Distribution characteristics of heavy metals in surface sediments of alkaline lake in Plateau

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Abstract: Hamatai lake represents important saline and alkaline resource in sandy land of Inner Mongolia plateau. In this study, the pollution degrees of heavy metals (Cu, Zn, Pb, Cd, Cr, Ni, Mn, As) in sediments of Hamatai Lake were analyzed, based on the national soil background value and the soil background value of Inner Mongolia, and single factor and potential ecological risk index. The results showed that the concentrations of heavy metals (Cu, Zn, Cu, Pb, Cd, Cr, Ni, Mn, As) were 15.22, 33.16, 5.32, 0.80, 61.60, 16.40, 286.50, 20.21 mg kg⁻¹, respectively. Among them, the contents of Cd in eight samples went beyond the soil background value of Inner Mongolia, the national soil background value and the screening value. Meanwhile, Cd had the highest potential ecological risk through potential ecological risk assessment. Overall, the potential ecological risk of the central area of the lake was significantly greater than that of the surrounding area. The results of this study can provide a scientific basis for the prevention and control of heavy metal pollution in alkaline lake of Plateau in arid area.

1. Introduction

Heavy metal pollution in lake sediment has attracted worldwide attention [1-3]. Their work focused on accurate analysis of pollution levels, sources of pollution and health risks in specific water bodies, including river, lakes, even marine environment. Heavy metal pollutants in the environment are persistent, hidden and highly toxic, which cannot be usually degraded by microorganisms [4]. Heavy metal pollutants are discharged into lakes through industry, agriculture, and sewage wastewater, and their accumulation in the water pose ecological risk to aquatic animals and plants, even human health [5].

The lakes are important collection points of pollutants in the whole basin in arid area. Because of their closed characteristics, pollution makes it difficult for them to recover, thus cause long-term harm to the water environment, and pose a serious threat to the surrounding environment and human health [3]. Lakes are the most important resources in arid area of Mongolia Plateau, mainly distributed in western area of Ordos. A total of 68 alkaline lakes with an area of more than 1 km² are distributed in Ordos desert plateau, accounting for a total area of 317 km² [6]. Hamatai lake is one of the most representative lakes in the area, Which famous for saline and alkaline characteristics, about 2.5 km², with a depth of 2-3 m in the central area of lake. It has a semi-arid and arid climate, high evaporation (2500-2700 mm year⁻¹), low rainfall (280-360 mm year⁻¹) and large temperature difference. There were high concentrations of alkali and salt in Hamatai Lake for a long history, with pH (8.63-10.30) and salinity (0.71%-4.46%). The naturally fragile lake ecological environment was greatly disturbed.
by anthropogenic activities, such as receiving large volumes of commercial *Spirulina* production, alkali plants discharge water as well as municipal and other industrial wastewater with high pollutant contents, including heavy metals around the Hamatai Lake. However, the distribution characteristics of heavy metals in the surface sediments of Hamatai Lake are unclear. This study is helpful to understand the real heavy metals pollution in sediments of Hamatai Lake, and provide basic data for the protection of alkali lakes in arid area of Mongolia Plateau.

2. Materials and methods

2.1 Sample collection and heavy metal analysis

A total of 8 sediment samples were collected in the lake with a distance of 2.0 km between sampling points (Fig. 1). Due to the shallow average depth of the lake, all sediment samples were collected at a depth of 0-20 cm. The sampling process was carried out in canoes with electric motors.

Sediment samples were digested with HNO₃-HClO₄ HF (3:1:1, v/v), and the concentrations of heavy metals were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES) (Jarrell ash ICAP-9000, USA). Each sample was repeated 3 times. After the detection of all samples, 20% of the sediment samples were detected for heavy metal concentration to evaluate its repeatability. The calculated relative error was less than 10%, which indicates that the heavy metals in sediment samples were effectively detected.

