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Distribution Characteristics and Pollution Evaluation of Heavy Metals in Surface Sediments in China's Largest Freshwater Lake

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Abstract: The spatial distribution characteristics and pollution sources of eight heavy metals Mercury (Hg), Copper (Cu), Lead (Pb), Cadmium (Cd), Zinc (Zn), Arsenic (As), Chromium (Cr) and Nickel (Ni) in the sediments around and within Poyang Lake were studied using the Kriging interpolation method, Pearson correlation analysis, and principal component analysis(PCA). The cumulative characteristics of heavy metals in the study area were analyzed, and risk assessment was conducted using the geo-accumulation, potential ecological risk, and pollution load index methods. The results showed that the average concentrations of Cr, Cu, Ni, Pb, Zn, and Hg in the overall surface sediments of Poyang Lake were 2.26, 5.13, 1.26, 2.46, 1.75, and 1.09 times higher than the background values, respectively, with Cu being the primary pollutant. The geo-accumulation index revealed that the accumulation degree of heavy metals in sediments was in the order of Cu > Pb > Cr > Zn > Cd > Hg > Ni > As. The total potential ecological risk showed that Poyang Lake was at a moderate risk level, with some areas having a slight risk. The pollution load index indicated that Poyang Lake was slightly polluted overall, with some regions experiencing moderate pollution. Spatially, the concentration of heavy metals in sediments was higher in the southern part of the lake and the spatial distribution of As, Ni, Pb, and Zn concentrations were consistent. The primary sources of As, Cu, Zn, Pb, and Cr were industrial, agricultural, and mineral sources. At the same time, human activities mainly caused Cd and Hg, and Ni was driven primarily by smelting and natural activities.

Key words：Poyang Lake; Sediments; Heavy metals; Distribution characteristics; Risk assessment

Introduction

Heavy metals have high toxicity, once released into the environment is difficult to be degraded, easy to be enriched through the food chain and other characteristics, Excessive concentration will affect the normal physiological functions of animals and plants (Kaplan et al.2016). Heavy metals come from a wide range of natural sources, usually caused by human production, life, and natural changes (Wang et al.2020;Martin et al.2013;Zhou et al.2018;Zhang et al.2021;Li et al.2018). Heavy metal pollution will seriously threaten the natural ecological environment when affected by various physical and chemical properties, excessive content and morphological changes (Yu et al.2020). When affected by the heavy metals in the process of plant growth, will be of certain enzymes or nutrient elements in plants to form negative effects, the heavy metal concentration is too high will directly cause plant death (Hudson et al.2004). When heavy metals harm animals, the normal growth of animals will be affected, resulting in functional damage of bones, nerves and organs (Moore et al.2015). Small particles of heavy metals in the atmospheric environment can enter the human body through the respiratory tract, skin, digestive tract and food chain, and their accumulation in the human body will endanger health to a certain extent (ERIKSEN et al.2017). Heavy metals can directly enter the atmosphere, water and soil sediments, causing damage to various environmental systems (Massos et al.2017). Compared with air and water environmental pollution, the public does not pay enough attention to sediment pollution, and the awareness of prevention and control is relatively weak, largely due to the hidden and lagging nature of sediment pollution. For example, people can intuitively see the haze when it comes and smell the deterioration of the river, but we can’t directly perceive the amount of toxic heavy metals in the sediment, and it will take a huge cost and time to repair after pollution. Therefore, the study of the sources of heavy metals in sediments is closely related to controlling pollution sources of heavy metals and protecting nature and human health.

Lake sediments are the primary habitat for animals and plants and carriers of heavy metals (Gao et al.2016). The accumulation degree of heavy metals in the surface sediments of the lake district can reflect the quality level of the ecological environment of the lake district and has a long-term impact on the environmental structure of the lake district (Lu et al.2014). Previous studies have shown that heavy metal pollution in lake sediments has received extensive attention from scholars at home and abroad (KUNWAR et al.2005). Heavy metals are easy to produce physical and chemical reactions and precipitate after entering lake water. As lake sediments settle, the lakebed rises, creating a marginal zone. Over time, as water environmental conditions change, heavy metals in the marginal areas can be transported into the lake and cause secondary pollution (Chen et al.2007). Following this cycle process, the persistent existence of heavy metals in sediments will bring more significant heavy metal pollution to the natural ecology of the lake. Therefore, the determination of heavy metal content in sediments and the analysis of pollution are helpful in clarifying the ecological changes of the lake area and the influencing factors of the mechanism of heavy metal damage in sediments.

