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Dataset-based Assessment of Heavy Metals Pollution in Taihu Lake Fish and Their Health Risk

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Abstract

The ecological risks and health hazards of heavy metals pollution in Taihu Lake have received widespread concern. This study has developed a nationwide dataset on pollutant loads in species, and the dataset records 55,297 data from 310 articles, covering 778 species and 537 pollutants. In this paper, we extract and systematically integrate data on heavy metals concentrations in Taihu fish from the dataset. The Pi (single pollution index) and MPI (metal pollution index) models were used to assess the level of contamination in fish and the THQ (target hazard quotient) and ILCR (incremental lifetime cancer risk) models were used to assess the health hazards of fish consumption. The contamination levels varied in a feeding habit and living habit dependent manner. The risk of non-cancer health is the highest in omnivorous fish, then in carnivorous fish and herbivorous fish. ILCR model predicted that the values of As and Cd in omnivorous fish for children exceeded the risk threshold limits set by the EPA, and the ILCR values of As in omnivorous fish and Cd in carnivorous fish for adults also exceeded the risk threshold limits. In all, this study provided a comprehensive understanding of the risk of heavy metals in Taihu.

Keywords: Dataset, Taihu Lake, Target Hazard Quotient, Incremental Lifetime Cancer Risk

1. Introduction

Located in the lower reaches of the Yangtze River, Taihu Lake is the third largest lake in China. The lake, also known as the land of fish and rice, provides the eastern region with drinking water, fisheries and tourism resources (Wu et al., 2019). After decades of development, Taihu has become an important industrial and agricultural base in China, which has also resulted in a huge inflow of industrial and urban sewage. Various types of pollutants are widely distributed through the sediment, water, and organisms in Taihu.

Of varied types of pollutants, heavy metals receive great concern as their high contents and adverse ecological impacts. Niu et al have performed systematic statistical and associated risk assessment of heavy metals in the surface sediments of Taihu using meta-analysis and showed that cadmium (Cd) is the main contaminant of heavy metals in the sediments of Taihu and is the main factor contributing to the potential hazards of heavy metals. Besides, arsenic (As), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn) in Taihu are also serious and should be given greater attention (Niu et al., 2020). Jiang et al found that the heavy metals content in the surface water of Taihu Lake is high, and some heavy metals content may cause chronic toxicity to the organisms in Taihu Lake (Jiang et al., 2012). Heavy metals also have been widely detected in aquatic organisms of Taihu. The enrichment of heavy metals in fish from Taihu has been shown in many studies (Fu et al., 2013; Rajeshkumar et al., 2018). However, those studies only revealed the short-term effect of heavy metal in some specific species. Compiling these data together and further analysing would provide a comprehensive understanding of the accumulation levels of heavy metals in the organism.

Heavy metals can be bio-accumulated through the food chain (Zuo et al., 2018). Some studies

have focused on the increasing levels of heavy metals in fish, raising concerns because of their accumulation and potential toxicity (Alamdard et al., 2017). Chronic toxicity assay showed that the increase of heavy metals content in fish results in physiological, morphological, and behavioral abnormalities, including decreased mobility, decreased perception, prolonged sexual maturity, and delayed hatching (Alm-Eldeen et al., 2018). Cd exposure would cause oxidative stress and immunotoxicity in organisms, and ultimately neurotoxicity and carcinogenicity in organisms (Abdelkrim et al., 2018; Shankar et al., 2020). The mechanism of Pb toxicity differs from that of Cd in that Pb causes damage to the organism by disrupting cellular functions and enzyme activities (Zhang et al., 2011; Zhang et al., 2019). In addition, heavy metals also could induce changes in metabolism, synthesis of proteins and nucleic acids, as well as inflammatory response and apoptosis (Jiaxin et al., 2020). As multiple metals exist in the organisms, their combined effects result in damage levels increasing with time and heavy metals dose, causing extreme tissue damage, reactive oxygen species generation, and gut microbial dysbiosis (Gao et al., 2019; Kakade et al., 2020).

