frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 19 April 2024
DOI 10.3389/fsufs.2024.1346389



OPEN ACCESS

EDITED BY
Sylvester Chibueze Izah,
Bayelsa Medical University, Nigeria

REVIEWED BY
Lochan Singh,
National Institute of Food Technology Entrepreneurship and Management, India
M. Belal Hossain,
Noakhali Science and Technology University, Bangladesh

*CORRESPONDENCE
Jiaojiao Yin
✉ yinjiaojiao@whpu.edu.cn
Xuezhen Zhang
✉ xuezhen@mail.hzau.edu.cn

†These authors have contributed equally to this work and share first authorship

RECEIVED 29 November 2023
ACCEPTED 01 April 2024
PUBLISHED 19 April 2024

CITATION
Yin JJ, Cheng LY, Jiang XM, Wang L, Gao P, Zhong W and Zhang XZ (2024) Metals levels and human health risk assessment in eight commercial fish species collected from a market, Wuhan, China.
*Front. Sustain. Food Syst.* 8:1346389.
doi: 10.3389/fsufs.2024.1346389



# Metals levels and human health risk assessment in eight commercial fish species collected from a market, Wuhan, China

Jiaojiao Yin[1,2*†], Liangyu Cheng[1†], Xiaoming Jiang[2], Li Wang[3], Pan Gao[1,2], Wu Zhong[1,2] and Xuezhen Zhang[4*]

[1]Hubei Key Laboratory for Processing and Transformation of Agricultural Products, School of Food Science and Engineering, Wuhan Polytechnic University, Wuhan, China, [2]Key Laboratory of Edible Oil Quality and Safety for State Market Regulation, Wuhan Institute for Food and Cosmetic Control, Wuhan, China, [3]School of Modern Industry for Selenium Science and Engineering, Wuhan Polytechnic University, Wuhan, China, [4]College of Fisheries, Huazhong Agricultural University, Wuhan, China

**Introduction:** Heavy metals are ubiquitous environmental pollutants, and fish could be contaminated by these metals, potentially posing a threat to human health through the food chain. Understanding the accumulation of these metals in fish tissues is crucial for assessing the safety of consuming fish products.

**Methods:** In this study, the distribution of nickel (Ni), copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb) in tissues of eight fish species (*Ctenopharyngodon idellus, Megalobrama amblycephala, Hypophthalmichthys molitrix, Hypophthalmichthys nobilis, Carassius auratus, Cyprinus carpio, Culter alburnus*, and *Lateolabrax japonicas*) collected from the Baishazhou market with different trophic levels and habitat preference was investigated using inductively coupled plasma mass spectrometry (ICP-MS). The metal accumulation capacity of different fish tissues and species was assessed, and the metal pollution index (MPI) was calculated to evaluate the extent of metal accumulation ability in each species. Additionally, the health risk assessment was conducted to evaluate the potential threat to human health posed by consuming these fish species.

**Results:** The levels of metals exhibited variation among different fish tissues and species, showing an order of Zn > Cu > Ni > Pb > Cd. In terms of tissues, fish head demonstrated a greater capacity for metal accumulation compared to the muscles. Regarding fish species, the extent of accumulation ability varied depending on the specific metal, exhibiting the following order according to MPI: *H. molitrix* (0.568) > *C. auratus* (0.508) > *M. amblycephala* (0.469) > *C. idellus* (0.336) > *C. alburnus* (0.315) > *C. carpio* (0.274) > *L. japonicus* (0.263) > *H. nobilis* (0.206). Furthermore, in accordance with the results of health risk assessment, there was no potential health risk associated with the consumption of these fish species, as all target hazard quotient (THQ) values (ranger from not detected to 0.192) were below 1, and the maximum hazard index (HI) value was observed in *C. carpio* (0.519 for adults, 0.622 for children).

**Conclusion:** The findings of this study demonstrate the distribution of heavy metals in fish tissues and indicate there were no potential health risk associated with consuming these fish bought from the Baishazhou market.

KEYWORDS

**metal, fish, muscle, head, tropic levels, feeding habits, health risk assessment**

# 1 Introduction

Public concerns about environmental pollution and food safety are significant worldwide. Heavy metals, as a type of environmental contaminant, are widely distributed through industrial and agricultural runoff and domestic sewage (Kumari and Maiti, 2020). Furthermore, heavy metals pose a significant threat to organisms due to its persistence, non-degradation and bioaccumulation (Islam et al., 2017; Ge et al., 2020). Heavy metals such as zinc (Zn) and copper (Cu) are essential for cellular metabolism, however, they can be toxic at high concentrations. For example, excessive Zn intake can induce adverse effects such as nausea, loss of appetite, and vomiting (Fosmire, 1990; Sandstead, 1994). Excessive intake of Cu may cause oxidative stress in liver and kidney, resulting in toxicity (Wan et al., 2020), and exposure to Cu can increase the risk of developing diabetes (Cai et al., 2022). On the other hand, nick (Ni), cadmium (Cd), and lead (Pb) are harmful even at low concentrations. Based on the International Agency for Research on Cancer (IARC), Ni and Cd are categorized as group 1 carcinogens (Haidar et al., 2023). Ni impedes spermatogenesis primarily by generating reactive oxygen species (ROS; Mukherjee et al., 2022). Cd and Pb are also responsible for reproductive toxicity, besides, they can cause damage to other organs such as liver and spleen (Matovic et al., 2015).

Besides providing essential nutrients, fish contributes a healthy diet through docosahexaenoic acid (DHA) and eicosapentaenoic (EPA; Djedjibegovic et al., 2020). Moreover, in daily diet, eating fish twice a week can help to reduce the occurrence of some diseases (Varol and Sunbul, 2018). However, fish, which inhabit high tropic levels in the aquatic ecosystems, have the ability to accumulate heavy metals from the living environment (such as the surrounding water and sediments), along with the process of bio-magnification in the food chain (Banerjee et al., 2015; Fang et al., 2019). Various studies have shown that the consumption of contaminated-fish is one of the major pathways for humans exposure to heavy metals (Saha et al., 2016; He et al., 2023). Consequently, a great deal of attention has been paid to the assessment of fish consumption safety (Banerjee et al., 2015; Liu et al., 2018; Yin et al., 2020; He et al., 2023).

In fish, metal accumulation patterns differ considerably, based on factors such as their weight, their length, their age, what they feed on, where they live in, and what type of metal they accumulate (Jiang et al., 2018; Ge et al., 2020; Li et al., 2020; Shen et al., 2020; Zerizghi et al., 2020). The metal levels in fish are heavily influenced by feeding habits. According to Jiang et al. (2018), the contents of As, Pb, Cu, and Zn between carnivorous and omnivorous fish showed no significant differences, while carnivorous fish have higher levels of Cr and Hg than omnivorous fish. Besides, a study conducted by Jia et al. (2018) indicated that omnivorous species have higher levels of Cu, Mg, and Ca than carnivorous species. These findings indicate that fish accumulate different metals differently, even within the same metal. In light of the uncertainty, further research on the regularity of metal accumulation in differences fish species remains necessary and important.

To our knowledge, muscle is often taken into account in studies of contaminants in fish species as it is considered as a major part of consumption, however, another main edible part fish head is ignored and the documents about metal levels in head of fish are insufficient. Our previous study has demonstrated that chromium (Cr) concentration in the head of bighead fish is higher than that in muscles, thereby presenting a greater potential health risk to its lovers (Yin et al., 2019). Therefore, it is imperative to exercise cautions regarding metal pollution in fish head. Fish are inherently susceptible to the accumulation of various metals due to their unique habitat (Jia et al., 2018; Yin et al., 2018). However, until now, it remains uncertain whether other metals exhibit a similar tendency to accumulate higher levels in fish head than muscles. Actually, this research question is of particular interest to us as fish head is deeply loved by Chinese. In comparison to fish residing in natural habitats such as ponds or farms, the heavy metal levels detected in fish being sold in the market serve as a reliable indicator of the potential hazards linked to fish consumption, given that the market fish are promptly subjected to cooking.

