Ranking Ecological Risk of Metals to Freshwater Organisms in Lake Taihu, China

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Received 27 December 2019; Accepted 15 February 2020; Published 9 March 2020

Guest Editor: Yihua Xiao

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Due to the persistence and the high toxicity of metals to many aquatic organisms, metals in aquatic ecosystems have attracted considerable attention. The objective of the present study was to rank metals in Lake Taihu based on the threat they pose to aquatic organisms. The method involved the assessment of the risks of metals to native aquatic organisms and the potential influence of concentration distributions. Both quotient and probabilistic methods were used to rank the risks of arsenic, cadmium, chromium, copper (Cu), mercury, manganese, nickel (Ni), lead, and zinc (Zn). Based on the probabilistic method, Cu, Ni, and Zn were the metals of great concern, with Cu posing the highest risk.

1. Introduction

With increasing urbanization and industrial development, large quantities of pollutants are discharged into aquatic environments, which, in turn, degrade wildlife habitats [1]. Therefore, a key focus of watershed management is the determination of the chemicals that pose high risks for aquatic organisms. Exposure of humans to metals is a major concern in China and globally due to their widespread occurrence and potential adverse health effects [2–4]. Metals are also highly toxic to numerous aquatic organisms, and they have attracted the attention of many researchers [5]. Several studies have demonstrated that metals pose the greatest risk to aquatic ecosystems. Johnson et al. [6] assessed the relative risks of 29 metals and organic pollutants to aquatic organisms in the Bohai region and the Yangtze and Pearl Rivers of China and found that the highest risks to aquatic ecosystems were from copper (Cu), followed by zinc (Zn) and iron (Fe). The authors also analysed the relative risks of 71 chemicals in the UK, and the highest relative risk was associated with Cu, aluminium (Al), and Zn although at lower risk levels in [7].

Lake Taihu is China’s third largest freshwater lake. Severe deterioration in species diversity and abundance has been observed in Lake Taihu, which has been attributed to habitat loss and chemical pollution [8]. Therefore, it is critical to investigate which group of chemicals should be prioritized in management efforts by identifying the chemicals posing the greatest risk to aquatic ecosystems. Considering that previous studies have reported higher risks of metals to aquatic organisms than organic pollutants, the objective of the present study was to rank metals in the water phase of Lake Taihu based on risk to aquatic organisms. Song et al. [1] assessed the risks of metals in the surface water in the Yellow River Delta using the hazard quotient method, while Donnachie et al. [9, 10] evaluated the relative risks of metals and some organic chemicals based on proximity of the median exposure and toxicity concentrations. Although there is no perfect system, both methods are simple and transparent. However, they do not take into account spatial distribution of metal pollution and regional distributions of aquatic organisms [11, 12]. Here, we conducted an assessment of the risks of metals to native aquatic organisms in Lake Taihu, China.
2. Methods

2.1. Environmental Concentration Collection. In the present study, we searched for relevant publications using the keywords of “metals” and “taihu” and extracted available data for the following metals: “arsenic (As),” “cadmium (Cd),” “chromium (Cr),” “Cu,” “mercury (Hg),” “manganese (Mn),” “nickel (Ni),” “lead (Pb),” and “Zn.” Studies and literature that adopted inductively coupled mass spectrometry for instrumental analyses were considered. A log-normal distribution was assumed for metal concentrations, which has been adopted widely. Therefore, to convert the mean \( \mu \) and standard deviation \( \sigma \) to the geometric mean \( \text{GM: } e^\mu \) and geometric standard deviation \( \text{GSD: } e^\sigma \), the following equations were used:

\[
\mu = \log \left( \frac{m^2}{\sqrt{v^2 + m^2}} \right),
\]

\[
\sigma = \sqrt{\left( \frac{v^2}{m^2 + 1} \right)}.
\]