As a key geographical unit of natural ecosystem and an important part of a community with a shared future of “mountains, rivers, forests, fields, lakes, grasses and sand”, lakes play an irreplaceable role in the fields of drinking water supply, flood control and drought relief, environmental purification and biodiversity maintenance, and have special resources, environmental ecology and historical and cultural values (Yang et al.2020). As inland waters, the lake is sensitive to global environmental changes, regional climate, and human behavior in the basin. Worldwide, lake ecological and environmental problems caused by rapid development such as industrialization, urbanization and agricultural modernization have become common challenges faced by countries all over the world (Zhang et al.2023). Poyang Lake has the function of regulating the water level of the Yangtze River, improving the local climate environment and providing fresh water resources. It is the largest freshwater lake in China. Jiangxi Province is a big agricultural province, and the water used for agricultural irrigation, aquaculture and fishery, and residents’ life can not be separated from the water resources of the lake region. The water quality safety of the lake area is directly related to the drinking water health of the Yangtze River’s lower reaches and the lake’s tributaries (Jin et al.2012). Periodic flooding changes in Poyang Lake promote upstream and downstream water to carry pollutants to Poyang Lake, resulting in heavy metal accumulation (Hua et al.2017;Zhang et al.2017). The heavy metals carried in and out of the water settle into the lake sediments, especially in Hukou County, located in the upper reaches of Poyang Lake and connected to the Yangtze River (GHREFAT et al.2006). The average contents of Cr, Cu, Hg and Pb in the lake estuary (Feng et al.2017). are all higher than the background values of Poyang Lake (Poyang,1998). The surface sediments of the lake body are located at the bottom of the water body. With the bottom environment’s disturbance, heavy metal content distribution varies greatly. The potential biological toxicity risk associated with heavy metals in Poyang Lake sediments follows the order of Cu > Cd > Pd > Zn > Cr (Hu et al.2011). In addition, the accumulation of heavy metals in the soil of Ganxian County on the plain downstream of Poyang Lake and the farmland soil in the lake area has reached a moderate ecological hazard level (Zou et al.2018;Zhao et al.2018). The heavy metal pollution in Poyang Lake will eventually settle into the soil and sediment and migrate and transform (Zhang et al.2010). Most scholars in past research of poyang lake research institute of the methods used for cumulative index evaluation method, the potential ecological risk evaluation method, to study the lake surface of heavy metal content, source, and the risk (Ao et al.2015). However, the pollution load index proposed by scholars is rarely used, which does not involve the ecological heavy metal load in the lake area. The migration of heavy metals in Poyang Lake is complex. Most scholars have studied the heavy metals in the lake area, mainly in the region, section and part of the point. Still, there is little research on the tractability and spatial distribution of heavy metals in Poyang Lake.

Therefore, this study of poyang lake surface sediment of Hg, Cu, Pb, Cd, zinc, As, Cr, Ni heavy metal concentrations were determined and designed to parse the distribution characteristics and the present situation of the concentration of heavy metals in sediments, source identification.Compared with the previous research, on the one hand, the accumulation of content can be interpreted from the data. On the other hand, we can get a clear understanding of the whole lake area from the mapping of the Poyang Lake vector map. The results of the analysis can provide theoretical support for the improvement of the overall environment of the lake area and the exploration of the distribution characteristics of heavy metal content in the surface sediments of the lake area, which has essential scientific significance for the protection of the green environment of Poyang Lake.

1.Materials and methods

1.1. Study Area

Poyang lake is China's second largest inland lake, located in the north of Jiangxi province, on the south bank of the middle and lower reaches of the Yangtze River. Poyang Lake is divided into two parts, north and south, with Songmen Mountain as the boundary, south is the main lake body. Poyang Lake is connected to the Ganjiang River, Fuhe River, Xinjiang, Raohe and Xiushui Rivers (the "five Rivers"), and its balance of power is constrained by the water levels of the Yangtze and the "five Rivers". The watercourse, continent beach, island, inner lake and Han Harbor form the landform of Poyang Lake. Poyang Lake is a shallow water lake with seasonal variations in water level, characterised by high and low water river facies. The area and volume of the lake will change with the change of flood period and dry period, and the range of change is extremely large. Poyang Lake waters and shoal land belong to Nanchang, Jiujiang, Shangrao and other areas along the Lake, collectively known as Poyang Lake Area, a total area of 19,761.5 km^2. In the southern branch of Poyang Lake are the dexing copper mine, Yongping copper mine and metallurgical industry, sand and ceramics industry in the northern region, and tungsten and uranium industry in the Ganjiang River basin. The water system development can promote rapid economic growth but also bring some pollution.

