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Original Research

Fuzzy Comprehensive Evaluation (FCE) and Toxic Risk Index (TRI) Analysis of the Heavy Metals in Sediments of Hongfeng Reservoir, Southwest China

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Abstract

This study investigated the pollution characteristics of heavy metals (Ni, Cu, Zn, As, Cd, Hg, Pb) in the sediments of the Hongfeng Reservoir in Guizhou. The fuzzy comprehensive evaluation method was used to evaluate the pollution level of heavy metals in the study area. The toxicity risk index method determined the biological harmful toxicity of heavy metals and the principal component analysis method determined the source of pollution of the heavy metals. The results show that the pollution level of heavy metals in the study area ranges from no pollution to strong pollution, and Ni and Zn have strong biological toxicity. According to the principal component analysis, domestic and industrial sewage and agricultural activities are the main pollution sources of Cu, Ni and Zn. The pollution sources of Cd, Pb and As are mainly the discharge of pollutants around the reservoir, industrial activities and human activities.

Keywords: fuzzy mathematics, heavy metal, sediment, Hongfeng Reservoir

Highlights

(1) The results of fuzzy comprehensive evaluation based on fuzzy mathematics showed that S4 and S6 were unpolluted (I), S3, S5, and S7 were unpolluted to moderately polluted (II), S2, S9, and S10 were moderately polluted (III), and S1 and S8 were moderately to strongly polluted (IV).
(2) S1, S8 and S9 were in considerable toxic risk and the value of toxicity risk index was in the range of 8.33-16.11 based on the PEL and TEL effect.
(3) Industrial and agricultural wastewater and urban domestic sewage were the main sources of principal

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component 1 in Cu, Ni and Zn, while the pollutants emitted by human activities around the reservoir were the source of principal components 2 in Cd, Pb and As.

Introduction

Lakes and reservoirs not only have the ecological function of providing biological habitat, regulating climate and water circulation [1-3], but also play the role of flood control, water storage, irrigation and water supply. However heavy metals from industrial, urban and agricultural sources are discharged into rivers and eventually flowed into lakes and are fixed in lake sediments [4-6]. Continuing retention of heavy metals in lakes and reservoirs may pose a major threat to ecosystem health [7]. Reservoir entrance environment is complicated and accepts different pollutants from various sources such as toxic, persistent, and bioaccumulative, and finally cause a permanent pressure on the environment. Sediment is the primary sink of heavy metals in aquatic ecosystems and has been recognized as an effective indicator of heavy metals pollution [8, 9].

Due to the long-term toxicity of heavy metals and their accumulation in the food chain, they will pose a threat to the ecological environment and human health. Heavy metals are deposited in sediment through adsorption, hydrolysis, and coprecipitation processes and can also be released from sediments back into the water when environmental conditions changed [10]. Therefore, heavy metals in lake and reservoir sediments have attracted worldwide attention [11, 12]. Therefore, objective and practical comprehensive evaluation of the pollution is of great significance.

Sediment quality indicators are needed to assess the risk of contamination and toxicity of metals in the aquatic environment, such as enrichment factor (EF), contamination factor (CF), contamination degree (Cd), geoaccumulation index (I-geo), pollution index (PI) and sediment quality guidelines (SQG), etc. [13-15]. Because heavy metal pollution in the environment usually occurred in the form of complex mixtures, metal pollution was not a single metal effect but a synergistic effect.

Fuzzy comprehensive evaluation was designed to interpret the uncertainties of the assessment [16]. FCE was used to explore the contributions of various pollutants according to predetermined weights and decreased the fuzziness by using membership functions [17]. It means that the sensitivity of the FCE was higher than other sediment quality indicators [18]. An accurately designed FCE can cover the uncertainties in the sampling and analysis process, in comparing with sampling results to quality standards for each parameter, and summarizing individual parameter values [19] FCE has been extensively applied in environmental quality assessment and has been proven effective in solving problems of fuzzy boundaries [20].

The principal component analysis (PCA) is a multivariate statistical method, which used to identify momentous components or factors that explain most of the variances of a system. PCA is conducted to reduce the quantity of variables to a small quantity of indexes while attempting to preserve the relationships present in the original data [21] The ecotoxicity in sediments may be underestimated because the toxicity unit (TUs) was not taken into account. Overall, toxic risk index was a new toxic risk index (TRI), which was based on the threshold effect level (TEL) and probable effect level (PEL) (Zhang et al. 2016; Ranjbar et al. 2017).

The purposes of this study are to: (1) determine the concentration and distribution characteristics of heavy metals (Ni, Cu, Zn, As, Cd, Hg, Pb) in the surface sediments, and more conduct quantitative and qualitative analysis of the predicted data; (2) apply fuzzy comprehensive evaluation and comprehensive evaluation of soil environmental quality to determine the pollution degree of sediments; (3) utilize principal component analysis (PCA) to analyze the source of heavy metals in surface sediments and the quantitative source contribution; (4) use toxicity risk index to assess the ecotoxicity risk of heavy metals in sediments.

Materials and Methods

Study Area and Sampling

Hongfeng Reservoir (106°21′16″-106°26′24″E; 26°25′20″-26°30′30″N) is located in the suburbs of Qingzhen, Guizhou Province, the reservoir was built in 1960 by damming the Maotiao River. It has a surface area of 57.2 km^2, a full volume of 6.01 × 108 m^3 and a maximum depth (zmax) of approximately 45 m. Wu et al. (2016) were reported that A volume-water level curve

Table 1. Principal characteristics of the Hongfeng Reservoir.

Year of impoundment (year)	1960
Lake surface (km^2)	57.2
Volume (109 m^3)	0.601
Water level (Wusong Elevation System) (m)	1240
Watershed area (km^2)	1596
Maximum depth (m)	45
Mean depth (m)	11
Annual average precipitation (mm)	1198
Mean water discharge (m^3 s^{-1})	31.6
Mean water influx (m^3 s^{-1})	28.7
Mean water retention time (year)	0.76
Lake level oscillation range (m)	6.58
Annual mean air temperature (°C)	14.1

over a range of 20 m (1220-1240 m, Wusong Elevation System). Table 1 displays the other characteristics of the reservoir. Hongfeng Reservoir belonged to the subtropical monsoon humid climate zone, with average annual temperature of 14.4ºC, average temperature of coldest month (January) of 4.1ºC, average temperature of hottest month (July) of 22.7ºC, average annual precipitation of 1174.5-1386.1mm, maximum annual precipitation of 1637.0-1879.6 mm, minimum annual precipitation of 669.1-947.6 mm, mainly concentrated in summer (June-August). In November 2018 (dry season), March 2019 (level season), and September 2019 (wet season), the sediments from the external source watershed of Hongfeng Reservoir and from the estuaries of the reservoir were collected respectively, the number of repetitions sampling are two times. A total of 10 sampling points are illustrated in Fig. 1.