In the present study, only the metal concentration data reported in the freshwater Lake Taihu were obtained. Data from the rivers flowing into the lake, which sometimes received high amounts of polluted discharge from sewage runoff, industrial effluent, and agricultural wastewater, etc., were not included in the present study. The collected data included total water concentration measurements reported in English and in Chinese publications. English publications were obtained from the Web of Science, while the Chinese publications were mainly from the CNKI databases, in which almost all the Chinese journals, master thesis, and PhD dissertations are deposited. The period for review was from 2009 to 2019. Considering that most literature focuses on Lake Taihu hot spots such as Meiliang bay and Gonghu bay, the concentrations obtained by averaging all the data could be biased. Therefore, we divided Lake Taihu into the following seven common regions (Figure 1): Zhushan bay (area 1, Figure 1), Meiliang bay (area 2), Gonghu (area 3), middle part (area 4), southern part (area 5), and southeastern part (area 6). In the case of some literature that did not indicate sampling sites, the metal concentrations were considered as data for the entire lake (area 7). The concentrations below the limits of detection were also included by reporting them as LOD/sqrt(2).

2.2. Toxicity Data Collection. The ecotoxicity database (EOCTOX, https://cfpub.epa.gov/ecotox/search.cfm) by the US EPA was used as the major source of information on metal toxicity data. First, toxicity data for each metal for all freshwater species were extracted from the database. The search terms included freshwater, aquatic organisms, endpoints reflected by mortality, growth inhibition, and survival rates and reproductive rates of the species. The toxicity indices included predicted no effect concentration (PNEC), no observed effect concentration (NOEC), and maximum acceptable toxicant concentration (MATC). In the present study, we placed an emphasis on NOEC toxicity indicators [13], and in its absence, LOEC and MATC were used as alternatives:

\[
\text{NOEC} = \frac{\text{LOEC}}{2},
\]

\[
\text{MATC} = \frac{\text{NOEC}}{\sqrt{2}}.
\]

Afterward, the toxicity data were selected for species relevant to Lake Taihu. Table 1 lists the Lake Taihu relevant species considered in this study, and they include fish, benthos, zooplanktons, phytoplanktons, and aquatic plants [14–21]. Finally, for each metal, the NOEC for an individual organism was assumed to be the GM for all eligible data for a specific organism. When multiple data were available for specific species, and the GM for all available NOECs for the species was adopted.

2.3. Risk Estimation. A two-tier approach was applied to characterize the ecological risk based on the ecotoxicological and environmental concentration data. In the first tier analysis, ecological risk was estimated based on the quotient method. For the second tier, risk was calculated using the probability approach.

2.3.1. Quotient Method. The risk (RQ) was estimated as the quotient between measured exposure concentration (MEC) and toxicity (HC5) for each metal:

\[
\text{RQ} = \frac{\text{MEC}}{\text{HC5}},
\]

where \( \text{HC5} \) is the 5% effect concentration of the pollutant based on the species sensitivity distribution (SSD).

2.3.2. Probabilistic Method. This method is used to calculate the probability that the estimated exposure value for a metal exceeds the predicted toxicity value; that is, the overlap between the exposure concentration curve of metals in the
3. Results and Discussion

3.1. Exposure Level. Based on data availability, nine metals were identified: As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, and Zn. Table 2 summaries the GM concentrations and GSDs of the nine metals in the seven regions of Lake Taihu. Zinc metals were frequently detected in Lake Taihu, and the detection frequencies were in the 76% (Cd) to 99% (Cu) range. Mn was observed with the highest concentration (27473 ± 1.5 ng/L), followed by Zn, Ni, Pb, Cu, As, Cr, Cd, and Hg. The spatial distributions of the metals in Lake Taihu were influenced by local industries. As shown in Table 2, Meiliang Bay had the highest levels of Zn, Pb, and Cd. The results could be explained by the fact that Changzhou and Wujin cities, which are close to Meiliang Bay, have industries that use Zn, Pb, and Cd as stabilizers and additives in synthetic rubber and PVC materials, and therefore, high amounts of industrial wastewater are discharged into Meiliang Bay [22]. The wastewater discharged from many leather manufacturing factories in the two cities also result in the
high Cr levels in Meiliang Bay [23]. Notably, there are much higher levels of As in Zhushan Bay and Pb in the southern part, which deserves attention.