1.2. Sampling point arrangement with sample collection

According to the topographic and geomorphologic characteristics of Poyang Lake, land distribution, water area, combined with tributaries and water flow into the lake mouth and other factors, the abundant and low water periods in summer and winter from 2019 to 2021.Seventy-nine sampling points were set up around Poyang Lake, Hu Lake and tributaries such as Ganjiang River, Xiuhe River, Xinjiang River, Raohe River and Fuhe River Figure.(1) to collect surface sediment samples. According to the standard HJ/T166-2004 "Technical Specifications for Soil Environmental Monitoring", with each point as the center of the circle and a radius of ten meters, the sediment is collected with a professional mud sampler. Then the surface samples with a zero to ten Centimeter depth are collected with a mud grab bucket or a wooden shovel. The mass of each sample is about one kilogram, the visible residue is removed, and the samples are packed into clean self-sealing bags. The air is drained, corresponding to the sampling point, labelled, stored in a refrigerated sampling box, and returned to the laboratory for storage on the same day.

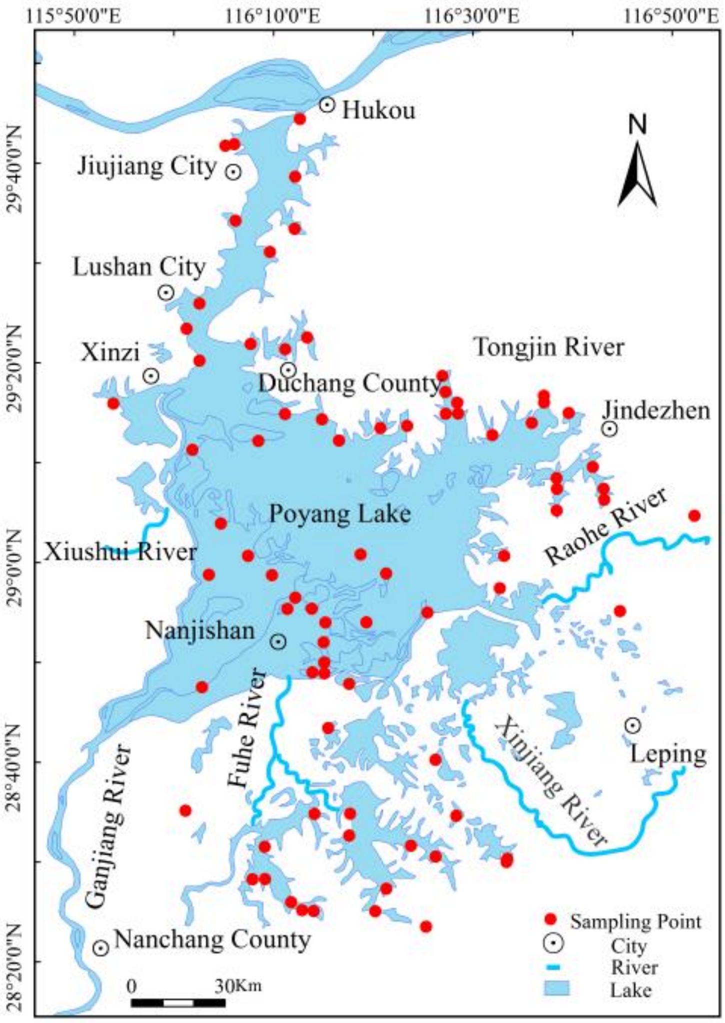


Figure 1. Setting of sampling points for surface sediments of Poyang Lake

1.3. Sample processing and evaluation method.

1.3.1. Sample pre-treatment and measurement method

The sediment samples were freeze-dried; the residual gravel was removed, and ground. After one hundred mesh sieve, the samples were put into polytetrafluoroethylene plastic bottles, numbered and placed in the sample refrigerator, and stored at Four degrees Celsius for the determination of heavy metals. The treated sediment samples were weighed to about 0.0001-0.3000 milligram in the digestion tube, and eight milliliters aqua regia (three to one Equal to concentrated hydrochloric acid: concentrated nitric acid) were adde to each sample, and then digested by microwave digester (Pean MARS XPRESS, USA). The Hg concentration was determined by atomic fluorescence (AFS-8230, Beijing Jitian) in accordance with standard HJ 680-2013 “Determination of Mercury, arsenic, selenium, bismuth and antimony in Soil and sediments by microwave digestion/Atomic fluorescence method”. The concentration of Cu, Pb, Cd, Zn, As, Cr, Ni is determined according to the standard HJ803-2016 “Determination of twelve metal elements in soil and sediment extraction - Inductively coupled plasma mass spectrometry method”, the use of ion mass spectrometry (ICAP-7000, the United States Thermo Fei inductively coupled plasma mass spectrometer) determination, all three effective determination. Take the average value as the analysis value.