In this study, a comprehensive study of five heavy metals (Ni, Cu, Zn, Cd, and Pb) in eight fish species with different trophic levels and habitat preference was conducted. There are three aims of this study: (1) to investigate the distribution characteristics of the heavy metals in different fish species, (2) to compare the accumulation difference of heavy metals in three main edible parts (dorsal muscle, ventral muscle, and head) of fish, (3) to evaluate the potential health risk associated with contaminated-fish consumption for adults and children populations.

# 2 Materials and methods

## 2.1 Sampling collection

Fish species used in this study were collected from the Baishazhou Market in Wuhan, Hubei, China. Wuhan, located in the central part of China, which is known as "city of hundreds of lakes" (Wang et al., 2018), possesses a unique advantage of fishery industry. Baishazhou market is a primary farmers' market in Wuhan, serving as a collection-distribution center for aquatic products. In the present study, a total of eight different fish species with relatively high consumption frequency in local were selected according to the trophic levels as well as habitat preference. The details were two herbivorous fish (grass carp *Ctenopharyngodon idellus* and Wuchang bream *Megalobrama amblycephala*), two filter feeder fish (silver carp *Hypophthalmichthys molitrix* and bighead carp *Hypophthalmichthys nobilis*), two omnivorous fish (crucian carp *Carassius auratus* and common carp *Cyprinus carpio*), and two carnivorous fish (topmouth culter *Culter alburnus* and largemouth bass *Lateolabrax japonicas*). To minimize error with samples, there were five samples of each fish species with similar sizes. Moreover, to better compare the metal distribution in different fish species, the studied fish were divided into four trophic levels and three habitat preference, details information about these fish are shown in Table 1. After collection, the fish species were transported to the laboratory by placing in ice boxes, then, a knife was used to dissect the fish, and the dorsal muscle, ventral muscle and head, which are the main edible parts of fish were obtained. Afterward, the samples were minced using a meat grinder and stored at −20°C until analysis.

TABLE 1 The relative information about the fish species studied.

| Common name | Scientific name | Trophic levels | Habitat preference | Length range (mm) | Weight range (g) |
|---|---|---|---|---|---|
| Grass carp | *Ctenopharyngodon idellus* | Herbivore | Benthopelagic | 370–410 | 1,014.4–1,220.2 |
| Wuchang bream | *Megalobrama amblycephala* | Herbivore | Benthopelagic | 275–330 | 514.4–775.0 |
| Silver carp | *Hypophthalmichthys molitrix* | Filter feeder | Pelagic | 350–440 | 1,186.2–1,660.5 |
| Bighead carp | *Hypophthalmichthys nobilis* | Filter feeder | Pelagic | 390–420 | 1,072.4–1,319.8 |
| Crucian carp | *Carassius auratus* | Omnivore | Demersal | 210–230 | 295.0–344.4 |
| Common carp | *Cyprinus carpio* | Omnivore | Demersal | 270–290 | 497.8–610.4 |
| Topmouth culter | *Culter alburnus* | Carnivorous | Pelagic | 350–385 | 504.2–646.8 |
| Largemouth bass | *Micropterus salmoides* | Carnivorous | Benthopelagic | 243–257 | 409.8–435.1 |

## 2.2 Trace element determination

The samples were digested by microwave digestion based on the methods of Liu et al. (2020) with some modifications. Approximately 0.3 g fish tissues (dry weight) were accurately weighed and then placed in a polytetrafluoroethylene digestion jar, afterward, 8.0 mL concentrated nitric acid were added. The samples were pre-digested at room temperature overnight. The digestion program of microwave digestion system was followed: firstly ramping up to 120°C within 5 min and kept for 5 min, subsequently ramping up to 150°C within 5 min and kept for 10 min, finally ramping up to 190°C within 5 min and kept for 30 min. After cooling to room temperature, the inner pot was picked out and placed on a board at 120°C heated by electric to eliminate the nitric acid and obtain a final solution of 1–2 mL. Final solutions were diluted by deionized water, and heavy metals concentrations in these solutions were determined by an inductively coupled plasma mass spectrometry (ICP-MS; Agilent Co., Ltd., USA), the optimized instrumental parameters were referred to the study of Liu et al. (2020), the details are demonstrated in Supplementary Table 1.

## 2.3 Quality assurance and control

Recovery and quality assurance (QA)/quality control (QC) experiments were carried out to quantify the metal content in the samples. A procedural blank, a spiked blank, and a spiked sample were analyzed for every 10 samples to ensure the accuracy of the procedure. No target compounds were detected in the blank samples. Limit of detection (LOD) and limit of quantification (LOQ) were defined as the concentration corresponding to 3 and 10 times the standard deviation of 10 blanks. The limits of detection (LOD) for the five metals were 0.002, 0.05, 0.2, 0.02 and 0.5 mg/kg for Cd, Cu, Ni, Pb, and Zn, respectively. In this study, standard solutions of these studied metals were spiked and digested to check recovery, the mean recovery rates of these metals ranged from 80.5 to 105.3%. The relative standard deviation (RSD) was found within 5% in this study. Supplementary Table 2 summarize the quality assurance and control data.

## 2.4 Metal pollution index (MPI)

To assess the comprehensive pollution in fish, the total metal pollution index (MPI) was performed (Kwaansa-Ansah et al., 2019). The THQ was calculated as following:

$$\mathrm{MPI} = \sqrt[n]{\mathrm{C}_1 \times \mathrm{C}_2 \times \mathrm{C}_3 \cdots \mathrm{C}_n}$$

where $C_n$ is the content of metal n in fish samples (mg/kg, ww).

## 2.5 Health risk assessment

To estimate the health risks associated with metal-contaminated fish consumption, the target hazard quotient (THQ) was performed, which was defined as the ratio of estimated daily intake (EDI) to the reference dose (RfD). The value of THQ $\geq$ 1 indicates potential health risks associated with the consumption. The THQ was calculated as following formulas:

$$\mathrm{EDI} = (\mathrm{C} \times \mathrm{IR})/\mathrm{BW}$$

$$\mathrm{THQ} = \mathrm{EDI}/\mathrm{RfD}$$

where EDI is expressed as μg/kg·bw/day, C is the content of heavy metal (mg/kg, ww) in tissue, IR is daily average ingestion rate (134 g/day for adults, 60% of the data for children; Dirtu and Covaci, 2010; Fu et al., 2018), BW is the average body weight (60 kg for an adult and 30 kg for a child; Zhong et al., 2018), RfD is the oral reference dose (μg/kg/day), the values are 1 for Cd, 40 for Cu, 20 for Ni, 4 for Pb, and 300 for Zn, respectively (Cui et al., 2015).

Considering comprehensive pollution, the hazard index (HI) was used, and it was calculated as follows:

$$\mathrm{HI} = \sum \mathrm{THQs}$$

where THQs represents the THQ value of metals.

## 2.6 Statistical analysis

Data analysis and graphical representation was performed by SPSS 26.0 and Graphpad prism 7.0. Data were expressed as mean ± standard deviation (SD). To compare metal contents in

TABLE 2 Levels (mg/kg wet weight) of the five studied heavy metals in tissues of the studied fish species.