The 10 surface sediment samples were collected from different locations of Hongfeng Reservoir by using Van Veen grab samplers (labeled with Sn where n = S1, S2, …, S10). The collected surface sediment samples were freeze-dried, ground in an agate mortar, then passed through a 100-mesh sieve to remove debris and pebbles, and finally stored at -20ºC before analysis.

Sample Measurement

The sediment sample (1.0 g) was digested by HNO_3-HF-H_2O_2 method and diluted to 25 ml with 0.5% HNO_3. The concentrations of Cd, Cu, Pb, Ni, and Zn were determined by atomic absorption spectrometry. The number of repetitions of chemical analyzes were two times.

Using 50% aqua regia (HCl: HNO_3 = 3:1) to digest sediment sample (0.2 g), adding acidified water to the digested sample, and diluted to 50 ml for determination. The concentrations of Hg and As were measured by atomic fluorescence spectrometry. The number of repetitions of chemical analyzes were two times.

Analytical Methods

Statistical Methods

A one-way Analysis of variance (ANOVA) was used to test the significant differences, if $p<0.05$, the difference is considered significant. Pearson correlation analysis was performed to reveal heavy metal element associations. Principal component analysis (PCA) was utilized to explore associations and identify origins of heavy metal elements. All statistical analysis was completed in R studio 4.0.2.

Fuzzy Comprehensive Evaluation

(1) Establishment of sets

$$U = \{u_1, u_2,... , u_n\}$$

the factors U is as a collection of factors that affect evaluation object. The assessment set $V = \{v_1, v_2,... , v_m\}$ is a collection of environmental quality levels.

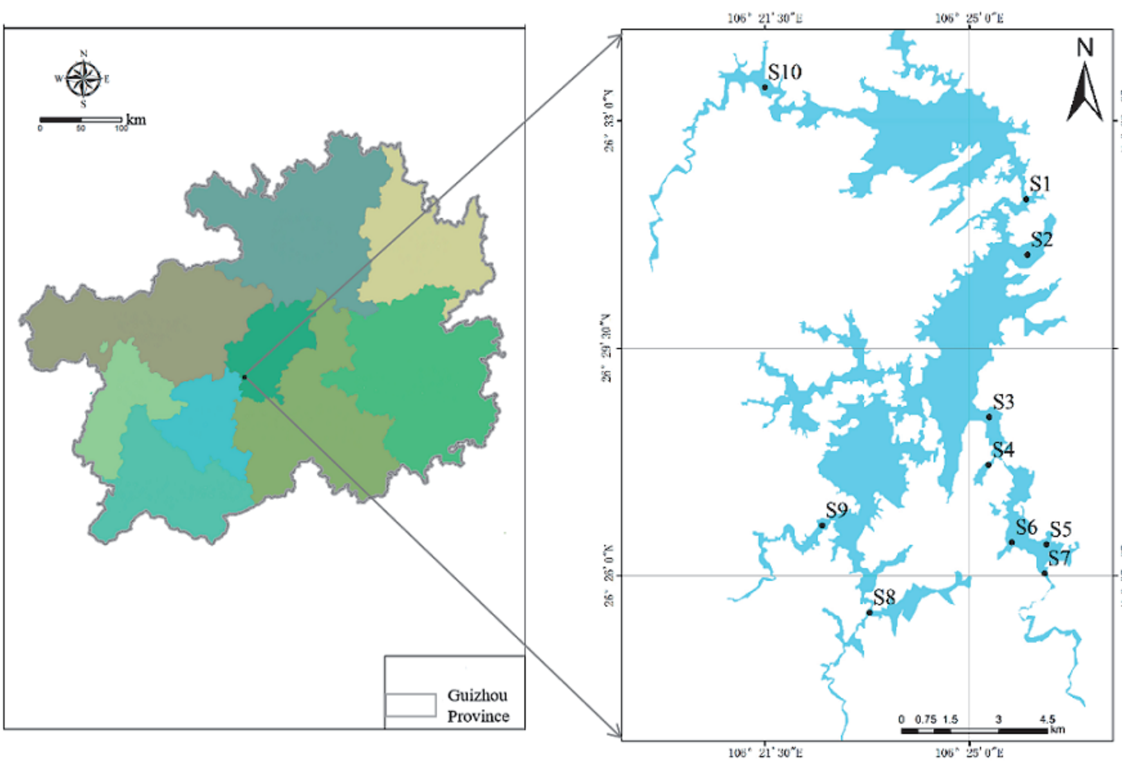

Fig. 1. Schematic diagram of the study area and the distribution of sample sampling points.

The weights set $A = \{a_1, a_2,... , a_n\}$ is a collection of factor weight, which is established with a different degree of importance. The weights are use entropy weight method to determine the weight of contaminated metals.

(2) Single-factor fuzzy evaluation, Single-factor fuzzy evaluation is defined as ensuring the membership between the evaluation object and the assessment criteria set V_j based on the ith factor u_i. The single-factor fuzzy evaluation set R_i is expressed as:

$$R_i = \{r_{i1}, r_{i2},... , r_{im}\}$$

the single-factor fuzzy evaluation matrix R is expressed as:

$$R = \begin{bmatrix} r_{11}, r_{12}, \cdots , r_{1m} \\ r_{21}, r_{22}, \cdots , r_{2m} \\ \cdots, \cdots, \cdots \ \cdots \\ r_{n1}, r_{n2}, \cdots , r_{nm} \end{bmatrix}$$

where r_{ij} (i = 1, 2, …, n; j = 1, 2, …, m) is the membership degree of the ith assessment parameter at the jth level.

