higher, and the concentration of Hg in *S. meriaionalis* was lower than that from the Three Gorges Reservoir (Li and Xie, 2016). The Hg concentrations in *H. leucisculus* and *S. meriaionalis* were higher than that from the downstream of the Wujiang River, whereas it was lower in *C. auratus* (Li *et al.*, 2009). Except for Fe and As, the concentrations of other metals in *S. meriaionalis* were lower than that from the Chishui River, which is another important tributary of the Yangtze River near the Wujiang River (Cai *et al.*, 2017).

Relationship between metal concentration and fish species

Many studies have indicated that the metal concentrations in the fish muscle are usually species-dependent (Jiang *et al.*, 2022; Korkmaz *et al.*, 2019; Monroy *et al.*, 2014). The highest concentration of Cu was found in *C. auratus* which is a demersal fish (Table 4). Bottom sediment is not only in the sink but also the source of metals in water system (Liu *et al.*, 2015). So, *C. auratus* could be easily exposed to more sediment-associated metals than pelagic fish species. Higher metal concentrations were also found in benthic fish species of other studies (Hosseini *et al.*, 2015; Yi *et al.*, 2011). *C. auratus*, *C. carpio*, and *H. leucisculus* are omnivorous species, *P. fulvidraco* and *S. meriaionalis* are carnivorous species, and *C. idellus* and *P. pekinensis* are herbivorous species. The highest concentrations of Zn, Fe, and Mn were found in *H. leucisculus*. The highest concentrations of Pb, Cd, and As were found in *P. fulvidraco*. This indicated that metal concentrations in omnivorous and carnivorous fish were higher than those in herbivorous fish, which was in agreement with other studies (Bi *et al.*, 2018; Okogwu *et al.*, 2019; Zhu *et al.*, 2016). The Hg concentration in *S. meriaionalis* was significantly higher than that in *C. idellus* and *P. pekinensis* ($P < 0.05$). *S. meriaionalis* is a top predator in a relatively long food chain. Predatory fish are at the top of the food chain and so tend to concentrate more Hg (Li and Xie, 2016). In addition, Hg is subject to food web bio-magnification processes in water environments (Squadrone *et al.*, 2013). Another carnivorous fish *P. fulvidraco* generally exhibited higher Hg levels than herbivorous fish. Similar results have also been reported by other studies (Burger *et al.*, 2001; Hosseini *et al.*, 2015). Furthermore, body size can also explain the varied metal concentrations in different fish species. The average length and weight of *P. fulvidraco* and *S. meriaionali* were relatively lower than those of *C. idellus* and *P. pekinensis* (Table 1), while the metal concentrations of the former were relatively higher than those of the latter in the present study (Table 4). It could be caused by higher potential intake of metals in smaller than larger fish (Balzani *et al.*, 2022; Merciai *et al.*, 2014). Actually, there were no consistent differences between the different fish species. It could be attributed to the differences of some parameters such as the water quality, metal characteristics, the body size, growth rate, sex, feeding habits, habitats, metabolisms of fish, and the process of metal uptake by fish (Cai *et al.*, 2017). However, it is currently not clear which ones play key roles in the metal accumulation of fish.

Metal pollution index

The metal pollution index (MPI) was used to determine the total metal accumulation in different fish species. Usually, higher MPI value indicates greater accumulation of metals in fish (Islam *et al.*, 2017). The MPI values of the seven studied fish species ranged from 0.21 to 0.40 (Figure 2). Compared with other publications, the MPI of *C. auratus* and *P. fulvidraco* in the present study were higher than that in the Nansi Lake (Li *et al.*, 2015), and the MPI of *C. auratus* was similar to that in the Taihu Lake (Chi *et al.*, 2007). It can be attributed to the differences of metal pollution in different study areas. The accumulation order based on MPI was *H. leucisculus* > *P. fulvidraco* > *S. meriaionalis* > *C. auratus* > *C. carpio* > *C. idellus* > *P. pekinensis* (Figure 2). The results indicated that *H. leucisculus* and *P. fulvidraco* accumulated higher metals than other fish species. Many studies have shown that the MPI values in the fish muscle are significantly correlated to fish species (Costanza *et al.*, 2012;