3.2. Toxicity Assessment. Due to the numerous and sustained toxicity studies on heavy metals, a large number of toxicity data have been obtained for the metals targeted in the present study. However, some data should be eliminated because some species are not found in Lake Taihu. After filtering the data, the number of species that was confirmed to be available was 11 for As, 33 for Cd, 21 for Cr, 54 for Cu, 10 for Hg, 2 for Mn, 12 for Ni, 11 for Pb, and 24 for Zn.

In the present study, the abscissa was considered as the maximum no impact concentration and the ordinate was considered as the proportion (%) of the affected species. Origin (OriginLab, Northampton, MA, USA) was used to illustrate the figure for obtaining the SSD curve and for fitting the model. The species composition would influence the shape and location of the SSD [24]. The different toxicity values of the Taihu species and all species indicate differences in species distribution. Therefore, difference between all the species and Taihu lake species would lead to different HC5 values, and, in turn, different ecotoxicity effects. The SSD curves of Cr and Cd for the Taihu species and all species are illustrated in Figure 2. In contrast to the case in all species, the HC5 value of Cr for the Taihu species was lower, while the HC5 value of Cd was larger.

In total, 90 different species and 1436 separate ecotoxicity data points were included in the toxicity assessment of...
the present study. Based on the data, the SSD curves for each metal were plotted and their HC₅ values were obtained (shown in Table 3).

### 3.3. Risk Characterization and Ranking of Metals

The risks the metals pose to aquatic organisms could be assessed based on differences between the ecotoxicity data and environmental concentrations. When the quotient method was used, Pb, Cr, Cu, Ni, and Zn (RQ > 1) were identified as the metals posing the greatest risk to aquatic organisms. When the probability method was applied, the metals that posed high risks to aquatic organisms were Cu, Ni, Zn, Cd, Pb, and Cr. In previous reports, Cu and Zn have also been identified as the metals posing the greatest risks to freshwater ecosystems in the UK [9], in Lake Taihu, and in the Bohai Region of China [25, 26] though the studies adopted different approaches. Notably, Al, which was reported in the first or second place in the order of risk in UK river water when water chemistry is not considered, was not targeted in the present study [7, 9]. This is because the pH value in Lake Taihu is usually in the 7–8.5 range, while the most toxic Al species are found at pH levels [9].

Each metal was initially analyzed using both the quotient and probability methods based on the data gathered in the present study. It should be noted that only seven metals were included in the present work. For other metals such as antimony and tin, we do not have both considerable measurement and local ecotoxicity data. Different forms of metals exhibit variable toxicity levels to aquatic organisms in aquatic environments. Therefore, using total metal concentrations could overestimate the risk. Another limitation is that the present work did not evaluate the influence of water physicochemical factors (e.g., pH, hardness, and DOC) on the metal bioavailability, and in turn, metal toxicity. Speciation and biotic ligand models [27] can be applied in real exposure and risk assessments at Lake Taihu, when such water chemistry factors are known. In the future, the metals could be analyzed further using the database that has been collated as ranking methodologies develop further.

### 4. Conclusions

The present work utilized a large amount of collected exposure and toxicity data to rank the metal ecological risk in Lake Taihu, China, based on current ecotoxicological data. The method involved the assessment of the risk posed by metals to native aquatic organisms, and it took into account the influence of metal spatial distribution. Based on the probabilistic method, Cu, Ni, and Zn were the metals posing the greatest risk to aquatic organisms in Lake Taihu.

### Data Availability

The experimental data used to support the findings of this study are included within the article. And, more detailed data are available from the corresponding author upon request.

### Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

### Acknowledgments

This work was financially supported by the Major Science and Technology Program for Water Pollution Control and Treatment of China (No. 2018ZX07208001), the Fundamental Research Funds for the Central Universities (Nos. 2015ZCQ-HJ-02 and JC2015-02), and a grant from the Open Foundation of State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences (No. SKLECRA2019OFP07).

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