(c) Fuzzy comprehensive evaluation, Composite operations are done between fuzzy weight vector A and fuzzy relation matrix R, namely fuzzy comprehensive evaluation vector B, which B is expressed as:

$$B = A \cdot R = \{a_1, a_2, \cdots , a_5\} \cdot \begin{bmatrix} r_{11}, r_{12}, \cdots , r_{1m} \\ r_{21}, r_{22}, \cdots , r_{2m} \\ \cdots, \cdots, \cdots, \cdots \\ r_{n1}, r_{n2}, \cdots \ r_{nm} \end{bmatrix} = \{b_1, b_2, \cdots , b_n\}$$

where B is normalized according to the principle of maximum membership degree of fuzzy math, and select the greatest level as rating of environmental quality. When the operation result is in the emergence of two identical (or nearly equal) maximum value, level is determined in accordance with the principles of the second largest level.

Toxic Risk Index (TRI)

Based on the threshold effect level (TEL) and the probable effect level (PEL) effects, a new toxic risk index (TRI) [22] has been applied to assess the toxic risk of heavy metals in sediment. The toxic risk index for a certain heavy metal (TRI_i), and several heavy metals (TRI) can be calculated as follows:

$$TRI = \sum_{i=1}^{n} TRI_i = \sqrt{\frac{(\frac{ci}{TEL})^2 + (\frac{ci}{PEL})^2}{2}}$$

where ci is the content of heavy metal i in sediments; n is the number of heavy metals. Pollution intensities were classified into five categories based on TRI values: (1) TRI≤5, no toxic risk; (2) 5<TRI≤10, low toxic risk; (3) 10<TRI≤15, moderate toxic risk; (4) 15<TRI≤20, considerable toxic risk; (5) TRI>20, very high toxic risk [23].

Results

Spatial Distribution of Heavy Metals in Surface Sediments

The concentrations and the basic statistical parameters of 7 heavy metals in the investigated sediment samples of Hongfeng Reservoir were summarized in Table 2. The mean values of heavy metals in the surface sediments were as follows: the ranges for Cu, Ni, Pb, Zn, Cd, Hg and As concentration were 85.62, 86.78, 47.45, 125.10, 0.34, 0.48, 37.13 mg/kg, respectively. Compared to the background values of heavy metals in Guizhou province, all the average values, except for Cd, were above their corresponding background values, which were indicated different levels of pollution in the surface sediment.

The spatial distribution characteristics of heavy metals in river sediments in the study area were presented in Table 2. Except for the average value of Cd, the average value of other heavy metals exceeded the corresponding background value. The average concentration of heavy metals in the sediment followed the order Zn>Ni>Cu>Pb>As>Hg>Cd. The sediments in different study regions were affected by heavy metals pollution to different degrees, especially S3, and the coefficient of variation of heavy metals was between 18.58% and 64.95%. The concentrations of Pb, Cd, Hg, and As in the sediments were significantly higher than those in sediments from the sampling sites in other study areas, which were 2.03, 1.02, 5.56, and 2.80 times higher than the background value, respectively.

Statistics of Geostatistical Prediction Maps

The spatially distributed concentrations of heavy metals in Hongfeng Reservoir surface sediment were presented in the geostatistical prediction maps (Fig. 2). The violin plot (Fig. 3) described the concentrations and statistical parameters from the geostatistical prediction maps. According to Figs. 2 and 3, the results of the concentrations for Cu, Ni, Pb, Zn, Cd, Hg, ranged from 35.29-175.62, 43.20-176.10,30.93-71.41, 98.09-169.10, 0.16-0.71,0.36-0.61 and 25.03-55.95 mg/kg, respectively. The patterns of the heavy metals' accumulation and distribution were illustrated in (Fig. 2), where red color stands for high concentration value, and dark green color signified low concentration. Extreme enrichment of Ni and Zn were occurred in the southern section of the study area. Compared to the PEL (Table 2), all the surface sample concentrations of As were higher than, which indicated significantly frequent adverse

Table 2. Descriptive statistics of heavy metal concentrations of samples in surface sediment (n = 30) of Hongfeng Reservoir (mg/kg).

	Cu	Ni	Pb	Zn	Cd	Hg	As
Min	35.29	43.20	30.93	98.09	0.16	0.36	25.03
Max	175.62	176.10	71.41	169.10	0.71	0.61	55.95
Mean	85.62	86.78	47.45	125.10	0.34	0.48	37.13
SD	54.75	44.30	11.25	25.77	0.18	0.09	8.56
CV %	64%	51%	24%	21%	54%	19%	23%
Background values	32.00	39.10	35.20	99.50	0.70	0.11	20.00
TEL	31.60	22.70	35.80	121.10	0.99	0.18	9.80
PEL	149.00	48.60	128.00	459.00	4.98	1.06	33.00