2.2 Potential ecological risk assessment

Potential Ecological Risk Index ($IR$) is a method proposed by Swedish scientist Hakanson in 1980 to evaluate the potential ecological risk of heavy metals in soil and sediments mainly from the perspective of sedimentology [7]. This study adopts the following formula:

$$P_i = \frac{C_{\text{heavy metals}}}{C_{\text{background}}} \quad E_i = T_i \times E_i \quad IR = \sum_{i=1}^{n} E_i$$

The measured IR was calculated, and the $T_i$ was the toxic reaction factors of Cu, Zn, Pb and Cd to different heavy metals, which were 40, 5, 1, 5 and 30, respectively. $E_i$ is the potential ecological risk index of single element, IR is the comprehensive potential ecological risk index.

2.3 Data analysis

The screening and control values in the National soil environmental background value and the Soil Environmental Quality Standard for The Control of Soil Pollution Risk in Agricultural Land (Trial) (GB15618-2018) were used to analyze the degree of sediment heavy metal pollution, and the single
factor and the potential ecological risk index were used to evaluate the status of heavy metal pollution. All data were collated and analyzed using Excel 2019 and SPSS 19.0.

3. Results and discussion

The mean (standard deviation) heavy metal values of Cu, Zn, Pb, Cd, Cr, Ni, Mn and As in the eight sediment samples in Hamatai Lake were respectively 15.22 (8.49), 33.16 (14.80), 5.32 (1.90), 0.80 (0.46), 61.60 (20.12), 16.40 (8.02), 286.50 (161.05) and 20.21 (4.46) mg kg⁻¹ (Table 1).

Table 1: High alkali content of heavy metals in lake surface sediment

|        | Cu   | Zn   | Pb   | Cd   | Cr   | Ni   | Mn   | As   |
|--------|------|------|------|------|------|------|------|------|
| Average (mg kg⁻¹) | 15.22 | 33.16 | 5.32 | 0.80 | 61.60 | 16.40 | 286.50 | 20.21 |
| SD (mg kg⁻¹)       | 8.49  | 14.80 | 1.90 | 0.46 | 20.12 | 8.02  | 161.05 | 4.46  |
| Background values of Soil in Inner Mongolia (mg kg⁻¹) | 12.9  | 48.6  | 15.0 | 0.037 | 36.5 | 17.3 | /     | 6.3   |
| National soil background values (mg kg⁻¹) | 20.0  | 67.7  | 23.6 | 0.074 | 53.9 | 23.4 | /     | 9.2   |
| Screening value (pH>7.5) (mg kg⁻¹) | 100   | 300   | 170  | 0.6  | 250  | 190  | /     | 25    |
| Control value (pH>7.5) (mg kg⁻¹) | /     | /     | 1000 | 4.0  | 1000 | 2000 | /     | 75    |

Note: The screening value and control value refer to the Soil Environmental Quality Standard for Soil Pollution Risk Management and Control of Agricultural Land (Trial) (GB15618-2018).

Compared with the background values of soil in Inner Mongolia, except Zn, Pb and Ni, the other heavy metals all exceeded the standard to varying degrees, among which Cd was the most serious, exceeding the standard by 21.622 times. Compared with the national standards for soil quality, heavy metal Cu, Cd, Cr, As, respectively 0.761, 10.810, 1.143, 2.197 times. The contents of Cu, Zn, Pb, Cr, Ni and As in the measured sediment samples were all lower than the screening values in the Soil Environmental Quality Control Standard for Soil Pollution Risk in Agricultural Land (Trial) (GB15618-2018). The content of all heavy metal elements did not exceed the agricultural sludge control standard.

Soil heavy metals usually have complicated relationships among them. Numerous factors control their relative abundance, e.g., the original concentrations of heavy metals in rocks and parent materials, the processes of soil formation, and the anthropogenic factors such as the pollution by human activities. To analyze the relationships among heavy metals concentrations, a Pearson’s correlation analysis was applied, and the results in Table 2. The high correlations between soil heavy metals might reflect that these heavy metals had similar pollution characteristic and similar pollution sources. Therefore, the close relationships among soil Cu, Zn, Pb and Cd in Hamatai Lake might indicate the combined soil pollution by multi-heavy metals as a result of long-term industrial activities.

