Hindawi
Journal of Chemistry
Volume 2020, Article ID 2536207, 6 pages
https://doi.org/10.1155/2020/2536207

Research Article

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

Qi Wang,[1] **Yalin Du**,[1] **Fuhong Sun**,[2] **Xinmiao Deng**,[1] **and Hong Chang**[1]

[1]*Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Sciences & Engineering, Beijing Forestry University, Beijing 100083, China*
[2]*State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China*

Correspondence should be addressed to Hong Chang; changh@bjfu.edu.cn

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

Guest Editor: Yihua Xiao

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 analyed 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 (m) and standard deviation (v) to the geometric mean (GM: e^{μ}) and geometric standard deviation (GSD: e^{σ}), the following equations were used:

$$\mu = \log\left(\frac{m^2}{\text{sqrt}\,(v^2 + m^2)}\right), \tag{1}$$

$$\sigma = \text{sqrt}\left(\frac{v^2}{m^2 + 1}\right). \tag{2}$$

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:

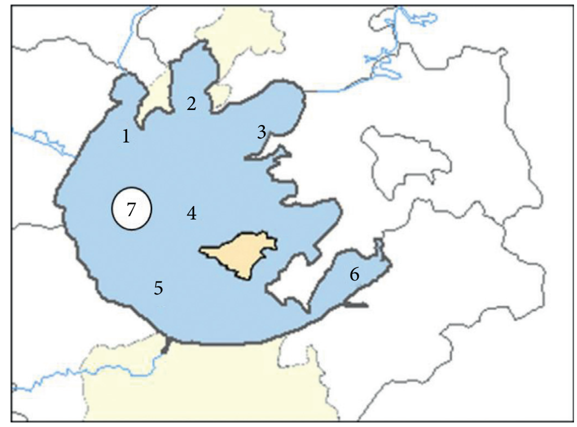

Figure 1: Spatial zoning in Lake Taihu. Area 1: Zhushan bay; area 2: Meiliang bay; area 3: Gonghu; area 4: middle part; area 5: south part; area 6: southeast part; area 7: the whole lake.

$$\text{NOEC} = \frac{\text{LOEC}}{2}, \tag{3}$$

$$\text{MATC} = \frac{\text{NOEC}}{\text{SQRT}\,(2)}. \tag{4}$$

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 (HC_5) for each metal:

$$\text{RQ} = \frac{\text{MEC}}{\text{HC}_5}, \tag{5}$$

where HC_5 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

Table 1: Taihu species used for the ecotoxicity data.

Scientific name	Species group
Achnanthes minutissima	Algae
Achnanthes lanceolata	Algae
Alternanthera philoxeroides	Plants
Anabaena doliolum	Algae
Anguilla anguilla	Fish
Atyaephyra desmarestii	Crustaceans
Azolla caroliniana	Plants
Azolla filiculoides	Plants
Azolla pinnata	Plants
Brachionus calyciflorus	Invertebrates
Carassius auratus	Fish
Carassius gibelio	Fish
Ceratophyllum demersum	Plants
Ceriodaphnia cornuta	Crustaceans
Ceriodaphnia dubia	Crustaceans
Ceriodaphnia reticulata	Crustaceans
Chironomus dilutus	Insects/spiders
Chironomus riparius	Insects/spiders
Chironomus tentans	Insects/spiders
Chironomus kiiensis	Insects/spiders
Chlamydomonas reinhardtii	Algae
Chlorella pyrenoidosa	Algae
Chlorella sorokiniana	Algae
Chlorella sp.	Algae
Chlorella vulgaris	Algae
Chlorococcum sp.	Algae
Chroococcus sp.	Algae
Chydorus sphaericus	Crustaceans
Clarias gariepinus	Fish
Clariidae	Fish
Cocconeis sp.	Algae
Corbicula sp.	Molluscs
Corbicula striatella	Molluscs
Corydoras paleatus	Fish
Cyclidium sp.	Invertebrates
Cyprinus carpio	Fish
Danio sp.	Fish
Daphnia longispina	Crustaceans
Daphnia pulex	Crustaceans
Eichhornia crassipes	Plants
Elliptio complanata	Molluscs
Elodea canadensis	Plants
Elodea nuttallii	Plants
Ephemerella sp.	Insects/spiders
Erythemis simplicicollis	Insects/spiders
Gammarus pulex	Crustaceans
Gammarus roeseli	Crustaceans
Hydrilla verticillata	Plants
Keratella quadrata	Invertebrates
Lamellidens marginalis	Molluscs
Lemna aequinoctialis	Plants
Lemna gibba	Plants
Lemna minor	Plants
Limnodrilus hoffmeisteri	Worms
Limnoperna fortunei	Molluscs
Lumbriculus variegatus	Worms
Mallomonas sp.	Algae
Mesocyclops leuckarti	Crustaceans
Microcystis aeruginosa	Algae
Moina irrasa	Crustaceans
Microcystis sp.	Algae
Mugil cephalus	Fish
Myriophyllum aquaticum	Plants
Navicula seminulum	Algae
Nymphaea spontanea	Plants
Oryzias latipes	Plants
Oscillatoria sp.	Algae
Palaemonetes varians	Crustaceans
Parachlorella kessleri	Algae
Parreysia corrugata	Molluscs
Pelteobagrus fulvidraco	Fish
Phragmites australis	Plants
Pistia stratiotes	Plants
Polyarthra sp.	Invertebrates
Potomida littoralis	Molluscs
Potamogeton natans	Plants
Salvinia minima	Plants
Salvinia natans	Plants
Scenedesmus acutus	Algae
Scenedesmus quadricauda	Algae
Scenedesmus subspicatus	Algae
Spirodela polyrhiza	Plants
Spirodela polyrhiza	Plants
Spirulina sp.	Algae
Staurastrum cristatum	Algae
Typha latifolia	Plants
Ulothrix sp.	Algae
Unionidae	Molluscs
Vorticella sp.	Invertebrates