| | Ni | Cu | Zn | Cd | Pb | MPI |
|---|---|---|---|---|---|---|
| **Dorsal muscle** | | | | | | |
| *C. idellus* | 0.095 ± 0.032[a] | 0.362 ± 0.200[ab] | 6.502 ± 1.374[c] | ND | 0.108 ± 0.031[e] | 0.115 |
| *M. amblycephala* | 0.075 ± 0.053[a] | 0.456 ± 0.134[ab] | 6.635 ± 1.579[c] | 0.005 ± 0.006[b] | 0.050 ± 0.024[d] | 0.126 |
| *H. molitrix* | 0.188 ± 0.037[b] | 0.305 ± 0.058[ab] | 5.895 ± 0.691[bc] | 0.007 ± 0.001[b] | 0.017 ± 0.009[bc] | 0.127 |
| *H. nobilis* | 0.066 ± 0.045[a] | 0.294 ± 0.079[ab] | 3.047 ± 0.547[a] | 0.004 ± 0.004[ab] | 0.020 ± 0.006[c] | 0.070 |
| *C. auratus* | 0.072 ± 0.017[a] | 0.498 ± 0.024[b] | 8.371 ± 0.359[d] | 0.003 ± 0.000[b] | 0.063 ± 0.031[de] | 0.137 |
| *C. carpio* | 0.160 ± 0.025[b] | 0.444 ± 0.116[ab] | 13.860 ± 2.375[e] | ND | 0.005 ± 0.002[a] | 0.085 |
| *C. alburnus* | 0.075 ± 0.014[a] | 0.493 ± 0.134[ab] | 6.348 ± 0.831[c] | 0.001 ± 0.001[a] | 0.033 ± 0.017[cd] | 0.084 |
| *L. japonicus* | 0.045 ± 0.031[a] | 0.279 ± 0.030[a] | 4.436 ± 0.321[ab] | 0.003 ± 0.000[ab] | 0.009 ± 0.002[b] | 0.065 |
| **Ventral muscle** | | | | | | |
| *C. idellus* | 0.064 ± 0.030[ab] | 0.417 ± 0.111[a] | 5.493 ± 1.918[ab] | ND | 0.108 ± 0.051[d] | 0.106 |
| *M. amblycephala* | 0.081 ± 0.017[ab] | 0.710 ± 0.286[a] | 9.980 ± 2.601[c] | 0.003 ± 0.000[b] | 0.061 ± 0.026[cd] | 0.151 |
| *H. molitrix* | 0.543 ± 0.283[c] | 0.362 ± 0.139[a] | 9.431 ± 0.783[c] | 0.012 ± 0.001[c] | 0.022 ± 0.015[bc] | 0.202 |
| *H. nobilis* | 0.041 ± 0.021[a] | 0.350 ± 0.094[a] | 2.905 ± 1.042[a] | 0.001 ± 0.001[a] | 0.039 ± 0.015[bcd] | 0.065 |
| *C. auratus* | 0.127 ± 0.102[ab] | 0.733 ± 0.246[a] | 9.765 ± 2.951[c] | 0.003 ± 0.000[b] | 0.058 ± 0.019[cd] | 0.164 |
| *C. carpio* | 0.112 ± 0.028[b] | 0.469 ± 0.116[a] | 14.840 ± 2.426[d] | ND | 0.005 ± 0.001[a] | 0.083 |
| *C. alburnus* | 0.119 ± 0.132[ab] | 0.431 ± 0.076[a] | 6.585 ± 1.364[bc] | 0.001 ± 0.000[a] | 0.058 ± 0.028[cd] | 0.104 |
| *L. japonicus* | 0.047 ± 0.031[ab] | 0.416 ± 0.102[a] | 4.100 ± 0.227[a] | 0.003 ± 0.001[b] | 0.018 ± 0.007[b] | 0.083 |
| **Fish head** | | | | | | |
| *C. idellus* | 0.259 ± 0.071[a] | 0.327 ± 0.127[ab] | 8.262 ± 1.351[b] | ND | 0.032 ± 0.016[b] | 0.114 |
| *M. amblycephala* | 0.308 ± 0.114[ab] | 0.982 ± 0.570[c] | 10.711 ± 1.192[bc] | 0.002 ± 0.002[a] | 0.060 ± 0.019[b] | 0.191 |
| *H. molitrix* | 0.610 ± 0.173[d] | 0.333 ± 0.068[ab] | 9.538 ± 1.857[bc] | 0.016 ± 0.003[c] | 0.027 ± 0.008[b] | 0.239 |
| *H. nobilis* | 0.257 ± 0.047[a] | 0.182 ± 0.055[a] | 3.463 ± 0.310[a] | ND | 0.020 ± 0.009[b] | 0.071 |
| *C. auratus* | 0.426 ± 0.030[bc] | 0.436 ± 0.047[b] | 11.936 ± 0.941[c] | 0.005 ± 0.000[b] | 0.047 ± 0.049[b] | 0.206 |
| *C. carpio* | 0.358 ± 0.077[abc] | 0.248 ± 0.056[a] | 21.502 ± 5.254[d] | ND | 0.008 ± 0.004[a] | 0.106 |
| *C. alburnus* | 0.474 ± 0.112[c] | 0.199 ± 0.107[a] | 8.974 ± 0.324[b] | 0.002 ± 0.001[a] | 0.033 ± 0.029[b] | 0.126 |
| *L. japonicus* | 0.427 ± 0.050[bc] | 0.239 ± 0.095[a] | 8.303 ± 3.246[b] | 0.005 ± 0.000[b] | 0.006 ± 0.002[a] | 0.116 |

Different lowercase letters (a, b, c) represent significant differences ($P < 0.05$) among different fish species.

TABLE 3 Comparison of metals levels in this study with other studies (mg/kg wet weight).

| | Ni | Cu | Zn | Cd | Pb | References |
|---|---|---|---|---|---|---|
| Baishazhou market | 0.210 | 0.415 | 8.370 | 0.004 | 0.038 | The present study |
| Yellow River Estuary | 0.34 | 1.03 | 12.8 | 0.02 | 0.21 | Matovic et al., 2015 |
| Songhua Lake | ND-0.141 | 0.112–0.834 | 1.078–6.001 | ND-0.029 | ND-0.024 | Fang et al., 2019 |
| Pearl River Delta | 0.44–9.75 | 0.79–2.26 | 15.2–29.5 | 0.02–0.06 | 0.03–8.62 | Li et al., 2020 |
| Yangtze River | 0.02 | 0.97 | 6.13 | 0.07 | 1.04 | Zerizghi et al., 2020 |
| Dongting Lake[&] | 0.138 | 0.146 | 4.188 | 0.002 | 0.029 | Shen et al., 2020 |
| Chinese markets | 0.02 | 0.39 | 5.92 | 0.004 | 0.02 | Jiang et al., 2018 |
| Missouri market | 0.10 | 0.30 | 2.83 | 0.033 | 0.17 | Jia et al., 2018 |
| Noakhali fish market, Bangladesh[&] | 0.293 | 7.289 | 22.665 | - | 0.104 | Yin et al., 2019 |
| Asafo Market, Ghana | - | 0.020–0.156 | 0.016–0.022 | 0.007–0.019 | 0.054–0.085 | Yin et al., 2018 |

[&]Means values were transformed from the reported dry weight to wet weight, considering the water content in fish was 80% (Saha et al., 2016).
"-" means no data.

different fish species, trophic levels and habitat preference, the data were firstly test using SPSS, Shapiro-Wilks and Levene's tests were performed to test the normal distribution and homogeneity of the variances, respectively. When the data were normally distributed, one-way analysis of variance (ANOVA) followed by Duncan's *post-hoc* test was performed, otherwise, non-parametric statistical analysis on ranks (Kruskal-Wallis) followed by Dunn-Bonferroni *post-hoc* test was performed (Yin et al., 2020). If the concentration of a heavy metal was lower than the limit of detection (LOD), half of the LOD was assigned for data analysis (Cheng et al., 2019). The level of significance was set at $P < 0.05$.

## 3 Results

### 3.1 The levels of metals in fish samples

The concentrations of targeted metals in different fish species are presented in Table 2. Zn was the most abundant element in fish among these elements, the maximum concentration of 21.502 mg/kg in head of *C. carpio* and the minimum level of 2.905 mg/kg in ventral muscle of *H. nobilis* were found with a mean value of 8.370 mg/kg. In the three edible parts, Zn in *C. carpio* was much higher than that in others ($P < 0.05$). Cu exhibited a relatively higher concentration than others except for Zn, with a mean concentration of 0.415 mg/kg. Cu in *C. auratus* was significantly higher than that in *L. japonicus* of the dorsal muscle, while in head, Cu in *M. amblycephala* was much higher than others with the highest concentration 0.982 mg/kg. Among these studied metals, the concentration of Cd was the lowest, and in the fish species of *C. idellus* and *C. carpio*, no Cd was detected, the maximum level of Cd was found in the head of *H. molitrix* (0.016 mg/kg). For metal Ni, the concentration ranged from 0.041 to 0.610 mg/kg, with a mean concentration of 0.210 mg/kg. In these studied fish, *H. molitrix* showed a significant higher content of Ni than others in all dorsal muscle, ventral muscle and head tissues ($P < 0.05$). Pb in *C. carpio* was significantly lower than other fish species and the minimum level of Pb was found in dorsal muscle of *C. carpio* (0.005 mg/kg), while the maximum level of Pb was in ventral muscle of *C. idellus* (0.108 mg/kg). As a whole, the mean concentrations of the 5 studied heavy metals in fish decreased in the order of: Zn (8.370 mg/kg) > Cu (0.415 mg/kg) > Ni (0.210 mg/kg) > Pb (0.038 mg/kg) > Cd (0.004 mg/kg), this accumulation pattern is in line with the reported literature (Table 3).