Table 2: Correlational matrix of heavy metal contents in Hamatai Lake

|        | Cu   | Zn   | Pb   | Cd   | Cr   | Ni   | Mn   | As   |
|--------|------|------|------|------|------|------|------|------|
| Cu     | 1    | 0.979** | 1    | 0.917** | 0.983** | 0.425* | 0.972** | 0.914** |
| Zn     | 0.979** | 1    | 0.891** | 0.993** | 0.913** | 0.330  | 0.975** | 0.955** |
| Pb     | 0.917** | 0.891** | 1    | 0.934** | 0.876** | 0.998** | 0.462*  | 1     |
| Cd     | 0.983** | 0.993** | 0.934** | 1    | 0.358  | 0.334 | 0.985** | 0.925** |
| Cr     | 0.425*  | 0.330  | 0.358  | 0.334 | 1     | 0.925** | 1     |   |
| Ni     | 0.972** | 0.975** | 0.876** | 0.983** | 1     | 0.962* | 1     |
| Mn     | 0.914** | 0.955** | 0.882** | 0.958** | 0.231 | 0.925** | 1     |   |
| As     | 0.750** | 0.636** | 0.754** | 0.649** | 0.660** | 0.663** | 0.530** | 1     |

Note: **P < 0.01; *P < 0.05

The single factor pollution degree analysis was carried out for the pollution of Cu, Zn, Pb, Cd, Cr, Ni, Mn, As and other heavy metals in the sediment soil. The results showed that the average single-factor pollution indexes of Cu, Zn, Pb, Cd, Cr, Ni, Mn and As were 1.194, 0.698, 0.393, 21.5,
3.724, 0.989, 0.660 and 3.270, respectively. Among them, Zn, Pb, Ni and Mn were unpolluted, while Cr and As were moderately to severely polluted. In all the samples, Cd content was high, which was considered as serious pollution. The high levels of heavy metal pollution in the sediments of the S7 and S8 samples in the lake center pose a high potential risk to the environmental quality, ecology and the health of the residents.

In order to better understand the ecological risk of heavy metal pollution in the sediments of Hamatai Lake, Figure 2 shows the spatial distribution of the $E_r$ values of individual elements and the $IR$ values of various points in the sediments. The $E_r$ values of Cu, Zn, Pb, Cd, Cr, Ni, Mn and As were 3.02-12.51, 0.38-1.26, 1.18-3.13, 260-1333.65, 1.91-4.98, 0.22-1.29 and 21.73-43.46, respectively. Cd contributed the most to $IR$ (92.84%), while Cu, Zn, Pb, Cr, Ni, Mn and As contributed 0.86%, 0.10%, 0.28%, 0.50%, 0.71%, 0.09 and 4.62%, respectively. The potential ecological risk of Zn, Pb, Cr, Ni and Mn was lower (< 40), and the potential risk of Cd was higher, which was As moderate potential ecological risk. The results show that most areas of Hamatai Lake have a large potential ecological risks ($300 < IR < 600$), including S1, S3, S4, S5 and S6. The $IR$ of the central site of the lake (S7 and S8) was the highest. Overall, the potential ecological risk of the central area of the lake was significantly greater than that of the surrounding area.

Note: $IR$=risk index; Pr= Practically uncontaminated; Mr= Moderate risk; Hr=Heavily risk

Figure 2 Potential ecological risk assessment of heavy metals ($E_r$, $IR$)

4. Conclusion
The statistical analysis showed that the average content of Cd in sediment samples at all sites was higher than the background value of soil in Inner Mongolia, the national background value of soil and the screening value in the Soil Environmental Quality Control Standards for Soil Pollution Risk in Agricultural Land (Trial) (GB15618-2018). Cd was the main pollution factor of surface sediments in Hamatai lake, and its potential ecological risk was the greatest. On the whole, the potential ecological risk in the central area of the lake was significantly higher than that in the surrounding area. The results can provide scientific basis for the prevention and control of heavy metal pollution in alkali lakes in northern China and provide data reference for ecological protection in arid areas of China.

Acknowledgments
The project was supported by Natural Science Foundation of Chongqing, China (Grant No. cstc2019jcyj-msxmX0808), Science and Technology Research Program of Chongqing Municipal Education Commission (Grant No. KJQN202001320, KJQN202001326), Special Project to Introduce Talents from Chongqing University of Arts and Sciences (Grant No. R2018SCH03, R2019FCH10).

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