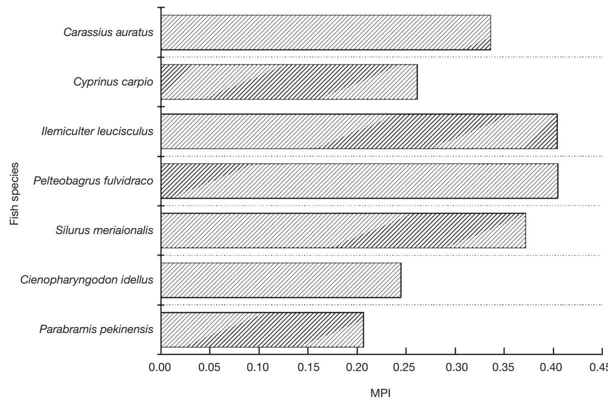

Figure 2. Metal pollution indices of seven fish species from the Wujiangdu reservoir, China.

Herrera-Herrera *et al.*, 2019; Kwaansa-Ansah *et al.*, 2019; Liu *et al.*, 2018). Bioaccumulation of metals was prone to be stronger in carnivorous and omnivorous species rather than in herbivorous species (*C. idellus* and *P. pekinensis*).

Bioconcentration factors (BCFs) of metals

The BCF values are given in Table 5. The BCF can be used to assess the metal accumulation ability of fish in the aquatic environment. The fish potentiality has to accumulate metal if the value of BCF is > 1 (Liu et al. 2018). The order of mean BCF values was as follows: Hg (1711.0) > Zn (751.1) > Pb (571.4) > Cd (205.8) > As (111.3) > Cu (108.2) > Fe (36.9) > Mn (14.5). It is considered bioaccumulative if the BCF of metal is between 1000 and 5000, while not bioaccumulative if the BCF of metal is less than 1000 (Costanza *et al.*, 2012). Obviously, the BCF of Hg were much higher than that of other metals in all fish species. It indicated that Hg accumulated in fish more easily than other metals. It is well known that Hg can be accumulated in fish through bioaccumulations and biomagnifications (Laffont *et al.*, 2021). The results also revealed that *C. auratus* and *H. leucisculus* have the potential to bioaccumulate Zn, and *P. fulvidraco* has the potential to accumulate Pb. The BCF of Fe and Mn in all fish species were lower than 100, suggesting that Fe and

Table 5. Bioconcentration factors (BCF) for metals in the muscle of seven fish species from the Wujiangdu reservoir, China.

Fish species	Cu	Zn	Fe	Mn	Pb	Cd	As	Hg
C. auratus	151.2	1135.1	36.2	15.6	474.6	118.6	62.4	2151.8
C. carpio	115.6	433.2	38.9	11.8	550.7	59.3	100.8	1299.2
H. leucisculus	80.1	1863.6	67.1	31.5	481.9	76.3	141.3	1948.8
P. fulvidraco	110.1	451.7	27.6	13.2	1003.6	567.8	147.9	2111.2
S. meriaionalis	81.6	543.5	33.1	11.1	655.8	483.1	140.2	2273.7
C. idellus	136.2	409.6	28.3	12.3	423.9	59.3	97.5	1218.0
P. pekinensis	82.5	421.2	27.5	5.8	409.4	76.3	88.7	974.4

Table 6. Pearson correlation coefficient between metal concentrations in the fish muscle from the Wujiangdu reservoir, China.

	Cu	Zn	Fe	Mn	Pb	Cd	As	Hg
Cu	1	–	–	–	–	–	–	–
Zn	–0.14	1	–	–	–	–	–	–
Fe	–0.326	0.907**	1	–	–	–	–	–
Mn	–0.144	0.928**	0.931**	1	–	–	–	–
Pb	–0.09	–0.25	–0.241	–0.067	1	–	–	–
Cd	–0.23	–0.278	–0.327	–0.173	0.892**	1	–	–
As	–0.64	0.122	0.649	0.657	0.295	0.361	1	–
Hg	0.001	0.42	0.54	0.656	0.256	0.419	0.431	1

** Significant at the 0.01 probability level.

Mn had lower bioaccumulation ability in these fish species. Fe and Mn have low toxicity and considerable biological importance. The highest BCF values for Cu and Hg were observed in *C. auratus* and *S. meriaionalis*, respectively. The highest BCF values for Zn, Fe, and Mn were recorded in *H. leucisculus*. The highest BCF values for Pb, Cd, and As were observed in *P. fulvidraco*.