### 3.2 Metal distribution in fish of different trophic levels and habitat preference

To better compare the metal distribution in different fish species, the studied fish were divided into 4 trophic levels and 3 habitat preference, and the results are exhibited in Figure 1. For metal Ni, it could be observed that only trophic levels influence the accumulation of Ni in fish head, and carnivorous fish had a higher accumulation of Ni than herbivorous fish. For metal Cd and Pb, habitat preference did not result in the difference contents of them in different fish species, however, trophic levels did, and for dorsal muscle, Cd level in carnivorous fish was lower than filter feeder and omnivorous, while for head, Cd level in filter feeder was higher than others. Pb level in herbivorous fish was much higher than others in both dorsal muscle and ventral muscle, while for head, Pb level in herbivorous fish was higher than that in carnivorous fish.

The accumulation of Cu and Zn in fish species not only influenced by trophic levels but also affected by habitat preference. Cu content in filter feeder fish was significantly lower than that in omnivorous for both dorsal muscle and ventral muscle, while Cu in herbivorous fish was higher than that in carnivorous for head. Considering habitat preference, demersal fish had a higher accumulation of Cu than that in pelagic fish in tissues of ventral muscle and head, besides, benthopelagic fish showed a higher accumulation of Cu than that in pelagic fish. Zn content in omnivorous was highest than that in others, additionally, Zn in demersal fish was higher than that in benthopelagic and pelagic fish for dorsal muscle, ventral muscle and head.

### 3.3 Metal pollution index (MPI)

The comprehensive pollution status of metals in fish is assessed using the total metal pollution index (MPI), and the results of MPI for different fish species are shown in Table 2. MPI values were in the range of 0.065–0.137, 0.083–0.202, and 0.071–0.239 for dorsal muscle, ventral muscle and head, respectively. By summing the MPI values of the three tissues in the same fish, the distribution pattern of MPI in the studied fish species follows a specific order: *H. molitrix* (0.568) > *C. auratus* (0.508) > *M. amblycephala* (0.469) > *C. idellus* (0.336) > *C. alburnus* (0.315) > *C. carpio* (0.274) > *L. japonicus* (0.263) > *H. nobilis* (0.206).

### 3.4 Potential health risk assessment

The THQs of elements through fish consumption for population of adults and children are presented in Table 4. For the present evaluation, in adult population, the mean THQ values of fish were 0.023 for Ni (range: 0.005–0.068), 0.023 for Cu (range: 0.010–0.055), 0.062 for Zn (range: 0.022–0.160), 0.007 for Cd (range: 0–0.035), and 0.021 for Pb (range: 0.003–0.060). While in children population, the mean THQ values of fish were 0.028 for Ni (range: 0.006–0.082), 0.028 for Cu (range: 0.012–0.066), 0.075 for Zn (range: 0.026–0.192), 0.008 for Cd (range: 0–0.042), and 0.025 for Pb (range: 0.003–0.072). The THQ values for fish consumption were all <1 for all fish species. Besides, the HI values in dorsal muscle, ventral muscle and head of the same fish were added to compare the potential risk of the whole fish, and the values were in the range of 0.206–0.519 for adults and 0.248–0.622 for children, with the lowest value in *H. nobilis* and highest value in *C. carpio*, respectively.

## 4 Discussion

In the present study, the mean concentrations of the studied five metals in all fish samples were much lower than the Chinese and FAO regulatory limits, which were below the limits of 30 mg/kg for Zn and Cu set in FAO (Achary et al., 2017), 0.5 mg/kg

 10.3389/fsufs.2024.1346389

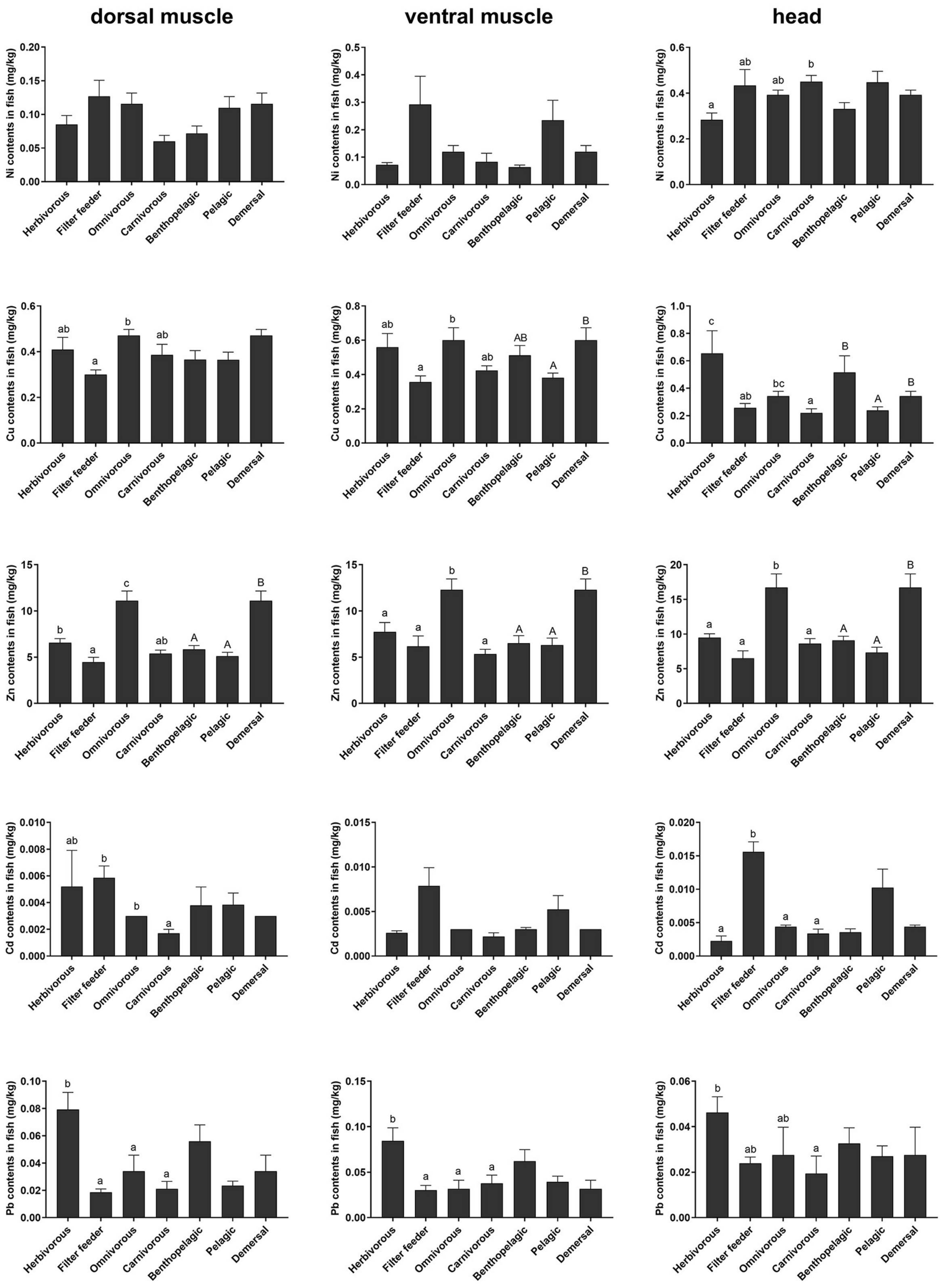


FIGURE 1
Metals (Ni, Cu, Zn, Cd, and Pb) levels in the tissues of fish species with different trophic levels and habitat preference. Lowercase letters (a, b, c) represent significant differences ($P < 0.05$) among different trophic levels, capital letters (A, B, C) represent significant differences ($P < 0.05$) among different habitat preference.