1.3.2. Pollution assessment method

The geoaccumulation index method is used to analyze the degree of heavy metal pollution in sediments. This method not only considers the geochemical background value of sediment pollution affected by human factors, but also reflects the natural distribution characteristics of heavy metals in sediments (NISSENBAUM,1989). Formula is:

$$I_{geo} = \log_2[C_i / K \bullet B_i] \quad (1)$$

Where, I_{geo} is geological accumulation index; C_i is the measured value of pollutant *i*, mg/kg; B_i is the background value of heavy metal *i*, As=13.37, Cd=0.75, Cr=29.5, Cu=4.75, Ni=19.0, Pb=12.5, Zn=45.75, Hg=0.064 (Feng et al.2017;Poyang,1998), mg/kg; K is the variation coefficient of background value caused by diagenesis, generally K=1.5. The ground accumulation index is divided into seven grades, representing different pollution levels of heavy metals, as shown in Table.(1).

Pollution load index (TOMLINSON et al.1980) is used to evaluate the overall level of heavy metal pollution in sediments, and the formula is:

$$F_i = C_i / B_i \quad (2)$$

$$P_{F_i} = \sqrt[n]{F_1 \times F_2 \times F_3 \cdots F_n} \quad (3)$$

Where: F_i is the pollution index of heavy metal *i*,*i* is 1, 2... , n, n is to evaluate the number of heavy metal elements; B_i is the background value of element *i* (Feng et al.2017;Poyang,1998), mg/kg; P_{Fi} is the pollution load index of sampling point *i*. TOMLINSON divided the pollution load index into four grades, as shown in Table.(1).

The potential ecological index method (HAKANSON,1980;Zhang et al.2023) is used to evaluate whether there is biological toxicity of heavy metals in sediments, and the formula is:

$$E_r^i = T_r^i \times \frac{C_i}{B_n^i} \quad (4)$$

$$RI = \sum E_r^i \quad (5)$$

Where: E_r^i is the potential ecological risk index of heavy metal *i*; B_n^i is the background value of element *i* (Feng et al.2017;Poyang,1998), mg/kg; :T_r^i are the toxicity response coefficients of element *i*, which are As=10, Cd=30, Cr=2, Cu=5, Ni=5, Pb=5, Zn=1, Hg=40, respectively. *RI* is the comprehensive potential ecological risk index. According to the different ranges of the total value of *RI*, the potential ecological hazards of heavy metals are also classified into four different levels, as shown in Table.(1).

Table 1. Classification standard of pollution index

geo-accumulation index		pollution load index		Potential ecological risk index	
I_{geo}	Pollution level	P_{Fi}	Pollution level	RI	level of risk
<0	No	≤1	No	≤150	Slight
0~1	No to medium	1~2	Mild	150~300	Moderate
1~2	Moderate	2~3	Moderate	300~600	Strong
2~3	Moderate to Strong	>3	Severe	＞600	Extremely strong
3~4	Strong				
4~5	Strong to extremely strong				
>5	Extremely strong				

1.4. Quality Control and Data Statistical Analysis

The soil standard sample (GBW07386) was used as the quality control for the determination of heavy metals in sediment, and the recovery was 93% ~ 113%. The reagents were all excellent and pure, and the standard curve R^2>0.999.

Data correlation analysis uses SPSS Statistics 22.0 software, data processing and drawing tabs are completed using Excel 2007, Origin 2017, ArcGIS10.2.

2. Results and discussion

2.1. Concentration of heavy metals in surface sediments

The analysis results of heavy metal concentration in surface sediments of Poyang Lake are shown in Table.(2) and Figure.(2). The concentration of Ni and Zn in the sediment is slightly skewed and does not obey normal distribution, but becomes normal distribution after correction conversion. As, Cd, Cr, Cu, Pb and Hg basically conform to normal distribution, and the geometric mean value can be used to represent the concentration characteristics of heavy metals. As can be seen from Table.(2) and Figure.(2), the average concentration of AS is 11.60 mg/kg, and the average concentration of Cd is 0.44 mg/kg, which is lower than the background value based on the background value of Poyang Lake, while other elements are higher than the background value (Poyang,1998). The average concentrations of Cr, Cu, Ni, Pb, Zn and Hg were 2.26, 5.13, 1.26, 2.46, 1.75 and 1.09 times higher than the background values of Poyang Lake, respectively. Taking the background value of Jiangxi Province As the standard, the concentrations of As and Zn were lower than the background value, while other elements exceeded the background value (Kuang et al.2020). The average concentrations of Cr, Cu, Ni, Pb, Cd and Hg exceeded the background value of Jiangxi Province by 1.46, 1.10, 1.11, 1.01, 4.07 and 1.32 times, respectively. In summary, it indicates that heavy metals in sediments have accumulated to a certain extent. The concentrations of As, Cd, Ni, Zn and Hg in 79 sediment samples are approximately 40.51%, 32.91%, 75.95%, 87.34% and 60.76%, respectively, while the concentrations of Cr, Cu and Pb are all greater than 90%. This indicates possible heavy metal contamination (Zhao et al.2018;LI et al.2018;Zhang et al.2014). The coefficient of variation can well describe the variation of heavy metal concentration and its spatial distribution in the study area (LI et al.2018). According to the coefficient of variation, the concentrations of As, Cr, Cu, Ni, Pb and Zn in the lake area vary greatly (Yang et al.2013). The coefficient of variation of Cd is 154.44% and that of Hg is 55.6%, indicating that the concentration distribution is uneven. Seriously affected by human factors (Martin et al.2013;Zhou et al.2018;Zhang et al.2021).