Fish consumption is an integral part of a healthy diet plan and is an important source of protein, long-chain omega-3 fatty acids, vitamins, and essential trace elements for humans. The global average consumption of fish exceeds 20 kg per year per person as reported by the Food and Agriculture Organization of the United Nations (FAO) (<http://www.fao.org/news/story/en/item/421871/icode/>). Edible fish has become one of the main ways through which heavy metals accumulated in human body (Al Osman et al., 2019; De La Rosa et al., 2009; Faial et al., 2015). Faial et al found that mercury levels in human hair accumulated mainly through fish consumption (Faial et al., 2015). The rise in mercury in children

could be from placenta transplants through the mother's consumption of fish in the later stages of pregnancy and post-natal ingestion of fish (Fok et al., 2007; Yassa, 2014). All these raised the risk concern of heavy metals through fish consumption. To reduce the risk, the U.S. Environmental Protection Agency (USEPA.) provides recommendations of fish consumption according to the principle of fewer contents of pollutants with higher nutrition in fish (<https://www.fda.gov/food/consumers/advice-about-eating-fish>).

Our team set up a species-pollution dataset, which collected data on the levels of pollutants in organisms from peer-reviewed papers since 2000. The dataset has been uploaded to a publicly available online database, scienceDB, and can be accessed through <http://www.dx.doi.org/10.11922/sciencedb.00310>. It integrated the concentrations of pollutants in the organism with a clear date and location. This dataset records a total of 55,297 data from 310 articles, covering 778 species, 537 pollutants, and is still being updating. Integrative analysis of published data in the absence of long-term testing is of great value for the study of contamination in various media. Therefore, this study extracted the data about heavy metals levels in Taihu fish in the dataset and provides a systematic statistical description of heavy metals contamination in Taihu fish. In addition, the Pi (single pollution index model) and MPI (metal pollution index) models were used to assess the level of contamination in fish and the THQ (target hazard quotient) and ILCR (incremental lifetime cancer risk) models were used to assess the health hazards of consuming these fish. The purpose of this study is to systematically describe the heavy metals content in fish from Taihu Lake, assessing the extent of heavy metal contamination in fish from Taihu Lake and evaluating the health risks of long-term consumption of fish from Taihu Lake on humans.

2. Methods

2.1 Data source

Data onto the study is extracted from our dataset named as a dataset of multi-pollutants in multi-species in China (<http://www.dx.doi.org/10.11922/sciencedb.00310>). The data scope for our dataset covers China from 2000 to the present. Data were from peer-reviewed papers available in China National Knowledge Infrastructure (CNKI) (<http://www.cnki.net/>), National Center for Biotechnology Information (<https://www.ncbi.nlm.nih.gov/>) and ISI Web of Science (<http://isiknowledge.com>). And the data onto contaminant levels in species in the literature were extracted according to certain criteria. These data are entered after the rigorous screening of the data, and the screening criteria include: (1) The literature contains data onto the concentration of contaminants in the species, with clear information on sampling time, location, and the number of samples; (2) The data need to originate from field sampling data rather than laboratory exposure data; (3) Contaminant concentration detection by mass spectrometry, chromatography and spectroscopy, and strict quality control, providing quality controls parameters such as recovery, standard curve, and detection limit; (4) The data entered into the dataset is reviewed several times. And data is extracted by one person and checked again by another person to ensure the accuracy of data entry and, at the same time, to ensure that no duplication of data occurs. Currently, the dataset records 55,297 data from 310 articles, covering 778 species and 537 pollutants. All data for this study were obtained from a publicly available dataset accessed at <http://www.dx.doi.org/10.11922/sciencedb.00310> (Huang Qiansheng et al., 2020). Since this study chose to focus on Taihu lake(**Fig. S1**), the data about the organisms in the Taihu Lake were extracted from the dataset. The process of extracted shown in **Fig. S2**.

The data from the Taihu Lake area was retrieved from the dataset, followed by filtering the fish data from these data, and finally, the data of Zn, Cr, As, Pb, Hg, and Cd in Taihu Lake fish were extracted separately. Ultimately, a total of 1174 data from species contaminant concentration records in 46 fish species were used for our statistical analysis. We further classified the fish into herbivorous, omnivorous and carnivorous according to their feeding habits, and all data units were transformed before being entered into the dataset.

2.2 Data and statistical analyses

2.2.1 Dry-wet weight conversion

For the purpose of comparison, we converted the wet weight concentration to the dry weight concentration, the formula is as follows:

$$C_d = \frac{100 - \%H}{100} \times C_w^{-1}$$

where C_d and C_w are the concentrations expressed relatively to dry and wet mass respectively, and with the percentage of humidity in wet tissues (%H) classically ranging around 80% for a vast range of species (Bonito et al., 2016; Cresson et al., 2017).