TABLE 4 The target hazard quotient (THQ) and hazard index (HI) for exposure population adults and children.

| Fish species | Tissues | Adults | | | | | | Children | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ni | Cu | Zn | Cd | Pb | HI | Ni | Cu | Zn | Cd | Pb | HI |
| *C. idellus* | Dorsal muscle | 0.011 | 0.020 | 0.048 | ND | 0.060 | 0.139 | 0.013 | 0.024 | 0.058 | ND | 0.072 | 0.167 |
| | Ventral muscle | 0.007 | 0.023 | 0.041 | ND | 0.060 | 0.132 | 0.009 | 0.028 | 0.049 | ND | 0.072 | 0.158 |
| | Head | 0.029 | 0.018 | 0.061 | ND | 0.018 | 0.127 | 0.035 | 0.022 | 0.074 | ND | 0.022 | 0.152 |
| | *Σ* | 0.047 | 0.061 | 0.15 | ND | 0.138 | 0.398 | 0.057 | 0.074 | 0.181 | ND | 0.166 | 0.477 |
| *M. amblycephala* | Dorsal muscle | 0.008 | 0.025 | 0.049 | 0.012 | 0.028 | 0.123 | 0.010 | 0.030 | 0.059 | 0.014 | 0.034 | 0.147 |
| | Ventral muscle | 0.009 | 0.039 | 0.074 | 0.006 | 0.034 | 0.162 | 0.011 | 0.047 | 0.089 | 0.007 | 0.041 | 0.195 |
| | Head | 0.035 | 0.055 | 0.080 | 0.004 | 0.033 | 0.206 | 0.042 | 0.066 | 0.096 | 0.005 | 0.040 | 0.248 |
| | *Σ* | 0.052 | 0.119 | 0.203 | 0.022 | 0.095 | 0.491 | 0.063 | 0.143 | 0.244 | 0.026 | 0.115 | 0.59 |
| *H. molitrix* | Dorsal muscle | 0.021 | 0.017 | 0.044 | 0.015 | 0.009 | 0.106 | 0.025 | 0.020 | 0.053 | 0.018 | 0.011 | 0.127 |
| | Ventral muscle | 0.061 | 0.020 | 0.070 | 0.027 | 0.012 | 0.190 | 0.073 | 0.024 | 0.084 | 0.032 | 0.014 | 0.228 |
| | Head | 0.068 | 0.019 | 0.071 | 0.035 | 0.015 | 0.208 | 0.082 | 0.022 | 0.085 | 0.042 | 0.018 | 0.249 |
| | *Σ* | 0.15 | 0.056 | 0.185 | 0.077 | 0.036 | 0.504 | 0.18 | 0.066 | 0.222 | 0.092 | 0.043 | 0.604 |
| *H. nobilis* | Dorsal muscle | 0.007 | 0.016 | 0.022 | 0.004 | 0.011 | 0.061 | 0.009 | 0.019 | 0.027 | 0.005 | 0.013 | 0.073 |
| | Ventral muscle | 0.005 | 0.019 | 0.022 | 0.001 | 0.022 | 0.069 | 0.006 | 0.023 | 0.026 | 0.001 | 0.026 | 0.083 |
| | Head | 0.029 | 0.010 | 0.026 | ND | 0.011 | 0.076 | 0.035 | 0.012 | 0.031 | ND | 0.014 | 0.092 |
| | *Σ* | 0.041 | 0.045 | 0.07 | 0.005 | 0.044 | 0.206 | 0.05 | 0.054 | 0.084 | 0.006 | 0.053 | 0.248 |
| *C. auratus* | Dorsal muscle | 0.008 | 0.028 | 0.062 | 0.006 | 0.035 | 0.140 | 0.010 | 0.033 | 0.075 | 0.008 | 0.042 | 0.168 |
| | Ventral muscle | 0.014 | 0.041 | 0.073 | 0.006 | 0.032 | 0.166 | 0.017 | 0.049 | 0.087 | 0.007 | 0.038 | 0.199 |
| | Head | 0.047 | 0.024 | 0.089 | 0.010 | 0.026 | 0.197 | 0.057 | 0.029 | 0.106 | 0.012 | 0.031 | 0.236 |
| | *Σ* | 0.069 | 0.093 | 0.224 | 0.022 | 0.093 | 0.503 | 0.084 | 0.111 | 0.268 | 0.027 | 0.111 | 0.603 |
| *C. carpio* | Dorsal muscle | 0.018 | 0.025 | 0.103 | ND | 0.003 | 0.148 | 0.021 | 0.030 | 0.124 | ND | 0.003 | 0.178 |
| | Ventral muscle | 0.012 | 0.026 | 0.110 | ND | 0.003 | 0.152 | 0.015 | 0.031 | 0.132 | ND | 0.003 | 0.182 |
| | Head | 0.040 | 0.014 | 0.160 | ND | 0.004 | 0.219 | 0.048 | 0.017 | 0.192 | ND | 0.005 | 0.262 |
| | *Σ* | 0.07 | 0.065 | 0.373 | ND | 0.01 | 0.519 | 0.084 | 0.078 | 0.448 | ND | 0.011 | 0.622 |
| *C. alburnus* | Dorsal muscle | 0.008 | 0.027 | 0.047 | 0.002 | 0.018 | 0.103 | 0.010 | 0.033 | 0.057 | 0.002 | 0.022 | 0.124 |
| | Ventral muscle | 0.013 | 0.024 | 0.049 | 0.002 | 0.032 | 0.121 | 0.016 | 0.029 | 0.059 | 0.003 | 0.039 | 0.145 |
| | Head | 0.053 | 0.011 | 0.067 | 0.002 | 0.019 | 0.152 | 0.064 | 0.013 | 0.080 | 0.003 | 0.022 | 0.182 |
| | *Σ* | 0.074 | 0.062 | 0.163 | 0.006 | 0.069 | 0.376 | 0.09 | 0.075 | 0.196 | 0.008 | 0.083 | 0.451 |
| *L. japonicus* | Dorsal muscle | 0.005 | 0.015 | 0.033 | 0.006 | 0.005 | 0.064 | 0.006 | 0.018 | 0.040 | 0.007 | 0.006 | 0.077 |
| | Ventral muscle | 0.005 | 0.023 | 0.031 | 0.007 | 0.010 | 0.076 | 0.006 | 0.028 | 0.037 | 0.009 | 0.012 | 0.091 |
| | Head | 0.048 | 0.013 | 0.062 | 0.011 | 0.003 | 0.137 | 0.057 | 0.016 | 0.074 | 0.013 | 0.004 | 0.164 |
| | *Σ* | 0.058 | 0.051 | 0.126 | 0.024 | 0.018 | 0.277 | 0.069 | 0.062 | 0.151 | 0.029 | 0.022 | 0.332 |

*Σ* represents the sum of THQ value of dorsal muscle, ventral muscle and head.

for Ni set in WHO (Storelli et al., 2020), and 0.5 mg/kg for Pb, 0.1 mg/kg for Cd set in GB 2762-2022 (2022), respectively. Based on the distribution of the content of these five metals in the main edible parts of fish, including the dorsal muscle, ventral muscle, and fish head, it was found that the metal accumulation in fish head is significantly higher than in the dorsal and ventral muscles. In other published literatures, similar results have also been observed that Cd content in fish head is higher than that in muscle (Mukherjee et al., 2022), Ni and Zn also accumulate more in the bones of fish than that in muscles (Jabeen et al., 2012; Dutton and Fisher, 2014). The higher content of these metals in fish head may be related to the higher bone content in fish head. This is supported by our previous study on Cr, in which the fish head was divided into seven different parts, and it was found that Cr primarily deposits in the bones (Yin et al., 2023).

The average concentration of the five studied metals in fishes is ranked as follows: Zn > Cu > Ni > Pb > Cd, the same pattern has also been observed in the study of Liu et al. (2018). The different accumulation of these metals may be related to their different solubility, generally in the order of Zn > Cu > Ni > Cd > Pb (Foster and Charlesworth, 1996; Liu et al., 2018). Besides, the level of metals in organisms is generally related to their function and biokinetics. For example, previous studies have demonstrated that essential elements required for life are more readily available in fish species compared to non-essential elements, leading to a relatively higher abundance of essential elements in organisms (Yu et al., 2020). Similarly, in our study, the contents of Zn and Cu in these studied fish species were also exceeded those of Cd and Pb. As shown in Table 3, comparing these studied metals concentrations in our study with other publications, the metal levels in fish collected from Baishazhou Market were lower than that in Pearl River Delta (Leung et al., 2014), but slightly higher than that in the study of Sun et al. (2022), in which the heavy metals were investigated in fish collected from five regions (Northeast, Northwest, North Coast, South Coast, and Midland) of China. These differences are most probably linked to the time and region of the collection of fish samples as well as the fish species.