Table 2. Descriptive statistical analysis of heavy metal concentration in sediments（mg/kg）

Element	As	Cd	Cr	Cu	Ni	Pb	Zn	Hg
Range	1.94~25.72	0.02~8.55	8.08~108.90	2.64~55.09	0.35~112.89	9.47~69.70	7.70~321.62	0.01~0.26
Standard deviation of arithmetic mean	12.56±0.52	1.69±0.29	70.79±2.24	26.49±1.05	28.11±1.71	32.98±1.41	89.58±4.68	0.09±0.01
Geometric mean	11.60	0.44	66.75	24.38	23.93	30.69	80.04	0.07
Measure of skewness	0.45	1.44	-0.62	0.04	2.84	0.77	2.06	1.08
Coefficient of variation (%)	36.94	154.44	28.13	35.41	54.22	37.87	46.41	55.56
Ultra background value rate (%)	40.51	32.91	96.20	98.73	75.95	96.20	87.34	60.76

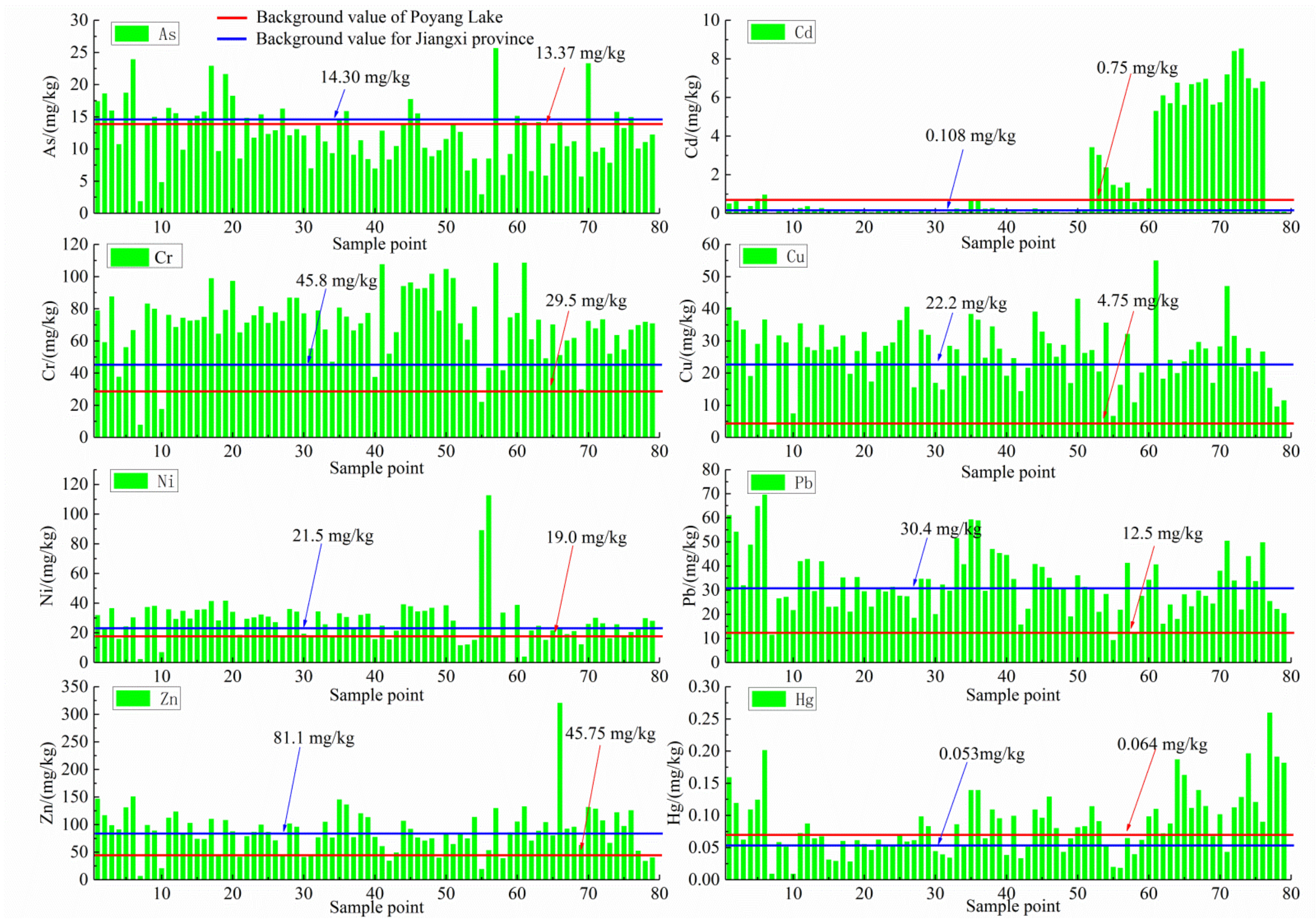
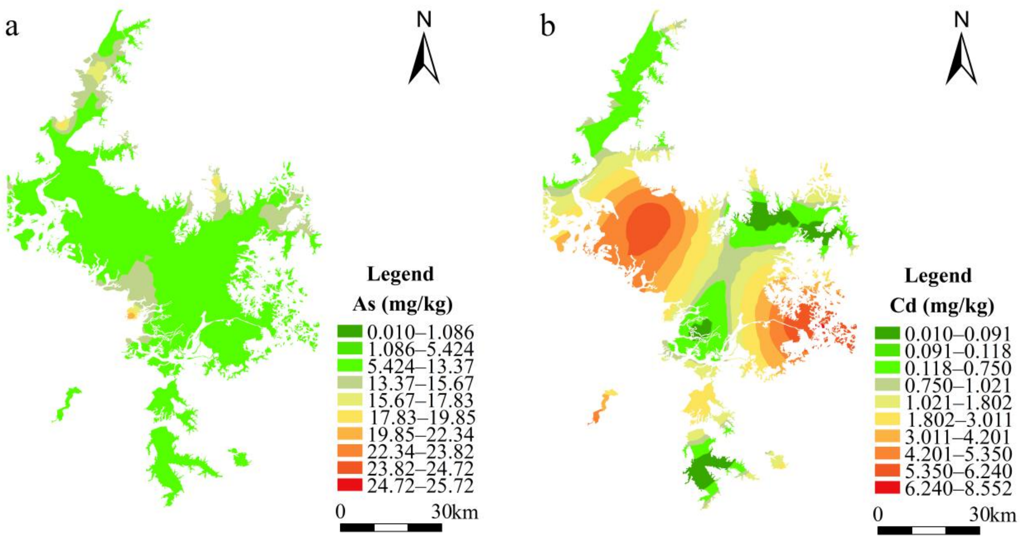