2.2.2 The sample number weighted mean (SNWM)

It is generally believed that the larger the number of samples, the more reliable the results obtained. In this study, the collected fish were divided into three kinds according to the food chain, herbivorous fish, omnivorous fish, and carnivorous fish. In order to make the data of each category more representative, we used a weighted average of the number of samples for each species as follows:

$$SNWM = \sum \frac{C_i \times N_i}{\sum_{i=1}^n N_i}$$

N_i represents the number of samples of Species i , C_i is the concentration of heavy metals in

species i , and both of N_i and C_i are obtained from the original references(Niu et al., 2020).

2.2.3 Heavy metals pollution index

In order to evaluate the pollution of various metals in fish, the single pollution index model (P_i) was used to evaluate the pollution degree of heavy metals in aquatic products(Liang et al., 2016; Liu et al., 2021). The formula is as follows,

$$P_i = C_i / S_i$$

In the formula, P_i is the single pollution index, C_i is the measured concentration of pollutants, and S_i is the standard value or reference value of pollutants (Liu Yang, 2013; NMPA, 2017). The unit is $\text{mg} \cdot \text{kg}^{-1}$. At present, there is no clear standard to classify the pollution level of the organism in our country. It is commonly believed that the average value of comprehensive pollution index (P_i) ≤ 0.2 , indicating no pollution; $0.2 < P_i \leq 0.6$, indicating light pollution; $0.6 < P_i \leq 1.0$, indicating moderate pollution; $P_i > 1.0$, indicating heavy pollution.

The metal pollution index (MPI) was used to compare the total metals accumulation level in various tissues of different fish. The MPI values were calculated using the equation by (Chi et al., 2007; Hao et al., 2013):

$$\text{MPI} = (C_{f1} \times C_{f2} \times \dots \times C_{fn})^{1/n}$$

where, C_{fn} is the contents for the metal n in the sample.

2.2.4 Health risk assessment

2.2.4.1 Non-carcinogenic risk assessment

The target hazard quotient (THQ) method was used to assess non-cancer risk based on the equation below (Ezemonye et al., 2019; Fakhri et al., 2019):

$$THQ_i = \frac{EF \times ED \times FIR \times C_i}{BW \times AT \times RFD} \times 10^{-3}$$

Where THQ is the target hazard quotient; EF is exposure frequency (365 days/year); ED is exposure duration (70 years); FIR is the food ingestion rate (g/person/d, fish: 36 g/person/day) (Storelli, 2008). C_i is the concentration of metal i in fish ($\text{mg}\cdot\text{kg}^{-1}$ dw); BW is the average body weight (children:30kg, adults: 70kg); AT is exposure time for non-carcinogens (365 days per year $\times$ ED). RfD is the oral reference dose (mg/kg/day), Oral RfD for As (inorganic), Cd, Hg (Methyl Mercury), Cr, Zn and Pb is 0.0003, 0.001, 0.0001, 1.5, 0.3 and 0.004 mg/kg/day respectively); If the ratio is less than 1, the exposed population is unlikely to experience obvious adverse effects (Zhuang et al., 2009). It is well known that inorganic arsenic is the main component of the toxic effects of arsenic, and according to EFSA, in this study we assumed that the inorganic arsenic content was 20% of the total arsenic content (EFSA, 2014).

The total target hazard quotient (TTHQ) was calculated with the aid of the following equation (Fakhri et al., 2019):

$$TTHQ = \sum_i^n THQ_i$$

where TTHQ is total target hazard quotient, and THQ_i is a non-carcinogenic risk of each metal.

2.2.4.2 carcinogenic risk assessment

The estimated daily intake is an important indicator of health risk assessment in humans. It is used to estimate the daily intake of heavy metals. This paper uses this formula to estimate the intake of heavy metals through the consumption of fish.

$$EDI = \frac{FIR \times C_i}{BW}$$

Where EDI is estimated daily intake(mg/kg/day), FIR is the food ingestion rate (g/person/d, fish: 36 g/person/day), C_i is the concentration of metal i in fish ($\text{mg}\cdot\text{kg}^{-1}$ dw).