Metal levels in fish are usually species-dependent, and the bioaccumulation of metals is influenced by the living habitat and feeding habits of fish has been demonstrated (Jiang et al., 2022; Cai et al., 2023; Wu et al., 2023). The studied eight fish species were divided into four trophic levels and three habitat preference. Some studies have demonstrated that the carnivorous fish showed higher metal levels in their muscle than other fish species (Jiang et al., 2018, 2022). However, in the present study, Zn levels in carnivorous fish were relatively lower than that in omnivorous, which was in line with previous study, the difference may be attributed to the uptake route of nutrition elements (Jia et al., 2017). Besides, the Cd levels in carnivorous fish were also significantly higher than that in filter feeder fish. As the Baishazhou market could receive fish from different regions, the metal levels in fish are not only related to the feeding habits of fish, but also related to the sampling locations of these fish (Liu et al., 2018).

Considering the fish with different living habitat, demersal fish had the highest levels of Cu and Zn, as demersal fish could absorb heavy metals from the bottom sediment (Cai et al., 2023). Thus, these demersal fish usually exhibited higher metal levels than others (Wei et al., 2014; Jiang et al., 2018; Liu et al., 2018; Hossain et al., 2022). Ni usually presents in the environment at a very low level, however, it can cause adverse health effects such as lung inflammation, fibrosis and tumors (Forti et al., 2011). No significant differences were observed among the fish with different living habitat. For Cd and Pb, which are extremely hazardous elements for organisms, the highest level of Cd and Pb was detected in *H. molitrix* (filter feeder) and *C. idellus* (herbivorous), respectively. These results were different compared with the previous study (Jiang et al., 2018), in which *H. molitrix* showed the lowest concentration of Cd and *C. idellus* showed the lowest concentration of Pb. The variation in metal levels within the same fish species may be attributed to the specific environment characteristics of each site, as the environmental conditions (such as the water quality) could influence the bioavailability of metals (Marengo et al., 2018).

A correlation analysis of the content of these different metals in tissues was conducted (Supplementary Table 3), and the results showed no significant correlation among the elements, indicating that the sources of these metals may be different. As the fish used in this study was obtained from the Baishazhou aquatic product trading market, these fish are more likely to be from pond aquaculture rather than wild-caught fish. Thus, the metal content in the feed of these 8 fish species was determined (Supplementary Table 4) and the correlation analysis between the metal content in the feed and the metal content in the fish tissues was established (Supplementary Table 5). It is observed that the content of Ni and Cu in feed is positively correlated with the content of Ni and Cu in tissues, while the content of Zn and Pb in feed is negatively correlated with the content of Zn and Pb in tissues, although the correlations are not significant. This suggests that the metal content in feed is not the primary source of metals in fish tissues in this study. The source of metals in fish species in this study may be related to their living environment or other factors.

The total metal pollution index (MPI) is commonly utilized to evaluate the comprehensive pollution status, and higher MPI values indicates greater contamination (Marengo et al., 2018). As depicted in Table 2, the MPI values in fish muscle exhibit significant correlations with fish species. Despite both species belonging to the same filter feeder and pelagic habitat, the MPI values in *H. molitrix* were relatively higher than those in *H. nobilis,* suggesting distinct accumulation pattern between the two species. Furthermore, the MPI values of the studied fish (such as *C. auratus*, *H. molitrix*, and *C. carpio*) in the present study were lower than those reported in certain studies (Liu et al., 2022; Cai et al., 2023), indicating potential variations in metal pollution levels across different study areas.

Health risk assessment has been extensively employed to evaluate the potential risk associated with the contaminated-fish consumption, and provide evidence of risk to the decision-makers (Gao et al., 2022). In the current investigation, the THQ values exhibited variability across distinct metals and fish species. Notably, the THQ values were all lower than 1, indicating that both adults and children populations are unlikely to encounter substantial health risks linked to the consumption of these studied fish species. Nevertheless, different potential health risks for different exposure groups could be manifested by the THQ values, and children population showed a higher potential risk compared to adults. Similar results were also found in other reports (Kumari et al., 2018; Hossain et al., 2022). Generally, if fish are exposed to more than one heavy metal at the same time, it is important to take into account the cumulative effects of these metals (Cheng et al., 2013). The results of HI values indicate that the consumption of omnivorous and demersal fish by both adults and children presents a relatively higher potential health risk compared to the consumption of herbivorous and benthopelagic fish, respectively.

It is worth noting that, besides dorsal muscle and ventral muscle, the head of fish is also a main edible portion, and our previous research has illustrated that fish head contaminated with Cr pose a higher potential health risk for consumers than muscles (Yin et al., 2019). Thus, it is imperative to consider the health risk assessment associated with the consumption of fish head. The present study reveals that the risk of consuming fish head is higher compared to the consumption of dorsal and ventral muscle. Notably, the highest HI values for fish head consumption in both the adults and children were observed in *C. carpio*, followed by *H. molitrix*, *M. amblycephala*, *C. auratus*, *C. alburnus*, *L. japonicus*, *C. idellus*, and *H. nobilis*. It is a good new for fish head lover as *H. nobilis* is a typical bighead fish as its head comprises ∼34% of the whole fish and is deeply loved by Chinese owing to its nutrition and delicious taste (Hong et al., 2013). Moreover, while fish may be at risk of metal contamination, it is believed that the increased consumption of fish and seafood, with their higher nutritional value and health benefits, far outweighs the potential negative risks to human health.

## 5 Conclusions

In this study, levels of five metals in eight fish species collected from the Baishazhou market in Wuhan were determined. The mean concentrations across all samples followed the order: Zn > Cu > Ni > Pb > Cd, These concentrations were found to be well below the regulatory limits set by Chinese and FAO standards. Furthermore, the metal concentrations exhibited variations among different fish tissues and species. Among fish species occupying different trophic levels, omnivorous fish exhibited higher accumulations of Cu and Zn compared to filter feeder fish, while filter feeder fish showed significantly elevated Cd levels relative to carnivorous fish. Herbivorous fish displayed greater Pb accumulation than other trophic groups. In terms of habitat preference, demersal fish demonstrated significant Cu and Zn accumulations compared to pelagic fish. The health risk assessment suggests that the consumption of these fish species is safe. However, the higher metal content in fish heads compared to muscle should be considered, particularly for consumers who enjoy consuming fish heads.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

## Ethics statement

The animal study was approved by the present experiment was carried out in accordance with the Attitude of the Animal Management and Ethics Committee of Huazhong Agricultural University, Wuhan, China (HZAUFI-2020-0027). The study was conducted in accordance with the local legislation and institutional requirements.

## Author contributions

JY: Conceptualization, Funding acquisition, Writing—original draft, Writing—review & editing. LC: Writing—original draft, Writing—review & editing. XJ: Formal analysis, Writing—original draft. LW: Formal analysis, Writing—original draft. PG: Investigation, Writing—original draft. WZ: Investigation, Writing—original draft. XZ: Resources, Supervision, Writing—review & editing.

## Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This study was supported by the Research Funding of Wuhan Polytechnic University (Grant No. 2022RZ037).