Figure 2. Heavy metal content in the study area

2.2. Spatial distribution of metal pollution in surface sediments

The spatial distribution of heavy metal elements in surface sediments of Poyang Lake is shown in Figure.(3). It can be seen from Figure.(3) that the spatial distribution characteristics of heavy metals Cr, Ni, Cu and Zn in the surface sediments of Poyang Lake are very significant, and their spatial distribution of pollution is relatively consistent. The concentration of heavy metals in the north, northeast, south, southeast and southwest of Poyang Lake as a whole is high, while the concentration is low in the west, northwest and northeast of Poyang Lake. The spatial distribution characteristics of heavy metals Cd, Pb and Hg are very significant, and their spatial distribution of pollution is consistent. The high concentration is mainly concentrated in the central area of the lake, and the concentration from the central area to the southern area is higher than other areas. Figure.(3) (f) shows that the concentration of Pb in sediments in Fuhe River in the southern part of the lake, Ganjiang River in the southwest part, Xinjiang River and Le' an River in the southeast part of the lake is higher (69.70 mg/kg), which is 5.58 times higher than the background value of Poyang Lake. The spatial distribution of Pb has a trend of spreading from south to north. Figure.(3) (a) and (g) show that the concentrations of As and Zn in sediments are higher in Hukou in the north, Ganjiang in the southwest, Xinjiang and Le' an in the southeast, and gradually decrease in the southeast and Northwest regions. Figure.(3) (e) shows that the concentration of Ni in sediments is higher in the lake estuary in the north and Changjiang area in the northeast, and tends to spread from the northeast to other areas, while the concentration in the center of the lake is extremely low. The spatial distribution characteristics of Cr and Cu in sediments as shown in Figure.(3) (c) and (d) show that the content distribution of the elements is higher in Le' an River, Xinjiang River and Changjiang River in the west, and higher in Fuhe River and near Ganjiang River in the south. The common feature of the distribution of the two elements is that the north is low and the south is high in sequence, and the concentration in the central lake area is in the transition section. The northern lake estuary is connected to the Yangtze River, and the concentration at the entrance and exit of the lake estuary is also higher. Figure.(3) (b) and (h) show that the concentration distribution characteristics of Cd and Hg in sediments are roughly similar. Ganjiang River and Fuhe River in the southwest of the Lake, and Xinjiang River and Le’ an River in the southeast of the lake are extremely high in concentration distribution, and the concentration distribution is high in the south and low in the north. The heavy metal tends to pass through Poyang Lake and enter the Yangtze River system from south to north. The concentrations of Cd and Hg decreased in the northern lake estuary. It can be seen that on the one hand, the migration, degradation and transformation process of heavy metals in the sediments is extremely difficult, and on the other hand, the pollution of heavy metals is almost all over the sediments of the lake district (Wang et al.2017).