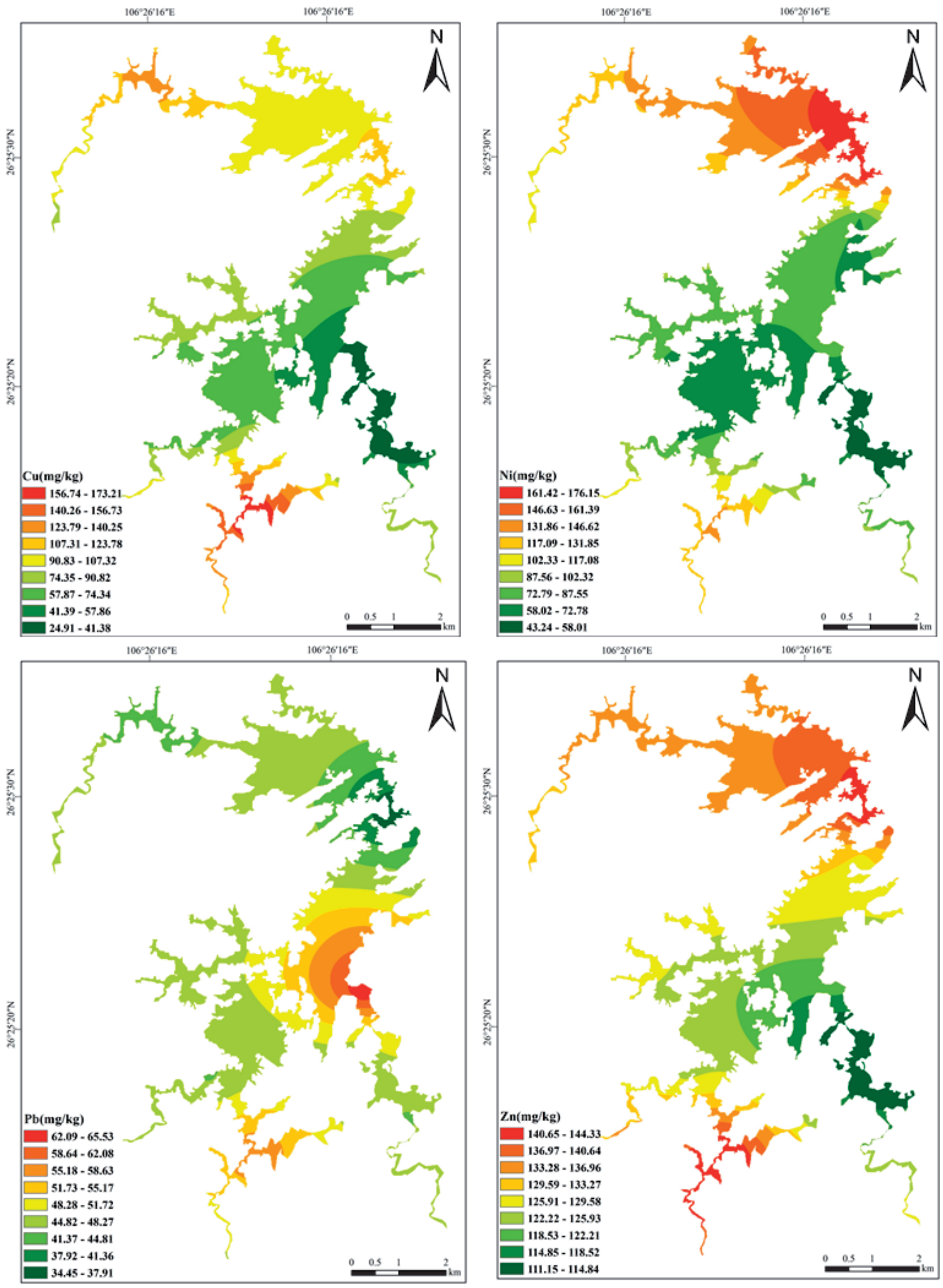

Fig. 2. Geostatistical prediction maps of heavy metals in the surface sediment.

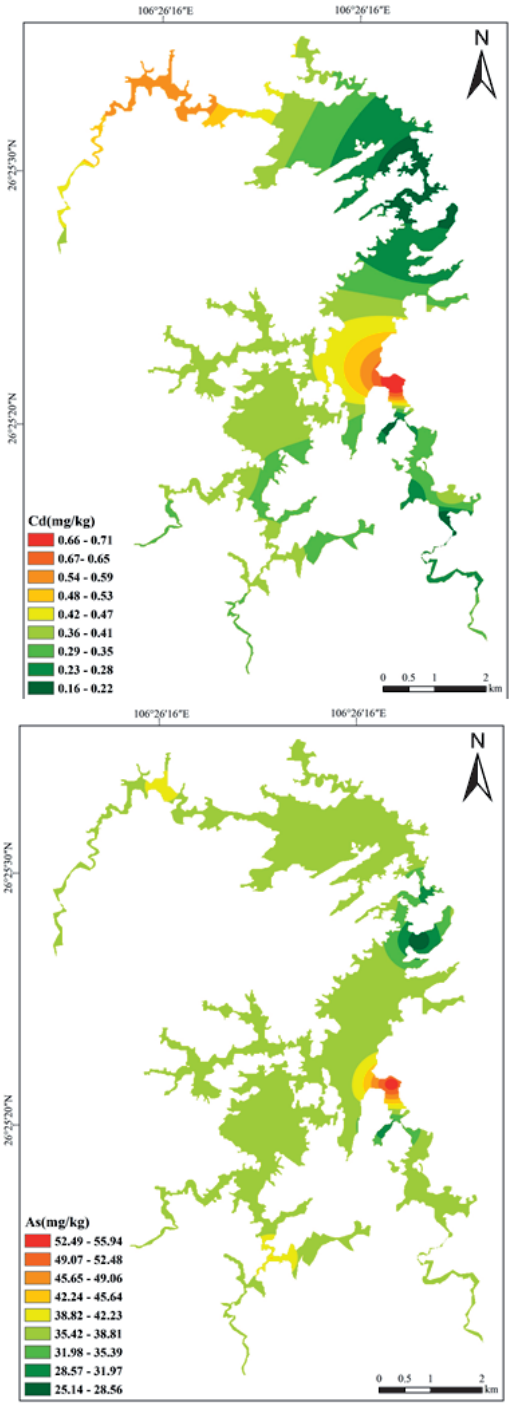

Fig. 2. Geostatistical prediction maps of heavy metals in the surface sediment.

biological effects. The Ni and Zn distribution had a similar distribution pattern; the high concentration areas occurred mostly in the northern part of Hognfeng Reservoir. Cu and Zn provided less nutrients for aquatic life when they were at low concentrations, but when they were higher than the threshold required contents, they can be toxic. The average concentration of As and Ni were higher than their TEL, and 90% of surface sample of the Ni concentrations in the prediction map were higher than the TEL, which indicated that adverse biological effects may happen.

Results of Sediments Contamination Level Evaluation

The results of the Fuzzy Comprehensive Evaluation are presented in Table 3. According to the principle of maximum membership, the results revealed that the S1 and S8 were moderately to strongly polluted (IV), S2, S9, and S10 were moderately (III), S3, S5, and S7 were unpolluted to moderately polluted (II), S4 and S6 were unpolluted (I). The results of FCE and I_{geo}, RI evaluation were shown in Table 4.