The incremental lifetime cancer risk (ILCR) indicates that a person's lifetime probability of developing cancer is increased by exposure to potential carcinogens. It was used to calculate the risk of heavy metals carcinogenesis through the ingestion of fish from Taihu Lake.

$$ILCR = EDI \times CSF$$

In this Equation, EDI is estimated daily intake of carcinogenic metals(mg/kg/day); and CSF is the cancer slope factor, risk by a lifetime average dose 1 mg/kg Bw/day(Aendo et al., 2019; Islam et al., 2015). The CSF value of Pb is 8.5×10^{-3} , Cd is 3.8×10^{-1} , and As (inorganic) is 1.5 (OEHHA, 2009; USEPA., 2011). EPA established the safe limit for cancer risk is $ILCR < 10^{-6}$; threshold risk limit $ILCR > 10^{-4}$; considerable risk limit $ILCR > 10^{-3}$.

3. Results

3.1 Heavy metals in Taihu Lake fish

The concentrations of heavy metals in various kinds of fish from Taihu Lake since 2000 were collected and all the wet weight data were transformed by the dry and wet weight conversion formula for a unified generalization of the data. Finally, a total of 1174 records were obtained, including 46 species of fish and 6 species of heavy metals. **Table 1** shows the levels of the six heavy metals in three different types of fish. It can be seen that there is a significant difference in the concentrations in fish between different heavy metals. and the overall level of each metal in descending order is Zn> Pb> Cr> As> Cd> Hg. The levels of heavy metals in different food chains are also different, the distribution of heavy metals in herbivorous fish is Zn> Cr> As> Pb> Hg> Cd, the distribution of heavy metals in omnivorous fish is Zn> Pb> Cr> As> Cd> Hg, the distribution of heavy metals in carnivorous fish is Zn> Cu> As> Pb> Cr> Cd> Hg.

At the level of the food chain, only Hg and Cd increased with the level of the food chain, and

the other four heavy metals, zinc, copper, arsenic, and mercury, were omnivorous fish, carnivorous fish, and herbivorous fishes. Overall, the levels of the heavy metals in different feeding fishes in Taihu Lake are omnivorous fish > carnivorous fish > herbivorous fish. In addition, there is significant variation in the content of the same metal in the same predatory fish, with the highest As content in carnivorous fish being 99.75 times higher than the lowest As content. **Table 1** also shows that the maximum concentration of Hg in Taihu fish is $0.521 \text{ mg}\cdot\text{kg}^{-1}$, which is the content of *Silurus asotus* collected in 2009. The highest concentrations of Pb and As appeared in the samples collected in 2011, which were $23.88 \text{ mg}\cdot\text{kg}^{-1}$ from *Pelteobagrus fulvidraco* and $3.99 \text{ mg}\cdot\text{kg}^{-1}$ from *Hemisalanx prognathus*. The highest concentration of Cd was detected in the body of *Monopterus albus* collected in 2016, and the content was $14.005 \text{ mg}\cdot\text{kg}^{-1}$; the highest concentration of Zn came from the content of $907 \text{ mg}\cdot\text{kg}^{-1}$ in *Cyprinus carpio* in 2005 and the highest concentration of Cr was $25 \text{ mg}\cdot\text{kg}^{-1}$ in *Coilia ectenes Jordan et Seale*, the sample is from Jiaoshan, Taihu Lake, 2007. It should be noted that the highest concentrations of As and Hg were found in carnivores, whereas when comparing average concentrations, the concentrations of both metals are higher in omnivorous fish than in predatory fish.

3.2 Time course change of the levels of heavy metals in Taihu Lake fish

A visual representation of the differences in the content of the different elements and the variation of the same element over the years is shown in **Fig. 1**. There are observed variations in heavy metals concentrations levels between years, as well as significant differences in fish levels within the same year. Overall, all elements showed a clear upward trend from 2009-2011, however, the extent of the increase varied from element to element. The fluctuation of Pb and Cd elements is more obvious, which shows explosive growth from 2009 to 2011, but also the biggest decline

from 2012 to 2016. The difference between the highest and lowest years for Pb and Cd elements concentration was 190.25 times and 109.66 times, respectively. The four elements Cr, As, Zn and Hg also showed significant fluctuations, with a difference of 39.19 times, 10.05 times, 4.27 times, and 2.13 times between the highest and lowest years, respectively.