In conclusion, the areas with high concentrations of As, Cd, Cr, Cu, Ni, Pb, Zn and Hg are mainly distributed in the south of Poyang Lake, which may be caused by the accumulation of various industrial and domestic pollutants due to the large number of tributaries in the south of poyang Lake. Dexing copper deposit, the largest copper deposit in Asia, exists in the lower reaches of Le’an River in southeast China, and Yongping copper deposit and smelting industry exist in the middle reaches of Xinjiang River (Xie et al.2022). Therefore, Cd, Cu, Pb and Zn concentrations in sediments are high, and there is accumulation phenomenon. The maximum concentration of Ni appeared in the outlet of the lake and the Duchang district, which is the transition zone of the Poyang river system, and the inlet and outlet water flow carried the pollutants containing Ni. Duchang County has sand and pottery industries, and the released Ni exceeded the background after long-term sedimentation and flocculation. The maximum concentration of Cr appears in Fuhe River Basin, while the maximum content of As and Hg appears in the exit of Ganjiang, Fuhe and Xinjiang, which may be influenced by the mining and smelting of dayu tungsten ore in Ganjiang River Basin and uranium ore in the upper reaches of Fuhe River (Li et al.2018). The high concentrations of As, Cd, Cr, Cu, Ni, Pb, Zn and Hg in the sediments of Poyang Lake appeared in the tributaries of Raohe, Ganjiang, Xinjiang, Hukou, Changjiang and Fuhe rivers, indicating that the high concentration of heavy metals in the sediments was related to the pollutants carried by the rivers into the lake. The pollutants carried by water flow are the main factors that cause the heavy metal content in sediments of the study area and the regional variation characteristics of the lake area (Kuang et al.2020).