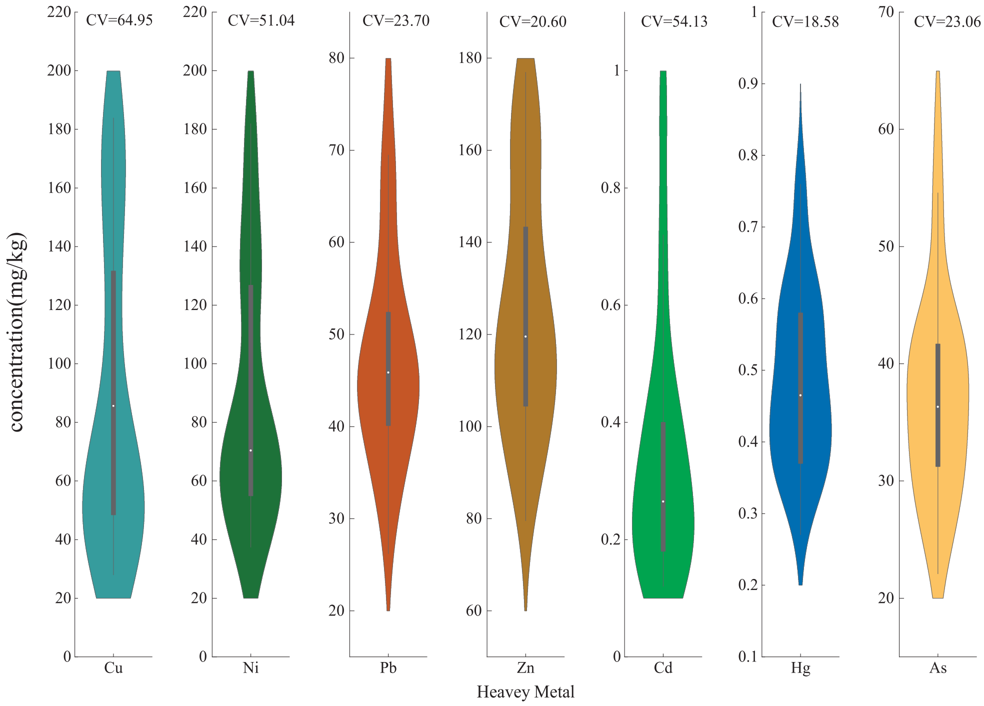

Fig. 3. Violin plots of heavy metal concentration in sediments within the study region.

Table 3. Fuzzy comprehensive evaluation results of heavy metals.

Study area	I	II	III	IV	V
S1	0.31	0.03	0.16	0.31	0.19
S2	0.11	0.18	0.45	0.24	0.02
S3	0.07	0.35	0.22	0.28	0.08
S4	0.48	0.05	0.41	0.06	0.00
S5	0.29	0.56	0.10	0.03	0.01
S6	0.32	0.30	0.19	0.17	0.02
S7	0.13	0.49	0.20	0.15	0.01
S8	0.06	0.06	0.35	0.38	0.15
S9	0.08	0.28	0.33	0.27	0.02
S10	0.07	0.02	0.48	0.28	0.15

According to the principle of maximum membership degree of fuzzy math, and select the greatest level as rating of environmental quality, as in chapter 2.3.2.

Results of Toxicity Risk Assessment of Heavy Metals in Sediments

Sediment quality guidelines (SQGs) were presented in Table 2. SQGs consist of TEL and PEL, which were applied to evaluate sediment heavy metals pollution level and the effects of the heavy metals on the local organisms in Hongfeng Reservoir.

The sediment quality threshold effect value (TEL) and possible effect value (PEL) had applied in experiment [24]. The concentration of heavy metals was lower than TEL, indicating that there will be no biological effects. The concentration of heavy metals was greater than PEL, illustrating that adverse biological effects will often occur. The concentration of heavy metals was between the two, demonstrating that biological effects may occur [25]. The sample proportion of TEL and PEL in the study area and the range of toxicity risk index were explained in Fig. 4a). The concentration of Ni and As were higher than the PEL value, accounting for 90% and 70% of the sample respectively, indicating the zoobenthos deposited at the bottom of the above sampling sites were more affected by the harmful effects of Ni and As.

Table 4. Rating results of heavy metal pollution with different evaluation methods.

Evaluation methods	Igeo	RI	FCE
S1	Unpolluted	Considerable toxic risk	Moderately to strongly polluted
S2	Unpolluted	Moderate toxic risk	Moderately
S3	Moderately to strongly polluted	Moderate toxic risk	Unpolluted to moderately polluted
S4	Unpolluted	Low toxic risk	Unpolluted
S5	Unpolluted	Low toxic risk	Unpolluted to moderately polluted
S6	Unpolluted	Low toxic risk	Unpolluted
S7	Unpolluted	Low toxic risk	Unpolluted to moderately polluted
S8	Moderately to strongly polluted	Considerable toxic risk	Moderately to strongly polluted
S9	Unpolluted to moderately polluted	Considerable toxic risk	Moderately
S10	Moderately to strongly polluted	Moderate toxic risk	Moderately

The concentrations of Cu, Pb, Cd, and Hg were between TEL and PEL at most sampling points, accounting for 80%, 90%, 90%, and 100% of the sample respectively, indicating the zoobenthos deposited at the bottom of the above sampling sites may be affected by the biologically harmful effects of Cu, Pb, Cd, and Hg.

In this study, a new toxicity risk index (TRI) based on TEL and PEL values was used to calculate the toxicity risk of sediment in the study area. As can be seen from Fig. 4b), the results indicated that the TRI value is between 8.33 and 16.11. S4,S5, S6, and S7 were at low toxic risk ($5<TRI\leq10$); S2, S3 and S10 are at moderate toxic risk ($10<TRI\leq15$), and S1, S8, S9 were at considerable toxic risk ($15<TRI\leq20$), respectively. Furthermore, Cu, Ni, As were the main contributors to TRI, because of the high concentration of these three heavy metals.