Correlation coefficients

The correlation coefficients between the investigated metal concentrations are shown in Table 6. Significant positive correlations ($P < 0.01$) were observed between several metal pairs: Pb-Cd (0.892), Zn-Fe (0.907), Zn-Mn (0.928), and Fe-Mn (0.931). It indicated that the metals in pairs might originate from common sources. There were positive correlations for Zn-As, Pb-As, Pb-Hg, Cd-As, Cd-Hg, Fe-As, Fe-Hg, Mn-As, Mn-Hg, and As-Hg, with corresponding r values of 0.42, 0.649, 0.54, 0.657, 0.656, 0.295, 0.256, 0.361, 0.419, and 0.432, respectively. The metal pairs of Cu-Hg and Zn-Hg were positive correlated weakly. These positive correlations may manifest that the origin of these metals in the fish samples was highly related to the differences in aquatic environments concerning the type and degree of water pollution, water quality characteristics, as well as the chemical form of metals (Duran *et al.*, 2014). Obviously, there were positive correlations between Hg and other metals, which indicated that Hg was widely distributed in the present study area (Jiang *et al.*, 2007; Zhao *et al.*, 2017b). The annual total input of Hg was 1.67×10^5 g in the Wujiangdu reservoir (Feng *et al.*, 2009). Besides, it might be the result of elevated concentrations of Hg in the bedrock (Feng and Qiu, 2008).

Health risk assessment

Health risk assessment has been used widely for identifying risk factors to human health associated with the ingestion of heavy metals and providing evidence of risk to the decision-makers (Bounar *et al.*, 2020; Gao *et al.*, 2022). The values of target hazard quotient (THQ) and hazard index (HI), and target cancer risk (TR) of metals for the consumption of the seven fish species are shown in Table 7. The THQ values were varied among the different metals. The THQ values of Mn (0–0.007) were the lowest, and the THQ values of Hg (0.054–0.525) were the highest, which were consistent with the previous study (Cai *et al.*, 2017). There were no THQ values above 1, suggesting that the people living in this area will not experience significant health risks associated with the consumption of these fish species. However, the THQ values manifested different potential health risks for different exposure groups. In Fisherman, the THQ values of all metals were much higher than that in the general population due to their increased consumption of fish. Similar results were also found in another report (Zhu *et al.*, 2015). Although single metal exposure was lower than its OR_fD, potential risks to the fishermen cannot be ignored. The highest HI values in both the general population and fishermen were observed in *P. fulvidraco*, followed by *S. meriaionalis*, *H. leucisculus*, *C. auratus*, *C. carpio*, *C. idellus*, and *P. pekinensis*, suggesting that the consumption of carnivorous and omnivorous fish posed relatively higher potential health risks than the consumption of herbivorous fish. It could be a hard decision for the residents because they prefer eating carnivorous fish. The health protection standard of a lifetime risk for TR is below 1.0×10^{-6} (USEPA), whereas, the TR values of the seven fish species for As in the general population and fishermen ranged from 2.6×10^{-6} to 6.0×10^{-6} and 1.1×10^{-5} to 2.5×10^{-5}, respectively (Figure 3). This indicated that the carcinogenic risk of As caused by fish intake in this study area could not be ignored.

According to the maximum allowable levels of contaminants in food recommended by the food safety criterion of China, the maximum acceptable metal concentrations of Pb, Cd, inorganic As, and methyl Hg were 0.5, 0.1, 0.1, and 0.5 mg kg^{-1}, respectively (GB 2762-2012). The concentrations of Cu, Zn, Fe, and Mn were not listed in the

Table 7. Target hazard quotient (THQ) and Hazard Index (HI) of metals for two exposure groups consuming different fish species from the Wujiangdu reservoir, China.