water and the density curve of the PNEC of metals. SSDs were established to describe the relationships between each species' toxicity values and their cumulative frequencies. The level of risk is calculated using the following formula:

$$\text{Risk} = \int_{0}^{+\infty} (f(t) - g(t))\,dt. \quad (6)$$

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. The 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

Table 2: Total concentrations (ng/L) of metals in Lake Taihu.

Metal		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Sample number	Mean
As	GM	5950	2112	1594	3653	1745	2006	1882	132	2417
	GSD	1.08	1.37	1.44	2.5	1.71	1.41	1.5		1.52
Cd	GM	673	806	820	772	756	785	731	282	762
	GSD	1.16	1.12	1.06	1.11	1.07	1.05	1.29		1.12
Cr	GM	3817	22105	595	1352	1981	2668	717	280	2210
	GSD	1.22	1.15	1.05	1.06	1.1	1.08	1.28		1.13
Cu	GM	5333	2364	2482	8180	3013	1946	4006	205	3466
	GSD	1.25	1.19	1.14	1.53	1.02	1.14	1.53		1.24
Hg	GM	10	1	3	22	5	18	40	46	8
	GSD	3.67	1.39	6.31	7.42	3.61	6.29	2.72		3.94
Mn	GM	41861	65836	23235	—	28418	6000	39382	105	27473
	GSD	1.45	1.64	1.59	—	1.43	1.52	1.49		1.52
Ni	GM	16332	19477	5150	5735	13715	11216	69306	156	10002
	GSD	1.12	1.06	1.06	1.05	1.12	1.07	1.37		1.12
Pb	GM	6597	7559	741.8	5172	14889	6993	5394	270	5233
	GSD	1.25	1.15	1.16	1.3	1.17	1.23	1.58		1.26
Zn	GM	6143	40183	31722	21433	6076	16324	11670	177	15277
	GSD	1.86	1.04	1.15	1.48	1.31	1.59	1.68		1.42

Area 1: Zhushan Bay; area 2: Meiliang Bay; area 3: Gonghu; area 4: middle part; area 5: south part; area 6: southeast part; area 7: the whole lake.