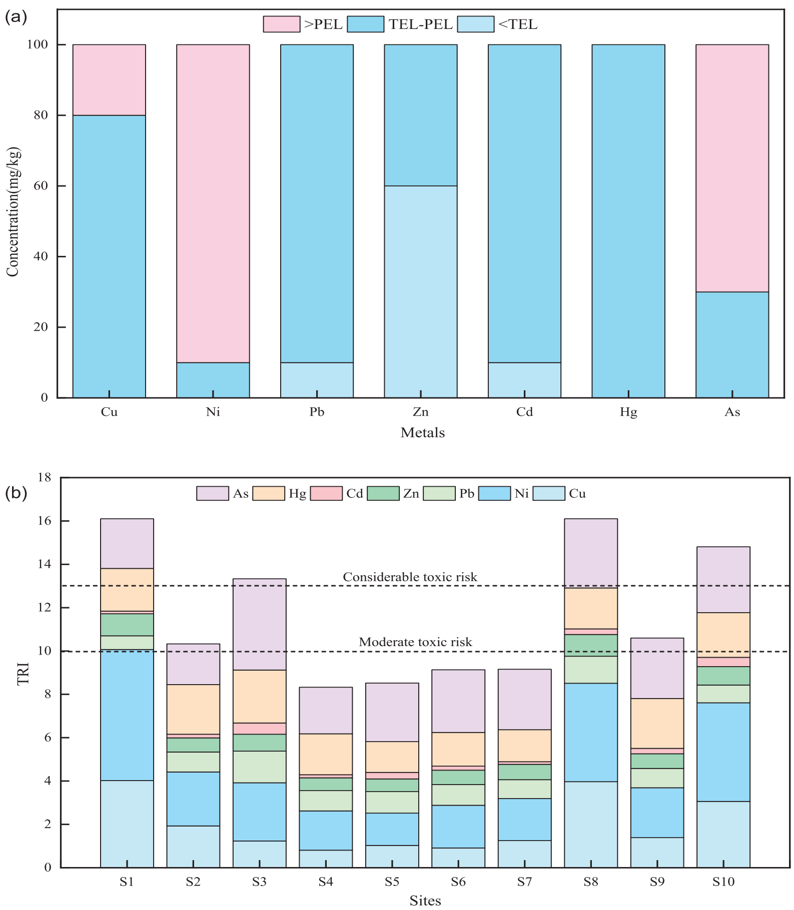

Fig. 4. Sample ratio of heavy metal sediment quality guidelines (SQGs) value and toxicity risk index of surface sediment.

Geostatistical Prediction Maps of the Toxicity Risk Index

The TRI is used to characterize the toxicity risk of heavy metals in the sediment.

The TRI of the heavy metals in the sediment indicated that Ni has a serious toxicity risk. All the TRI of Cd in the sediment were below 1.00, indicating that Cd of the contribution to the toxic effects of benthic organisms was small. Ni, Cu, As has a high toxic effect contribution value, which indicated that benthic organisms in the study area will be poisoned by these three heavy metals. TRI values showed that the toxic of S1, S8, S10 in three study areas was high. The Cu, Ni and Zn distribution had a similar distribution pattern (Fig. 5), and the toxic effects areas occurred mostly in the northern part of Hongfeng Reservoir.

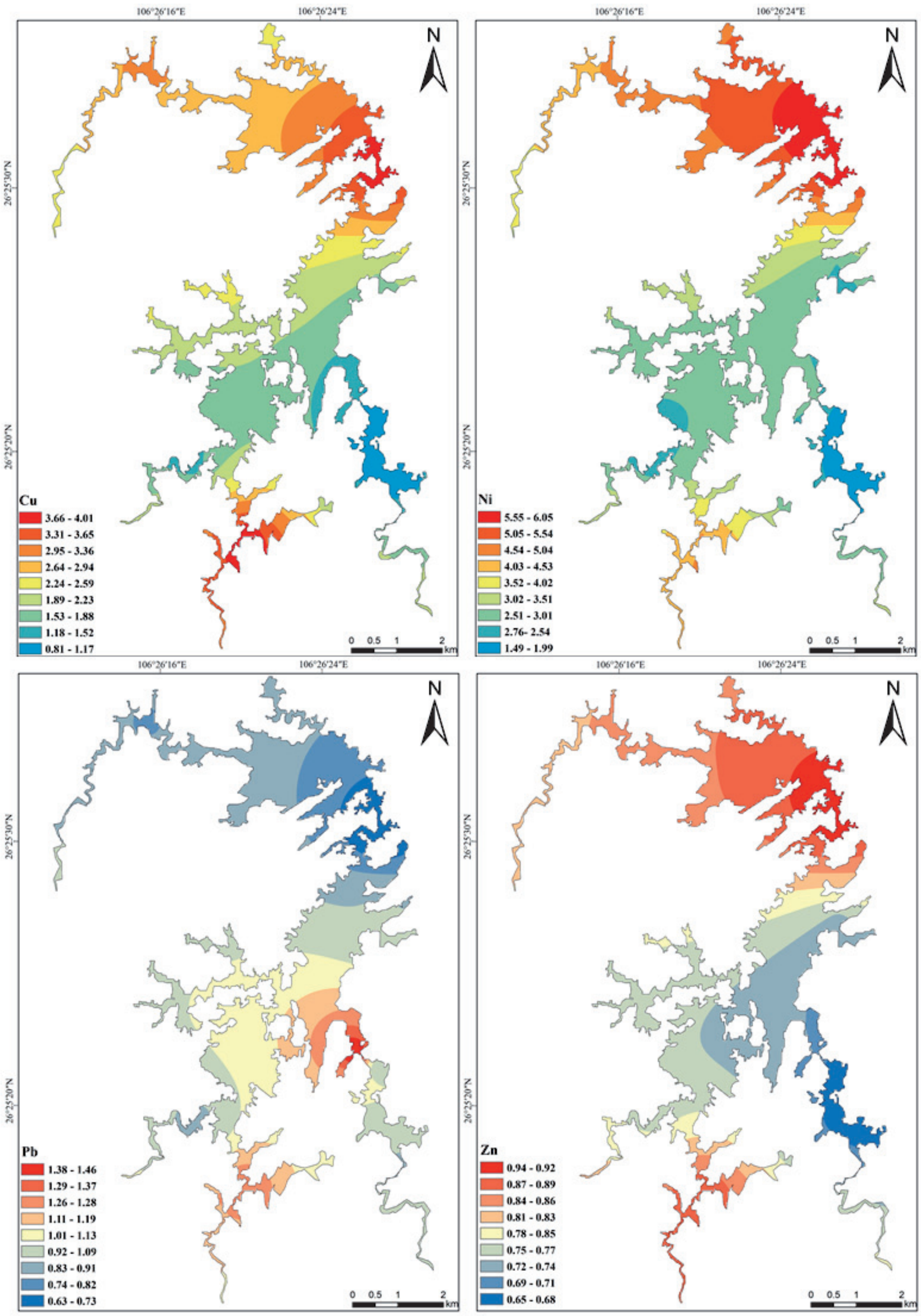

Fig. 5. Toxicity risk index (TRI) maps of heavy metals in the surface sediment.