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1346389/full#supplementary-material

## References

Achary, M. S., Satpathy, K. K., Panigrahi, S., Mohanty, A. K., Padhi, R. K., Biswas, S., et al. (2017). Concentration of heavy metals in the food chain components of the nearshore coastal waters of Kalpakkam, southeast coast of India. *Food Control* 72, 232–243. doi: 10.1016/j.foodcont.2016.04.028

Banerjee, S., Maiti, S. K., and Kumar, A. (2015). Metal contamination in water and bioaccumulation of metals in the planktons, molluscs and fishes in Jamshedpur stretch of Subarnarekha River of Chotanagpur plateau, India. *Water Environ. J.* 29, 207–213. doi: 10.1111/wej.12108

Cai, J., Li, Y., Liu, S., Liu, Q., Xu, M., Zhang, J., et al. (2022). Associations between multiple heavy metals exposure and glycated hemoglobin in a Chinese population. *Chemosphere* 287:132159. doi: 10.1016/j.chemosphere.2021.132159

Cai, S., Zeng, B., and Li, C. (2023). Potential health risk assessment of metals in the muscle of seven wild fish species from the Wujiangdu reservoir, China. *Qual. Assur. Saf. Crops Foods* 15, 73–83. doi: 10.15586/qas.v15i1.1121

Cheng, J., Zhang, X., Ren, S., Wang, T., and Tang, Z. (2019). Metals in wild fish from Gaotang Lake in the area of coal mining, China: assessment of the risk to human health. *Environ. Sci. Pollut. Res.* 26, 23754–23762. doi: 10.1007/s11356-019-05732-8

Cheng, Z., Man, Y. B., Nie, X. P., and Wong, M. H. (2013). Trophic relationships and health risk assessments of trace metals in the aquaculture pond ecosystem of Pearl River Delta, China. *Chemosphere* 90, 2142–2148. doi: 10.1016/j.chemosphere.2012.11.017

Cui, L., Ge, J., Zhu, Y., Yang, Y., and Wang, J. (2015). Concentrations, bioaccumulation, and human health risk assessment of organochlorine pesticides and heavy metals in edible fish from Wuhan, China. *Environ. Sci. Pollut. Res.* 22, 15866–15879. doi: 10.1007/s11356-015-4752-8

Dirtu, A. C., and Covaci, A. (2010). Estimation of daily intake of organohalogenated contaminants from food consumption and indoor dust ingestion in Romania. *Environ. Sci. Technol.* 44, 6297–6304. doi: 10.1021/es101233z

Djedjibegovic, J., Marjanovic, A., Tahirovic, D., Caklovica, K., Turalic, A., Lugusic, A., et al. (2020). Heavy metals in commercial fish and seafood products and risk assessment in adult population in Bosnia and Herzegovina. *Sci. Rep*. 10, 13238–13238. doi: 10.1038/s41598-020-70205-9

Dutton, J., and Fisher, N. S. (2014). Modeling metal bioaccumulation and tissue distribution in killifish (*Fundulus heteroclitus*) in three contaminated estuaries. *Environ. Toxicol. Chem*. 33, 89–101. doi: 10.1002/etc.2392

Fang, T., Lu, W., Cui, K., Li, J., Yang, K., Zhao, X., et al. (2019). Distribution, bioaccumulation and trophic transfer of trace metals in the food web of Chaohu Lake, Anhui, China. *Chemosphere* 218, 1122–1130. doi: 10.1016/j.chemosphere.2018.10.107

Forti, E., Salovaara, S., Cetin, Y., Bulgheroni, A., Tessadri, R., Jennings, P., et al. (2011). *In vitro* evaluation of the toxicity induced by nickel soluble and particulate forms in human airway epithelial cells. *Toxicol. Vitro* 25, 454–461. doi: 10.1016/j.tiv.2010.11.013

Fosmire, G. J. (1990). Zinc toxicity. *Am. J. Clin. Nutr*. 51, 225–227. doi: 10.1093/ajcn/51.2.225

Foster, I. D. L., and Charlesworth, S. M. (1996). Heavy metals in the hydrological cycle: trends and explanation. *Hydrol. Process*. 10, 227–261. doi: 10.1002/(SICI)1099-1085(199602)10:2<227::AID-HYP357>3.0.CO;2-X

Fu, L., Lu, X., Tan, J., Zhang, H., Zhang, Y., Wang, S., et al. (2018). Bioaccumulation and human health risks of OCPs and PCBs in freshwater products of Northeast China. *Environ. Pollut*. 242, 1527–1534. doi: 10.1016/j.envpol.2018.08.046

Gao, L., Huang, X. L., Wang, P., Chen, Z., Hao, Q., Bai, S., et al. (2022). Concentrations and health risk assessment of 24 residual heavy metals in Chinese mitten crab (*Eriocheir sinensis*). *Qual. Assur. Saf. Crops Foods* 14, 82–91. doi: 10.15586/qas.v14i1.1034

GB 2762-2022 (2022). *National Food Safety Standards—Maximum Levels of Contaminants in Foods*.

Ge, M., Liu, G., Liu, H., and Liu, Y. (2020). Levels of metals in fish tissues of *Liza haematocheila* and *Lateolabrax japonicus* from the Yellow River Delta of China and risk assessment for consumers. *Mar. Pollut. Bullet*. 157:111286. doi: 10.1016/j.marpolbul.2020.111286

Haidar, Z., Fatema, K., Shoily, S. S., and Sajib, A. A. (2023). Disease-associated metabolic pathways affected by heavy metals and metalloid. *Toxicol. Rep*. 10, 554–570. doi: 10.1016/j.toxrep.2023.04.010

He, Y., Fang, H., Pan, X., Zhu, B., Chen, J., Wang, J., et al. (2023). Cadmium exposure in aquatic products and health risk classification assessment in residents of Zhejiang, China. *Foods* 12:163094. doi: 10.3390/foods12163094

Hong, H., Luo, Y., Zhou, Z., Bao, Y., Lu, H., Shen, H., et al. (2013). Effects of different freezing treatments on the biogenic amine and quality changes of bighead carp (*Aristichthys nobilis*) heads during ice storage. *Food Chem*. 138, 1476–1482. doi: 10.1016/j.foodchem.2012.11.031

Hossain, M. B., Tanjin, F., Rahman, M. S., Yu, J., Akhter, S., Abu Noman, M., et al. (2022). Metals bioaccumulation in 15 commonly consumed fishes from the lower Meghna river and adjacent areas of Bangladesh and associated human health hazards. *Toxics* 10:30139. doi: 10.3390/toxics10030139

Islam, M. S., Ahmed, M. K., and Habibullah-Al-Mamun, M. (2017). Heavy metals in sediment and their accumulation in commonly consumed fish species in Bangladesh. *Archiv. Environ. Occup. Health* 72, 26–38. doi: 10.1080/19338244.2016.1152946

Jabeen, G., Javed, M., and Azmat, H. (2012). Assessment of heavy metals in the fish collected from the River Ravi, Pakistan. *Pak. Vet. J*. 32, 107–111. Available online at: https://api.semanticscholar.org/CorpusID:85678115

Jia, Y., Wang, L., Cao, J., Li, S., and Yang, Z. (2018). Trace elements in four freshwater fish from a mine-impacted river: spatial distribution, species-specific accumulation, and risk assessment. *Environ. Sci. Pollut. Res*. 25, 8861–8870. doi: 10.1007/s11356-018-1207-z

Jia, Y., Wang, L., Qu, Z., Wang, C., and Yang, Z. (2017). Effects on heavy metal accumulation in freshwater fishes: species, tissues, and sizes. *Environ. Sci. Pollut. Res*. 24, 9379–9386. doi: 10.1007/s11356-017-8606-4

Jiang, X., Wang, J., Pan, B., Li, D., Wang, Y., Liu, X., et al. (2022). Assessment of heavy metal accumulation in freshwater fish of Dongting Lake, China: effects of feeding habits, habitat preferences and body size. *J. Environ. Sci*. 112, 355–365. doi: 10.1016/j.jes.2021.05.004

Jiang, Z., Xu, N., Liu, B., Zhou, L., Wang, J., Wang, C., et al. (2018). Metal concentrations and risk assessment in water, sediment and economic fish species with various habitat preferences and trophic guilds from Lake Caizi, Southeast China. *Ecotoxicol. Environ. Saf*. 157, 1–8. doi: 10.1016/j.ecoenv.2018.03.078

Kumari, P., Chowdhury, A., and Maiti, S. K. (2018). Assessment of heavy metal in the water, sediment, and two edible fish species of Jamshedpur Urban Agglomeration, India with special emphasis on human health risk. *Hum. Ecol. Risk Assess*. 24, 1477–1500. doi: 10.1080/10807039.2017.1415131

Kumari, P., and Maiti, S. K. (2020). Metal(loid) contamination in water, sediment, epilithic periphyton and fish in three interconnected ecosystems and health risk assessment through intake of fish cooked in Indian style. *Environ. Sci. Pollut. Res*. 20:8. doi: 10.1007/s11356-020-10023-8