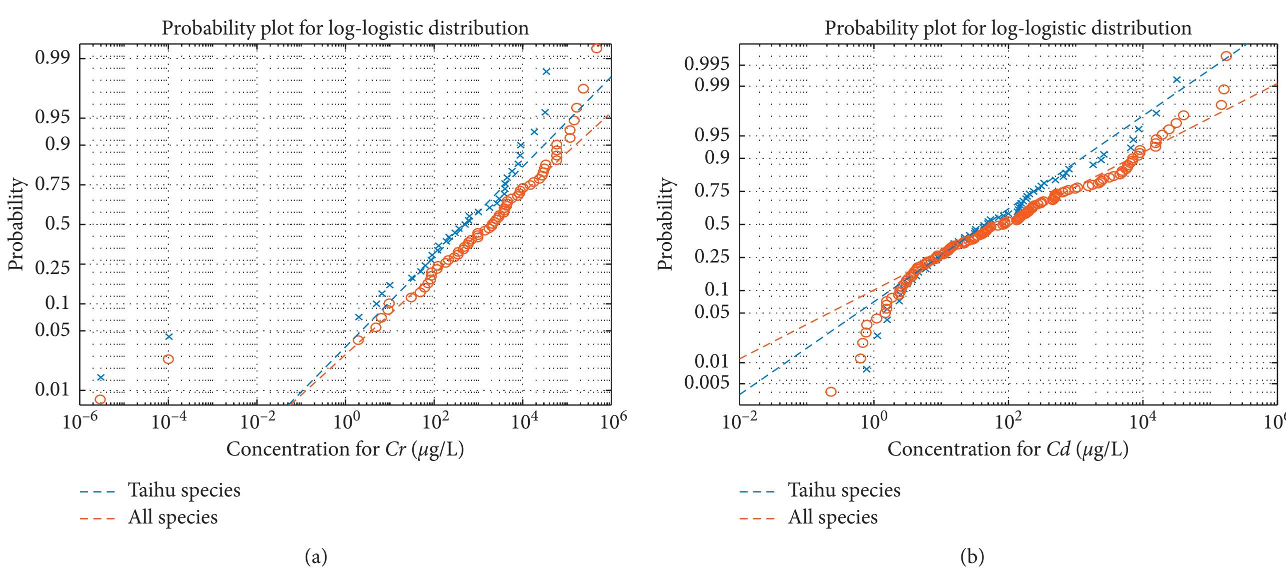

Figure 2: The SSD distributions of Cr and Cd for all species and Taihu species.

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 HC_5 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 HC_5 value of Cr for the Taihu species was lower, while the HC_5 value of Cd was larger.

In total, 90 different species and 1436 separate ecotoxicity data points were included in the toxicity assessment of

Table 3: Exposure and risk results of metals in Lake Taihu.

Metal	Exposure concentration (μg/L)	HC_5 (μg/L)	Quotient method (RQ)	Probability method (risk)
As	2.42	9.43	0.26	0.021
Cd	0.76	0.77	0.99	0.066
Cr	2.21	0.57	3.88	0.039
Cu	3.47	1.27	2.73	0.101
Pb	5.23	1.1	4.75	0.047
Mn	27.47	97.65	0.28	0.02
Hg	0.01	0.07	0.14	0.017
Ni	10	3.71	2.7	0.09
Zn	15.28	15.16	1.01	0.068

the present study. Based on the data, the SSD curves for each metal were plotted and their HC_5 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 ˂6–>8.5 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).

References

[1] S. Song, F. Li, J. Li, and Q. Liu, "Distribution and contamination risk assessment of dissolved trace metals in surface waters in the Yellow River Delta," *Human and Ecological Risk Assessment: An International Journal*, vol. 19, no. 6, pp. 1514–1529, 2013.

[2] Z. Dong and J. Hu, "Development of lead source-specific exposure standards based on aggregate exposure assessment: Bayesian inversion from biomonitoring information to multipathway exposure," *Environmental Science & Technology*, vol. 46, no. 2, pp. 1144–1152, 2012.

[3] Z. Dong, C. Liu, Y. Liu, K. Yan, K. T. Semple, and R. Naidu, "Using publicly available data, a physiologically-based pharmacokinetic model and Bayesian simulation to improve arsenic non-cancer dose-response," *Environment International*, vol. 92-93, pp. 239–246, 2016.

[4] A. Navas-Acien, E. Guallar, E. K. Silbergeld, and S. J. Rothenberg, "Lead exposure and cardiovascular disease: a systematic review," *Environmental Health Perspectives*, vol. 115, no. 3, pp. 472–482, 2007.

[5] W. Zhuang and X. L. Gao, "Integrated assessment of heavy metal pollution in the surface sediments of the Laizhou bay and the coastal waters of the Zhangzi Island, China: comparison among typical marine sediment quality indices," *PLoS One*, vol. 9, no. 4, Article ID e94145, 2014.

[6] A. C. Johnson, M. D. Jürgens, C. Su et al., "Which commonly monitored chemical contaminant in the Bohai region and the Yangtze and Pearl Rivers of China poses the greatest threat to aquatic wildlife?" *Environmental Toxicology and Chemistry*, vol. 37, no. 4, pp. 1115–1121, 2018.

[7] A. C. Johnson, R. L. Donnachie, J. P. Sumpter, M. D. Jürgens, C. Moeckel, and M. G. Pereira, "An alternative approach to risk rank chemicals on the threat they pose to the aquatic environment," *Science of the Total Environment*, vol. 599-600, pp. 1372–1381, 2017.

[8] X. L. Wang, "Thoughts on the protection of aquatic organisms diversity in Taihu lake," *Morden Fisheries Information*, vol. 21, no. 2, pp. 22–29, 2006.

[9] R. L. Donnachie, A. C. Johnson, C. Moeckel, M. G. Pereira, and J. P. Sumpter, "Using risk-ranking of metals to identify which poses the greatest threat to freshwater organisms in the UK," *Environmental Pollution*, vol. 194, pp. 17–23, 2014.