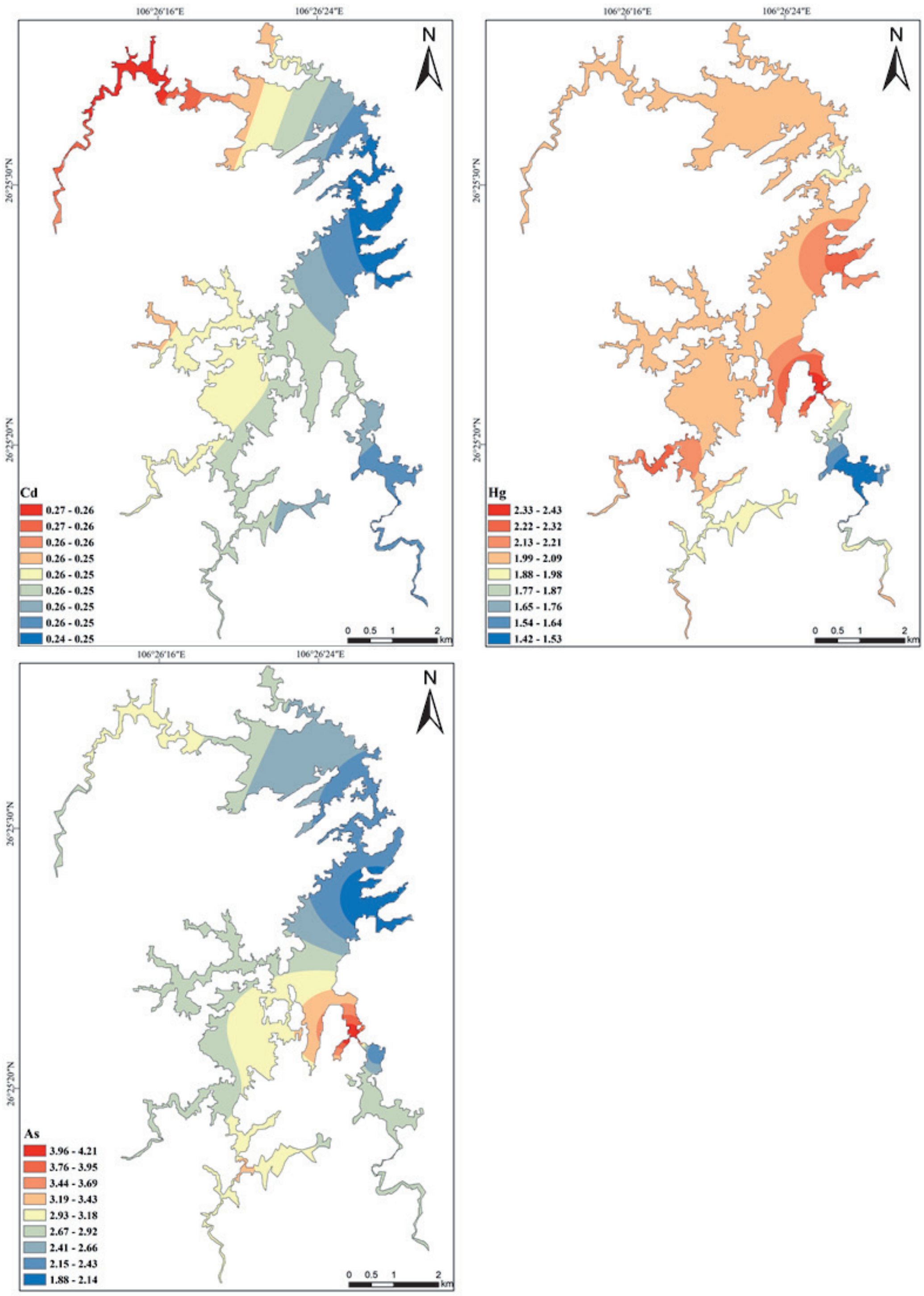

Fig. 5. Toxicity risk index (TRI) maps of heavy metals in the surface sediment.

Discussion

Heavy Metals Pollution Characteristics

From Table 2, it is evident that the coefficients of variation for Cu in Hongfeng Reservoir sediments were as high as 64.23%, followed by Cd and Ni (54.49% and 51.37%). These indicated the large regional differences in total As, Cd and Ni concentrations in sediments, which may be caused by anthropogenic inputs of heavy metals. We observed significantly higher concentrations of all the seven heavy metals in the surface sediments of the S1 and S2 than other regions, which might be impacted by different sources.

Heavy Metals Potential Toxicity Risk

In Fig. 4b), it is found that when the TEL and PEL baseline values in heavy metal sediment quality guidelines (SQGs) value were taken as references,

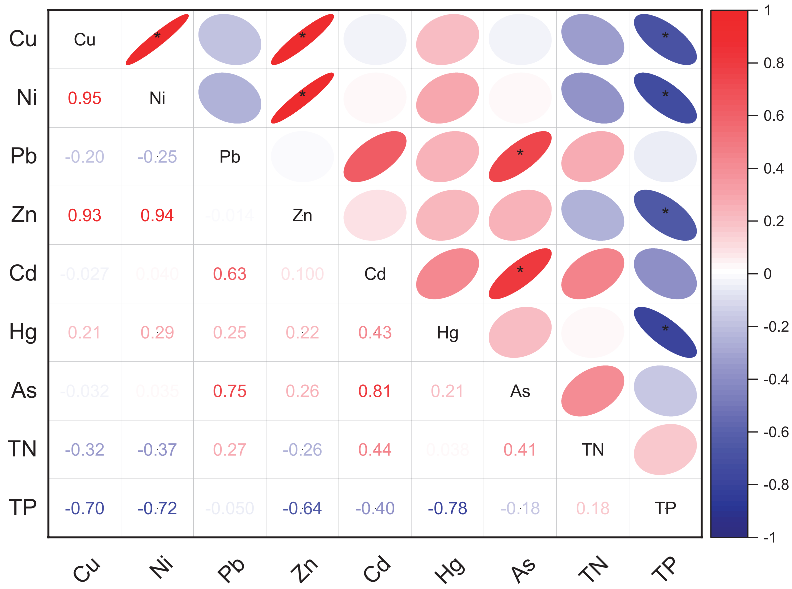

Fig. 6. Correlation matrix of heavy metal indexes of sediments in the external watershed of Hongfeng Reservoir.

the potential toxicity risk declined in the order of Ni>As>Cu>Hg>Pb>Zn>Cd, Ni and As were the most serious polluting element among these heavy metals. The value of TRI_i for Ni and As were 2.98 and 2.79 on average respectively, demonstrating a considerable toxic risk for Hongfeng Reservoir. The values of TRI_i ranged from 0.12 to 6.05. All of the TRI_i values for the other elements studied in this investigation were lower than 2. The toxicity risk posed by the heavy metals at different sampling sites descended in the order of S1>S8>S10 >S3>S9>S2>S7>S6>S5>S4.