3.3 Single-factor evaluation of heavy metals in Taihu fish

In order to accurately calculate the PI and MPI values, the present study extracted whole-body concentration data from a dataset of 23 species of fish tested, and based on the information in the literature and the fish database (www.fishbase.org), the fish were classified into herbivorous fish, omnivorous fish, carnivorous fish according to their feeding habits, and classified fish into upper fish, middle-upper fish, middle-lower fish, bottom fish according to the layer in which they live. A comprehensive and detailed list of fish taxonomies is given in **Table S1**. All the results of the calculations are presented in **Table 2**, the PI values of Hg, Pb, Cd, Zn, As and Cr in Taihu Lake fish were 0.074~1.042, 0.064~19.36, 0.03~10.6, 0.09~1.70, 0.08~7.56, 0.11~1.81 respectively. According to the average PI values for all species, the heavy metals are contaminated with As > Pb > Cd > Zn > Cr > Hg in that order. And the three metals Pb, Cd, and As, which had pi values higher than 1, indicating heavy pollution.

In **Fig. 2**, the pollution level of fish in different living habits and feeding habits was calculated. The results showed that in fish with different living habits, the heavy pollution degree was the most in the upper layer fish and the lower layer fish, the least pollution level in the middle-lower layers. And a high proportion of uncontaminated and light pollution fish in middle-lower and middle-upper fishes. The overall level of contamination is in the order of bottom fish > upper fish > middle-upper fish > middle-lower fish. Among the different feeding fishes, omnivorous fishes had

the highest proportion of heavy pollution degree, followed by carnivorous fishes and herbivorous fishes had the lowest proportion of heavy pollution degree. Overall, the contamination levels of these three types of fish were in the following order omnivorous fish > carnivorous fish > herbivorous fish.

3.4 Comprehensive evaluation of heavy metals contamination in Taihu fish

The results of the MPI values for all fish are presented in **Table 2**. It can be seen that the bottom fish has the highest MPI value, followed by the upper fish, and the middle fish has a smaller MPI value, compared to the middle-low fish, the MPI value of the middle-upper fish is slightly higher than the lower middle fish (**Fig. 3A**). Concerning the feeding habit, it is obvious from **Fig. 3B** that the MPI values of different feeding fishes are ranked as omnivorous fish > carnivorous fish > herbivorous fish.

3.5 Risk of fish consumption

3.5.1. Non-carcinogens risk

In order to analyze more accurately the impact of eating Taihu fish on human health, our further collated the heavy metals content of Taihu fish, the concentrations in each organ known in the literature were averaged as a whole, and the results were presented in **Table S2**. Because of the differences in body weight and food consumption between adults and children, the THQ model was used to calculate the body weight and food consumption of Taihu fish separately. The results of the TTHQ values in this study can be observed in **Fig. 4**, where each column represents the TTHQ value for the type of fish consumed and the different colored areas represent the THQ values for individual metals. The THQ of heavy metals for herbivorous fish ranked in the order of Hg > As > Cr > Zn > Pb > Cd for children; Hg > Pb > As > Cr > Zn > Cd for omnivorous fish; Hg >

Cd > As > Zn > Pb > Cr for carnivorous fish. Compared with children, the THQ values of heavy metals exposed to adults by eating fish are lower than those of children, but the ordering distribution in each fish is consistent. And detailed information on THQ is provided in **Fig. S3**. Noteworthy, the THQ values of Hg, Pb in omnivorous fish and Hg in carnivorous fish are higher than 1. This suggests that they have potential non-carcinogenic effects on children's health. And the THQ of Hg in omnivorous fish is close to 2, indicating that the Hg content in omnivorous fish may cause non-carcinogenic health effects in adults.

From **Fig. 4**, the TTHQ for all fish is greater than 1 for both children and adults, suggesting that consumption of fish from the Taihu Lake region may have adverse non-carcinogenic health effects for consumers. It should be noted that children consuming omnivorous fish from Taihu Lake with TTHQ above 5, which means a possible negative non-carcinogenic effect on human health and should be of great concern. The highest contribution of Hg to TTHQ can be clearly seen in **Fig. 4**, with herbivorous, omnivorous, and carnivorous fish accounting for 66.21%, 29.87%, and 44.03%, respectively. The contribution rate of Pb in three types of fish accounted for 2.09%, 22.98%, and 6.77% of children's TTHQ respectively. TTHQ values also differed among different types of fish, but the trend was consistent in adults and children, with the largest TTHQ values in omnivorous fish, followed by carnivorous fish and finally herbivorous fish (**Fig. 4**). In general, the consumption of Taihu fish by adults and children may have adverse non-carcinogenic health effects, especially for children. The risk of human health from different types of fish consumption is different, and the risk of non-cancer health is highest in omnivorous fish, then in carnivorous fish, and the potential risk of herbivorous fish is lowest.