[10] R. L. Donnachie, A. C. Johnson, and J. P. Sumpter, "A rational approach to selecting and ranking some pharmaceuticals of concern for the aquatic environment and their relative importance compared with other chemicals," *Environmental Toxicology and Chemistry*, vol. 35, no. 4, pp. 1021–1027, 2016.

[11] Y. Song, *Distribution and Ecological Risk Assessment of Heavy Metals in Surface Sediments of Typical Inflow Rivers in Nansi Lake*, Shandong University, Jinan, China, 2014.

[12] H. Y. Niu, Q. H. Wu, X. G. Chen et al., "Potential biological toxicity risk of heavy metals in the column sediments from Guangzhou section of the Pearl River," *Environmental Science & Technology*, vol. 33, no. 8, pp. 185–190, 2010, in Chinese.

[13] L. Zheng, Z. Liu, Z. Yan et al., "pH-dependent ecological risk assessment of pentachlorophenol in Taihu Lake and Liaohe River," *Ecotoxicology and Environmental Safety*, vol. 135, pp. 216–224, 2017.

[14] H. L. Su, *The Aquatic Biota Characteristics of Taihu Lake and its Relationship with the Derivation of Lake Water Quality Criteria in China*, Chinese Research Academy of Environmental Sciences, Beijing, China, 2011.

[15] K. Zhao, Y. F. Zhou, Z. L. Jiang et al., "Changes of aquatic vegetation in Lake Taihu since 1960s," *Journal of Lake Sciences*, vol. 29, no. 2, pp. 351–362, 2017, in Chinese.

[16] H. Xu, Y. J. Cai, X. M. Tang et al., "Community structure of macrozoobenthos and the evaluation of water environment in Lake Taihu," *Journal of Lake Sciences*, vol. 27, no. 5, pp. 840–852, 2015, in Chinese.

[17] D. Li, X. W. Li, Z. C. Niu et al., "Investigation on community structure of Zooplankton in Taihu," *Journal of Anhui Agricultural Science*, vol. 42, no. 29, pp. 10173-10174, 2014, in Chinese.

[18] Y. Chen, X. D. Hu, J. H. Zhang et al., "Phytoplankton community structure and its relationship with environmental factors in different regions of Taihu lake," *Journal of Hydroecology*, vol. 38, no. 3, pp. 38–44, 2017, in Chinese.

[19] H. S. Xu, Y. Zhang, Y. C. Wang et al., "Spatial and temporal variation in the composition of phytoplankton species in Taihu lake," *Environmental Monitoring and Forewarning*, vol. 4, no. 6, pp. 38–41, 2012, in Chinese.

[20] Z. G. Mao, X. H. Gu, Q. F. Zeng et al., "Fish community structure and diversity in Taihu lake," *Chinese Journal of Ecology*, vol. 30, no. 12, pp. 2836–2842, 2011, in Chinese.

[21] Y. Chen, *Updated Study of Water Quality Criterion of Pentachlorophenol for Protection of Aquatic Organism in Tai Lake*, Nanjing University, Nanjing, China, 2014.

[22] W. C. Qu, D. Mike, and S. M. Wang, "Multivariate analysis of heavy metal and nutrient concentrations in sediments of Taihu Lake, China," *Hydrobiologia*, vol. 450, pp. 83–89, 2001.

[23] H. B. Yin, Y. N. Gao, C. X. Fan et al., "Distribution, sources and ecological risk assessment of heavy metals in surface sediments from Lake Taihu, China," *Environmental Research Letters*, vol. 6, no. 4, pp. 83–89, 2011.

[24] J. Park, S. Lee, E. Lee et al., "Probabilistic ecological risk assessment of heavy metals using the sensitivity of resident organisms in four Korean rivers," *Ecotoxicology and Environmental Safety*, vol. 183, Article ID 109483, 2019.

[25] C. Su, Y. L. Lu, A. C. Johnson et al., "Which metal represents the greatest risk to freshwater ecosystem in Bohai Region of China?" *Ecosystem Health and Sustainability*, vol. 3, no. 2, 2017.

[26] Z. Fu, F. Chang, L. Chen et al., "Copper and zinc, but not other priority toxic metals, pose risks to native aquatic species in a large urban lake in Eastern China," *Environmental Pollution*, vol. 219, pp. 1069–1076, 2019.

[27] D. M. Di Toro, H. E. Allen, H. L. Bergman, J. S. Meyer, P. R. Paquin, and R. C. Santore, "Biotic ligand model of the acute toxicity of metals. 1. Technical basis," *Environmental Toxicology and Chemistry*, vol. 20, no. 10, pp. 2383–2396, 2001.