		THQ								
Exposure group	**Fish species**	**Cu**	**Zn**	**Fe**	**Mn**	**Pb**	**Cd**	**As**	**Hg**	**HI**
General population	*C. auratus*	0.004	0.016	0.004	0.001	0.011	0.004	0.006	0.119	0.164
	C. carpio	0.003	0.006	0.004	0.001	0.013	0.002	0.009	0.072	0.109
	H. leucisculus	0.002	0.027	0.007	0.002	0.011	0.003	0.013	0.107	0.171
	P. fulvidraco	0.003	0.006	0.003	0.001	0.023	0.020	0.013	0.116	0.186
	S. meriaionalis	0.002	0.008	0.003	0.001	0.015	0.017	0.013	0.125	0.184
	C. idellus	0.005	0.006	0.003	0.001	0.010	0.002	0.009	0.067	0.101
	P. pekinensis	0.002	0.006	0.003	0.000	0.009	0.003	0.008	0.054	0.085
Fishermen	*C. auratus*	0.016	0.068	0.016	0.004	0.045	0.018	0.024	0.497	0.687
	C. carpio	0.012	0.026	0.017	0.003	0.053	0.009	0.038	0.300	0.457
	H. leucisculus	0.009	0.111	0.029	0.007	0.046	0.011	0.054	0.450	0.717
	P. fulvidraco	0.012	0.027	0.012	0.003	0.096	0.084	0.056	0.488	0.777
	S. meriaionalis	0.009	0.032	0.014	0.003	0.063	0.071	0.053	0.525	0.770
	C. idellus	0.021	0.024	0.012	0.003	0.041	0.009	0.037	0.281	0.422
	P. pekinensis	0.009	0.025	0.012	0.001	0.039	0.011	0.034	0.225	0.356

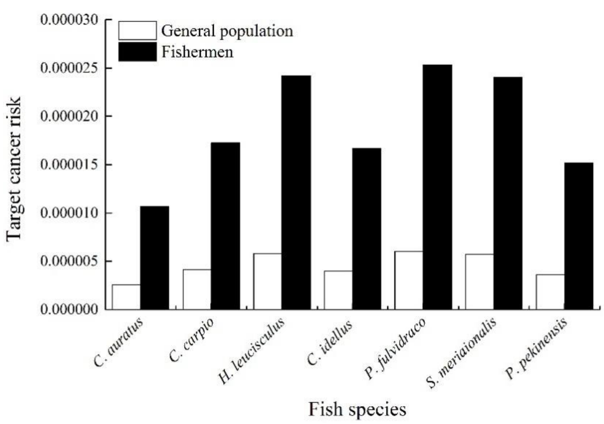

Figure 3. Target cancer risk (TR) of As for two exposure groups consuming different fish species from the Wujiangdu reservoir, China.

latest national standard. All mean metal concentrations in the muscle of selected fish species were lower than the allowable levels. However, in some samples of *P. fulvidraco*, the levels were above the maximum acceptable levels. Besides, the concentrations of Cd in *P. fulvidraco* and *S. meriaionalis* also exceeded the maximum allowable levels (0.05 mg kg^{-1}) according to the European Commission (EC 2006). This indicated that some of these selected fish species from the Wujiangdu reservoir were not totally safe for human consumption.

Conclusions

According to the results of the present study, the average level of metals in the water of the Wujiangdu reservoir were generally low. All metals were detected in levels much lower than grade one water quality values. The mean metal concentrations in the muscle of seven fish species from the Wujiangdu reservoir decreased in the following order: Zn (10.765 mg kg^{-1}) > Fe (8.908 mg kg^{-1}) > Mn (0.373 mg kg^{-1}) > Cu (0.369 mg kg^{-1}) > Pb (0.158 mg kg^{-1}) > As (0.102 mg kg^{-1}) > Hg (0.042 mg kg^{-1}) > Cd (0.024 mg kg^{-1}). Metal concentrations in omnivorous and carnivorous fish were higher than those in herbivorous fish. The highest concentrations of Zn, Fe, and Mn were found in *H. leucisculus*. The highest concentrations of Pb, Cd, and As were found in *P. fulvidraco*. The MPI values also indicated that bioaccumulation of metals was stronger in carnivorous and omnivorous species rather than in herbivorous species. The BCF of Hg was much higher than that of other metals in all fish species. Correlations between metal concentrations indicated that the pairs Pb-Cd, Zn-Fe, Zn-Mn, and Fe-Mn might originate from common sources. The target hazard quotient (THQ) and hazard index (HI) exhibited different potential risks for different exposure groups. There were no THQ values above 1, suggesting that the people living in this area will not experience significant health risks associated with the consumption of these fish species. However, the carcinogenic risk of As caused by fish consumption in this study area cannot be ignored. In conclusion, the present study indicated that some of the fish species from the Wujiangdu reservoir are not totally safe for human consumption. Long-term monitoring of metal pollution is needed in this area.

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Authorship Contributions

Shenwen Cai was involved in methodology, validation, formal analysis, investigation, writing of the original draft, and funding acquisition; Boping Zeng was concerned with methodology and funding acquisition; and Chuntao Li reviewed the draft and curated the data.

Conflict of Interest

The authors declare that they have no conflict of interest.

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