3.5.2. Carcinogens risk

The results in **Table 3** show that the carcinogenic risk of herbivorous fish from the Taihu Lake area for adults and children is below the EPA threshold risk limit of $ILCR > 10^{-4}$. This indicates that the carcinogenic risk from consumption of herbivorous fish from Taihu Lake is acceptable. However, in omnivorous fish, the ILCR values of As for adults and children were $1.74E-04$ and $4.06E-0$ respectively, and the ILCR value of Cd for children was $1.52E-04$, both of which were greater than 1×10^{-4} and exceeded the EPA threshold risk limit. Unlike omnivorous fish, the ILCR values for Cd in carnivorous fish exceeded 1×10^{-4} for adults and children, and the ILCR values for As in children exceeded the EPA threshold risk limit. After rigorous examination, it was discovered that the ILCR values of As in omnivorous fish and Cd in carnivorous fish in Taihu exceeded the EPA threshold risk limit for both adults and children, and the ILCR values of Cd in omnivorous fish and As in carnivorous fish for children also exceeded the threshold risk limit.

4. Discussion

4.1 Concentration differences between heavy metals

From the results of **Table1** and **Fig. 1**, there are obverse difference in the contents of heavy metals in Taihu fishes. and there are also significant variations in the year. These differences are due to a number of factors, for instance fish accumulate heavy metals through a variety of means, including contact with the living habits, respiration, and feeding, and the extent of accumulation depends on the chemical elements and the species involved (Griboff et al., 2018; Lavoie et al., 2013). The water layer and sediments are the main sources of heavy metals in fish, and the concentrations of heavy metals in fish in Taihu Lake vary greatly depending on the sediment content in different areas of Taihu Lake and the location of fish capture. Taihu Lake is bordered by four different types of industrial cities which results in different levels of pollution in different

areas (Yi et al., 2011). This may be an important reason for the differences in heavy metals in conspecific fish.

In addition, the difference in heavy metals content is also reflected in time. In recent years, government departments have begun to strengthen measures to control heavy metals pollution, including local governments' attention to heavy metals pollution and the application of environmental monitoring technology (Li et al., 2018). This shows that since 2011, the State Council approved the implementation of the "Twelfth Five-Year Plan for the Comprehensive Prevention and Control of Heavy Metal Pollution", the prevention and control of heavy metals pollution in the Taihu region has achieved certain results, the concentrations of the six heavy metals in the fish concerned in this study are lower than those in 2011, but still need to continue to strengthen the prevention and control of pollutants. Pb, Cd, and As are three kinds of heavy metals that should be paid more attention to in the prevention and control of heavy metals in the Taihu Lake area in the future.

4.2 Comparison of heavy metals contents in fish

Table 1 shows detailed information on the concentrations of six heavy metals in fish samples collected from Taihu. In this study the concentrations of Zn (64.92, 14-157.675 mg·kg⁻¹ dw), Cd (0.2053, ND-14.005 mg·kg⁻¹ dw), Cr (0.7296, ND-25 mg·kg⁻¹ dw) and Pb (0.7423, ND-9.68 mg·kg⁻¹ dw) in fish from Taihu were significantly higher than concentrations of Zn (33.7, 10.7–134 mg·kg⁻¹ dw), Cr (0.646, 0.047- 6.18 mg·kg⁻¹ dw), Cd (0.032, 0.047- 0.135 mg·kg⁻¹ dw), Pb (0.175, 0.006–0.559 mg·kg⁻¹ dw) in fish observed from the Xiang River (Jia et al., 2018b). The range of Hg (0.1173, 0.027-0.521 mg·kg⁻¹ dw) concentrations in fish in this study were similar to that in fish from the Yellow River Estuary (0.02–0.61 mg·kg⁻¹ dw), but the range of As (0.6475,