In general, the main heavy metal contaminants in Hongfeng Reservoir sediment were Ni, and 90% sampling sites exceeded the PEL value. Followed by was As, and 70% sampling sites exceeded the PEL value. The three sampling points S1, S8 and S10 in the study area were more affected by the harmful effects, with the biologically harmful effects effected region mainly concentrated in the northern of Hongfeng Reservoir.

Sources of Heavy Metals in the Sediments of Hongfeng Reservoir

Song et al [26] and Tchounwou et al [27] reported that the intercorrelation between the heavy metals can interpret their sources and pathways in the environment.

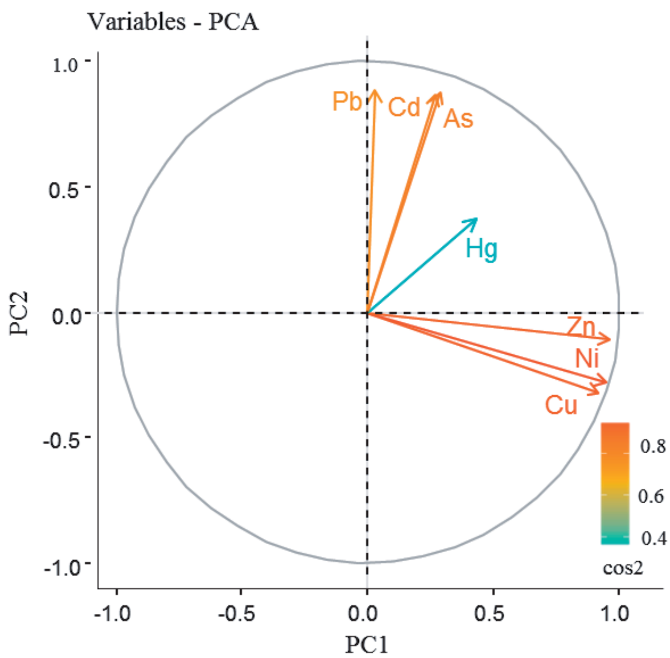

Fig. 7 Principal component analysis (PCA) of heavy metals in Hongfeng Reservoir.

The correlation heat map (Fig. 6) shows the correlation of the seven heavy metals in the surface sediment. Based on the Pearson correlation coefficient, Zn and Ni and Cu was a significant positive correlation ($P<0.01$). Cu demonstrated a significant positive correlation with Ni ($P<0.01$), and As illustrated significant positive correlation with Cd ($P<0.01$), while Hg explained irrelevance with others ($P>0.05$).

Principal component analysis can be used to assist the identification of sources of heavy metals in the entire study area [28]. The results of PCA are shown in Fig. 7. Two principle components (PCs) explained 80.6% of total variance based on eigenvalues (eigenvalue>1). The PC1 (Cu, Ni, Zn), explaining 43.2% of the total variance, was strongly and positively related to Cu, Ni, and Zn (Fig. 7), and correlation analysis also exhibited significant correlations between them (Fig. 6). The PC2 (Pb, Cd, As), explaining 37.4% of the total variance, showed highly positive factor loadings on Cd, Pb and As.

The result of PCA showed that Cu, Ni, and Zn might derive from the common sources, Cd, Pb and As might share another similar sources, whereas Hg might originate from the third source. The significant correlations among these metals (Table 2) further implied that they had common sources, which is consistent with the result of the PCA.

PC1 (Cu, Ni and Zn) of the total variability can be considered to reveal the impact of anti-corrosion coatings, heavy metal-containing waste accumulation, sewage irrigation and other domestic and industrial impacts. Ni mainly resulted in the burning of fossil fuels, the excessive use of chemical fertilizers and pesticides, etc. The result of Pearson correlation pointed out the close relation between Zn and Cu. Some studies have proved that Hg may be ascribed to industrial discharge [29]. Hongfeng Reservoir has a more developed tourism function, but the overuse of petroleum will deteriorate the water quality. Meanwhile, there were machinery industry, fertilizer, and coal mining companies around the reservoir. Therefore, it was speculated that the domestic and industrial sewage, and agricultural activities, resulting in contaminated water quality in Hongfeng Reservoir.

Conclusions

This study demonstrated that the mean concentrations of Ni, Cu, Zn, As, Cd, Hg, and Pb in sediments of Hongfeng Reservoir were commonly higher than the background values. The prediction results of geostatistical maps illustrated the heavy metal distribution patterns in sediments had a similar trend, In general, the high concentration values were mainly located in northern part of Hongfeng Reservoir. The relationship among the heavy metals in the sediment, were shown by the Pearson analysis. Based on correlation matrix analysis and PCA, Zn, Cu, and Ni were in the PC1 group, Cu and Zn were mainly affected by domestic and industrial sewage and agricultural activities, while Ni mainly came from the burning of fossil fuels, overuse of fertilizers and pesticides. In PC2, As in the reservoir perhaps from the development of agriculture in the process of pesticide and fertilizer residues through rainfall into the reservoir. Cd pollution also came from the early combustion at Qingzhen power plant by coal and other industrial pollution, as well as the use of pesticides, fertilizers pollution of agricultural activities. Pb is adopted from motor vehicles and ships exhausted pollution potentially, etc. Therefore, reducing the discharge of industrial wastewater and agricultural domestic sewage can effectively improve the environment.

Credit Authorship Contribution Statement

Shihui Zhou performed the conceptualization, methodology, investigation, writing-original draft and was a major contributor in writing the manuscript. Qiuhua Li acted as a role of funding acquisition, project administration, and manuscript supervision. Pan Kuang was a major contributor of the data curation. Mengshu Han was a major contributor of investigation, formal analysis and data curation. Zhenhui Yuan analyzed and interpreted the data and was a major contributor in preparing figures related to data. Jiwei Hu regulated the research methodology and English checking of the manuscript. All authors read and approved the final manuscript.

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Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare no conflict of interest.

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