Kwaansa-Ansah, E. E., Nti, S. O., and Opoku, F. (2019). Heavy metals concentration and human health risk assessment in seven commercial fish species from Asafo Market, Ghana. *Food Sci. Biotechnol*. 28, 569–579. doi: 10.1007/s10068-018-0485-z

Leung, H. M., Leung, A. O. W., Wang, H. S., Ma, K. K., Liang, Y., Ho, K. C., et al. (2014). Assessment of heavy metals/metalloid (As, Pb, Cd, Ni, Zn, Cr, Cu, Mn) concentrations in edible fish species tissue in the Pearl River Delta (PRD), China. *Mar. Pollut. Bullet*. 78, 235–245. doi: 10.1016/j.marpolbul.2013.10.028

Li, J., Miao, X., Hao, Y., Xie, Z., Zou, S., Zhou, C., et al. (2020). Health risk assessment of metals (Cu, Pb, Zn, Cr, Cd, As, Hg, Se) in angling fish with different lengths collected from Liuzhou, China. *Int. J. Environ. Res. Public Health* 17:72192. doi: 10.3390/ijerph17072192

Liu, H., Liu, G., Wang, S., Zhou, C., Yuan, Z., Da, C., et al. (2018). Distribution of heavy metals, stable isotope ratios (delta C-13 and delta N-15) and risk assessment of fish from the Yellow River Estuary, China. *Chemosphere* 208, 731–739. doi: 10.1016/j.chemosphere.2018.06.028

Liu, S., Liu, Y., Yang, D., Li, C., Zhao, Y., Ma, H., et al. (2020). Trace elements in shellfish from Shenzhen, China: implication of coastal water pollution and human exposure. *Environ. Pollut*. 263:114582. doi: 10.1016/j.envpol.2020.114582

Liu, X. B., Lin, C., Wu, Y. Y., Huang, H. N., Zhu, L. T., Jiang, R., et al. (2022). Dataset-based assessment of heavy metal contamination in freshwater fishes and their health risks. *Environ. Sci. Pollut. Res*. 22:19427. doi: 10.1007/s11356-022-19427-0

Marengo, M., Durieux, E. D. H., Ternengo, S., Lejeune, P., Degrange, E., Pasqualini, V., et al. (2018). Comparison of elemental composition in two wild and cultured marine fish and potential risks to human health. *Ecotoxicol. Environ. Saf*. 158, 204–212. doi: 10.1016/j.ecoenv.2018.04.034

Matovic, V., Buha, A., Dukic-Cosic, D., and Bulat, Z. (2015). Insight into the oxidative stress induced by lead and/or cadmium in blood, liver and kidneys. *Food Chem. Toxicol*. 78, 130–140. doi: 10.1016/j.fct.2015.02.011

Mukherjee, A. G., Wanjari, U. R., Renu, K., Vellingiri, B., and Gopalakrishnan, A. V. (2022). Heavy metal and metalloid-induced reproductive toxicity. *Environ. Toxicol. Pharmacol*. 92:103859. doi: 10.1016/j.etap.2022.103859

Saha, N., Mollah, M. Z. I., Alam, M. F., and Rahman, M. S. (2016). Seasonal investigation of heavy metals in marine fishes captured from the Bay of Bengal and the implications for human health risk assessment. *Food Control* 70, 110–118. doi: 10.1016/j.foodcont.2016.05.040

Sandstead, H. H. (1994). Understanding zinc—recent observations and interpretations. *J. Lab. Clin. Med*. 124, 322–327.

Shen, M., Kang, C., Song, T., Lu, H., Wang, Y., Yu, B., et al. (2020). Content and health risk assessment of heavy metals and polybrominated diphenyl ethers in fish from Songhua Lake (Jilin City), China. *Environ. Sci. Pollut. Res. Int*. 20:10067. doi: 10.1007/s11356-020-10067-w

Storelli, A., Barone, G., Dambrosio, A., Garofalo, R., Busco, A., Storelli, M. M., et al. (2020). Occurrence of trace metals in fish from South Italy: assessment risk to consumer's health. *J. Food Composit. Anal*. 90:103487. doi: 10.1016/j.jfca.2020.103487

Sun, S., Zhang, H., Luo, Y., Guo, C., Ma, X., Fan, J., et al. (2022). Occurrence, accumulation, and health risks of heavy metals in Chinese market baskets. *Sci. Tot. Environ*. 829:154597. doi: 10.1016/j.scitotenv.2022.154597

Varol, M., and Sunbul, M. R. (2018). Multiple approaches to assess human health risks from carcinogenic and non-carcinogenic metals via consumption of five fish species froma large reservoir in Turkey. *Sci. Tot. Environ*. 633, 684–694. doi: 10.1016/j.scitotenv.2018.03.218

Wan, F., Zhong, G., Ning, Z., Liao, J., Yu, W., Wang, C., et al. (2020). Long-term exposure to copper induces autophagy and apoptosis through oxidative stress in rat kidneys. *Ecotoxicol. Environ. Saf*. 190:110158. doi: 10.1016/j.ecoenv.2019.110158

Wang, T., Yan, J., Ma, J., Li, F., Liu, C., Cai, Y., et al. (2018). A fuzzy comprehensive assessment and hierarchical management system for urban lake health: a case study on the Lakes in Wuhan City, Hubei Province, China. *Int. J. Environ. Res. Public Health* 15:122617. doi: 10.3390/ijerph15122617

Wei, Y., Zhang, J., Zhang, D., Tu, T., and Luo, L. (2014). Metal concentrations in various fish Organs of different fish species from Poyang Lake, China. *Ecotoxicol. Environ. Saf*. 104, 182–188. doi: 10.1016/j.ecoenv.2014.03.001

Wu, D., Feng, H., Zou, Y., Xiao, J., Zhang, P., Ji, Y., et al. (2023). Feeding habit-specific heavy metal bioaccumulation and health risk assessment of fish in a tropical reservoir in Southern China. *Fishes* 8:40211. doi: 10.3390/fishes8040211

Yin, J., Liu, Q., Wang, L., Li, J., Li, S., Zhang, X., et al. (2018). The distribution and risk assessment of heavy metals in water, sediments, and fish of Chaohu Lake, China. *Environ. Earth Sci*. 77:7276. doi: 10.1007/s12665-018-7276-y

Yin, J., Wang, L., Chen, Y., Zhang, D., Hegazy, A. M., Zhang, X., et al. (2019). A comparison of accumulation and depuration effect of dissolved hexavalent chromium (Cr6+) in head and muscle of bighead carp (*Aristichthys nobilis*) and assessment of the potential health risk for consumers. *Food Chem*. 286, 388–394. doi: 10.1016/j.foodchem.2019.01.186

Yin, J., Wang, L., Liu, Q., Li, S., Li, J., Zhang, X., et al. (2020). Metal concentrations in fish from nine lakes of Anhui Province and the health risk assessment. *Environ. Sci. Pollut. Res*. 20:1. doi: 10.1007/s11356-020-08368-1

Yin, J. J., Wang, L., Huang, T. T., Zhang, F., and Zhang, X. Z. (2023). A combined survey and exposure study reveals the distribution characteristic of chromium in fish head. *Environ. Sci. Pollut. Res*. 30, 40630–40640. doi: 10.1007/s11356-022-25013-1

Yu, B. J., Wang, X. L., Dong, K. F., Xiao, G. X., and Ma, D. (2020). Heavy metal concentrations in aquatic organisms (fishes, shrimp and crabs) and health risk assessment in China. *Mar. Pollut. Bullet*. 159:111505. doi: 10.1016/j.marpolbul.2020.111505

Zerizghi, T., Yang, Y., Wang, W., Zhou, Y., Zhang, J., Yi, Y., et al. (2020). Ecological risk assessment of heavy metal concentrations in sediment and fish of a shallow lake: a case study of Baiyangdian Lake, North China. *Environ. Monitor. Assess*. 192:8. doi: 10.1007/s10661-020-8078-8

Zhong, W., Zhang, Y., Wu, Z., Yang, R., Chen, X., Yang, J., et al. (2018). Health risk assessment of heavy metals in freshwater fish in the central and eastern North China. *Ecotoxicol. Environ. Saf*. 157, 343–349. doi: 10.1016/j.ecoenv.2018.03.048