0.04–3.99 mg·kg⁻¹ dw) was higher than that in fish from the Yellow River Estuary (0.04, 0.03–2.8 mg·kg⁻¹ dw) (Liu et al., 2018). For level of As (0.010–0.084 mg·kg⁻¹ dw), Cd (0.0009–0.009 mg·kg⁻¹ dw), Cr (0.186–0.291 mg·kg⁻¹ dw), Pb (0.014–0.084 mg·kg⁻¹ dw) were lower in the fish observed in Poyang Lake compared to those in Taihu Lake (Wei et al., 2014). Although the concentration range of Zn (69.44, 45.72–112.92 mg·kg⁻¹ dw), Cd (0.91, 0.48–1.4 mg·kg⁻¹ dw) and Pb (1.68, 1.12–2.6 mg·kg⁻¹ dw) in Nansi Lake fish was smaller than that in Taihu fish, the average concentration was higher than that in Taihu fish, while the As (0.3, 0.2–0.4 mg·kg⁻¹ dw) content was significantly smaller than that in Taihu fish (Zhu et al., 2015). In the comparison with Taihu fish, only the mean concentration of Zn, Cd, Pb in the Nansi Lake was higher than that of Taihu fish, while the range and mean concentration of heavy metals in the remaining fish were lower than that in Taihu Lake.

4.3 Contamination assessment of metals in Taihu fish

In addition to region and year, the diet and habitat of the fish, as well as the trophic level, had a great influence on the levels of the heavy metals in fish (Liu et al., 2019; Yi et al., 2011). Combining the results in **Fig. 2** and **Fig. 3**, it can be seen that the benthic fishes have the highest level of contamination, which may be due to longer exposure of their skin to sediment and greater absorption of heavy metals from benthic organisms (Yi et al., 2011). The second most polluted fish is the pelagic fish, which is probably caused by the severe bloom in Taihu Lake in recent years, where the heavy metals in the bloom are transferred to the fish through the food chain, leading to an increase in the bodyweight metal content of the pelagic fish (Garcia-Hernandez et al., 2005; Jia et al., 2018a). The concentration results in this study showed that only Hg and Cd increased with food chain transfer, while the remaining heavy metals did not show

biomagnification, which is similar to the results of Sang et al, 2019 (Sang et al., 2019). Espejo et Al. (2020) speculate that the biomagnification of heavy metals such as Cu and Zn in living organisms is species and region-specific (Espejo et al., 2020). The results of contamination level evaluation showed that omnivorous fish were the most contaminated with heavy metals, and the heavy metals levels of carnivorous fish were not higher than those of omnivorous and herbivorous fish, indicating that habitat may have a greater influence on the distribution of heavy metals in fish than dietary habits (Fu et al., 2013).

4.4 Health risk to humans from consumption of Taihu Lake fish

Fish is a good indicator of pollution in the aquatic environment and an important way to expose humans (Guo et al., 2012). Taihu fish is an important commercial fish product in the Yangtze River Delta region and is a daily food for the local people (Aendo et al., 2019; Fang et al., 2014). Therefore, it is necessary to assess the potential health risks caused by the consumption of local aquatic products. The Target Hazard Quotient (THQ) and Incremental Lifetime Cancer Risk (ILCR) were used to assess the potential health risks associated with chronic exposure to chemical pollutants (Bortey-Sam et al., 2015). The method of THQ and ILCR estimation does not provide a quantitative estimate of the probability of adverse health effects in exposed populations, but rather provides an indication of the risk level of exposure (Storelli, 2008). In this study, the TTHQ for all types of fish is greater than 1 for children and The TTHQ of omnivorous and carnivorous fish to adults was also higher than 1 suggesting that consumption of fish from the Taihu Lake region may have adverse non-carcinogenic health effects for consumers. In contrast to the results of this study, several existing studies have shown that human consumption of Taihu fish had a TTHQ of less than 1, and there were no significant health risks to humans (Liu et al., 2009; Tao et al., 2012; Xia

et al., 2019). The results of ILCR showed that the exposure hazard of As and Cd in omnivorous fish and carnivorous fish in Taihu to children exceeded the threshold risk limit specified by EPA, and the ILCR values of As in omnivorous fish and Cd in carnivorous fish to adults also exceeded the threshold risk limit, although these values only just exceeded the threshold risk limit, they should cause people to pay attention. There is a lack of studies on ILCR assessment of fish from Taihu. In this study, we calculated the inorganic arsenic content as 20% of the total arsenic, which may overestimate the inorganic arsenic content in fish (Julshamn et al., 2012). And in the calculation process, we used different standards such as FIR, BW, etc. than other literature, and on the other hand, the fish heavy metals data used in this study is the average of long-term data, while other data in the literature only calculate the fish heavy metals of a period of time. This may be the reason for the difference between the results of this study and those of other studies.

It is worth noting that the levels of Zn, Pb, and Cr are relatively high in these three elements, but the THQ results show that the intake of these three heavy metals does not pose a health risk to humans. As and Hg, on the other hand, have lower concentrations, but higher health risks than the first three metals. Therefore, in the process of pollution prevention and control, the hazard quotient of the pollutant should be used as a guide rather than simply the concentration of the pollutant mass. It is recommended that the scope of biological testing be extended to include regular monitoring of organisms within a certain range. Long-term continuous testing in heavily contaminated areas is necessary. Meanwhile, a unified detection method should be established to standardize the monitoring data, and these standardized monitoring data should be integrated regularly.

5. Conclusion

In this paper, we extracted the data related to the heavy metals content in fish of Taihu Lake using a dataset that has already been built, and we systematically counted and described the data. A total of 1174 records were obtained, including 46 species of fish and 6 kinds of heavy metals. The concentration of heavy metals in Taihu Lake fish were Zn (64.92, 14-157.675 mg·kg⁻¹ dw), Cd(0.2053, ND-14.005 mg·kg⁻¹ dw), Cr(0.7296, ND-25 mg·kg⁻¹ dw) and Pb(0.7423, ND-9.68 mg·kg⁻¹ dw), Hg(0.1173, 0.027-0.521 mg·kg⁻¹ dw), As (0.6475, 0.04-3.99 mg·kg⁻¹ dw), respectively. Results of heavy metals contamination of fish in Taihu lake show the contamination levels in different feeding fishes are omnivorous fish > carnivorous fish > herbivorous fish. The overall level of contamination is in the order of bottom fish > upper fish > middle-upper fish > middle-upper fish. The observations from the results of TTHQ indicate that for all fish is greater than 1 for children and omnivorous and carnivorous fish for adults was also greater than 1, suggesting that consumption of Taihu fish by adults and children may have adverse non-carcinogenic health effects, especially for children. The risk of human health from different types of fish consumption is different, and the risk of non-cancer health is highest in omnivorous fish, then in carnivorous fish, and the potential risk of herbivorous fish is lowest. The results of the ILCR presented that the values of As and Cd in omnivorous fish for children exceeded the risk threshold limits set by the EPA, and the ILCR values of As in omnivorous fish and Cd in carnivorous fish for adults also exceeded the risk threshold limits given by the EPA.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing Interests The authors declare that they have no competing interests.

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Authors' contributions

Xiaobo Liu: Writing - Original Draft, Data Curation, Validation. Congtian Lin: Data Curation, Software, Validation. Yangyu Wu: Data Curation, Data Curation. Haining Huang: Methodology, Software. Liting Zhu: Software, Validation. Ru Jiang: Supervision, Writing- Reviewing. Qiansheng Huang: Designing, Funding acquisition, Writing- Reviewing and Editing.

Availability of data and materials

The data used in this paper are from *A dataset of multi-pollutants in multi-species in China* (data available in <http://www.dx.doi.org/10.11922/sciencedb.00310>).

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Figures

Figure 1

Annual variation of heavy metals contents in Taihu Lake fish. The thick horizontal lines indicate Median, thin horizontal lines indicate 95% CI (confidence intervals). Each blue dot represented a data record on the concentration of pollutant in fish. The x-axis represents the sampling year.

Figure 2

Pollution levels of different types of fish according to Pi values. Fish are classified as upper fish, middle-upper fish, middle-lower fish, bottom fish according to their living habitat and herbivorous fish, omnivorous fish, carnivorous fish according to their feeding habits. Different colors indicate different levels of contamination and the size of the circle indicates the proportion of the level of contamination, and the larger the circle the higher the proportion of the type of contamination. pollution-free: (P_i) ≤ 0.2 , slight pollution: $0.2 < P_i \leq 0.6$, moderate pollution $0.6 < P_i \leq 1.0$, heavy pollution $P_i > 1.0$.

Figure 3

MPI for fishes with different living habits and feeding habits. The thick horizontal lines indicate Median, thin horizontal lines indicate 95% CI (confidence intervals). A) shows the MPI values of fish living in

different water layers, U, Upper; M-U, Middle-Upper; M-L, Middle-Low, B, Bottom. B) shows the MPI values of the different feeding fish.

Figure 4

Total target hazard factor in adults and children due to ingestion of metals in Taihu Lake fish. H, herbivorous; O, omnivorous; C: carnivorous, Different colors indicate different heavy metals and the area of different colors in the column indicates the THQ value of that heavy metal.

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