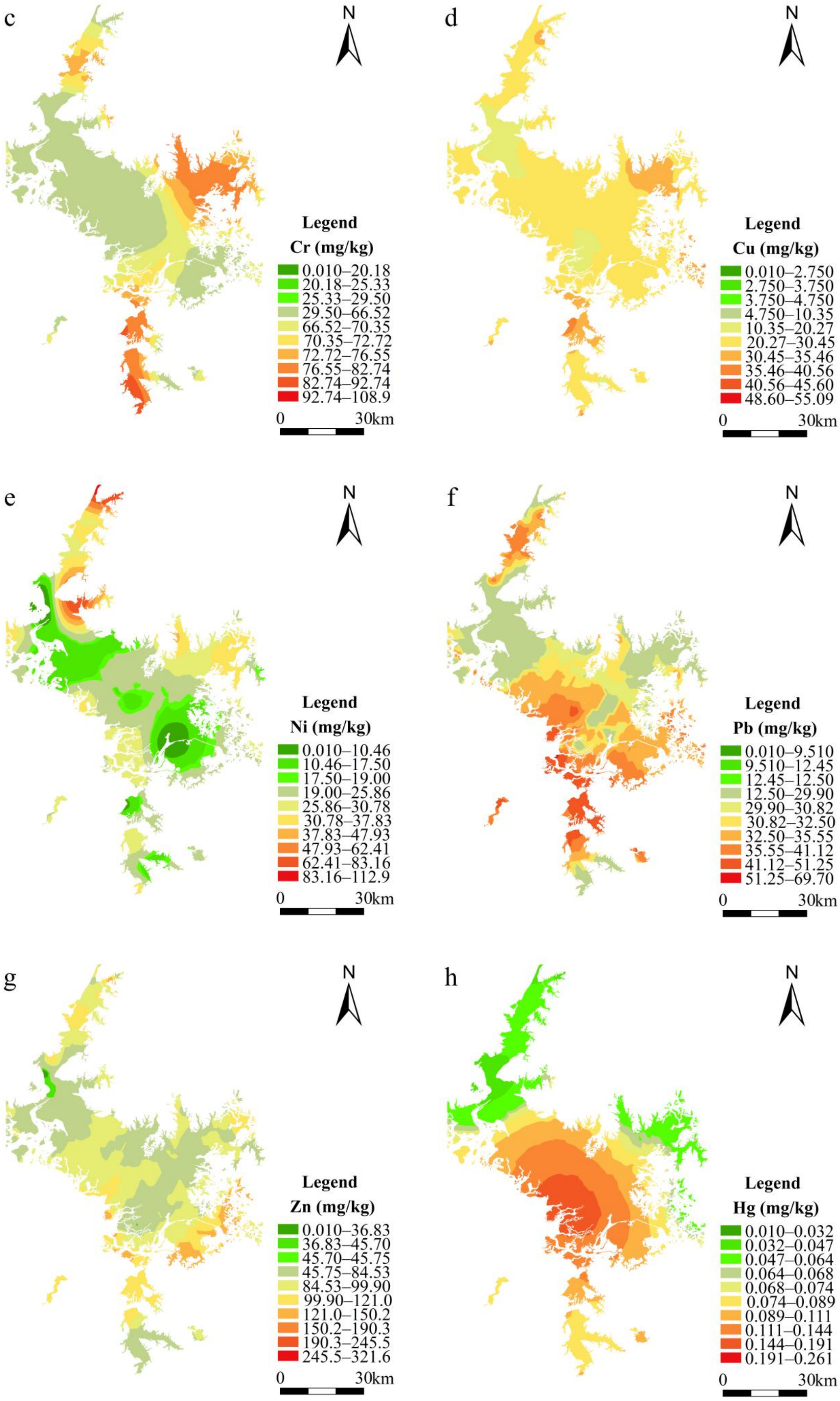


Figure 3. Spatial distribution of heavy metal concentrations in surface sediments around Poyang Lake

2.3. Source analysis of heavy metals in sediments

The correlation analysis data of heavy metals As, Cd, Cr, Cu, Ni, Pb, Zn and Hg in sediments are shown in Table 3. Table 3 shows that Hg has no significant correlation with Cr, Cu and Ni (P>0.05). There was significant correlation between Zn and other elements (P<0.05), but significant correlation between Zn and Cd, Cu and Hg (P<0.01), indicating similar sources of Zn. As was correlated with the other five elements except Cd and Ni (P<0.05), and was significantly correlated with Cr, Cu and Pb (P<0.01), indicating that their sources were similar.

Table 3. Correlation analysis of heavy metal content in sediments

Elements	As	Cd	Cr	Cu	Ni	Pb	Zn	Hg
As	1	-0.102	0.572**	0.542**	0.107	0.539**	0.511**	0.243*
Cd		1	-0.205	0.083	-0.224*	-0.035	0.334**	0.323**
Cr			1	0.645**	0.087	0.252*	0.240*	0.136
Cu				1	0.060	0.623**	0.615**	0.158
Ni					1	-0.021	-0.026*	-0.162
Pb						1	0.574**	0.370*
Zn							1	0.328**
Hg								1

Note: * indicates that there is correlation when P<0.05; ** indicates that when P<0.01, the correlation is significant.

In order to accurately analyze the pollution sources of heavy metals in the sediments of Poyang Lake, principal component analysis was used to trace the pollution sources. Bartlett sphericity and test statistics (Kaiser-Meyer-Olkin, KMO) were used to test the feasibility of the data. When KMO > 0.5 after standardization, factor analysis was suitable (Kuang et al.2020;Yong et al.2014). Correlation analysis showed that there was a good correlation between the eight heavy metals in the surface sediments of the study area, which was suitable for principal component factor analysis. In order to better explain the cause of the formation of principal components, the characteristic value of the components is set to be greater than 0.8, and the data can be corrected by VARImax to make the analysis results more scientifically significant (Kuang et al.2020;Yang et al.2017).

The principal component rotation load of heavy metals in poyang Lake sediments is described in Table.(4). As can be seen from Table.(4), with the help of principal component rotation load of heavy metals in surface sediments, the meaning of cumulative contribution rate of 71.37% in Table.(4) is described and analyzed. The characteristics of the first principal component in the table are 3.21 and contribution rate is 40.15%, and its main factors are As, Cr, Cu, Pb and Zn. Cr has a lower load than As, Cu, Pb and Zn. As was significantly correlated with Cr, Cu, Pb, Zn (P<0.01). Interpolation in Figure.(3).(b), (f) and (h) shows that the distribution area with high concentrations of Hg, Pb and Cd is close to Nanchang, which may be the source of domestic and production water resources in the urban area from Ganjiang River, which runs through Nanchang. It carries a large number of pollutants produced by industrial, agricultural and domestic wastewater and heavy metals in the soil in the process of soil erosion into Poyang Lake And causes heavy metal pollution (Gong et al.2006). In northwest branch in addition to the Cd, As, Cr, Cu, Ni, Pb, Zn and Hg concentration were the lowest, the reason may for Xiushui river drainage along the mineral resources and ChangJiang, RaoHe stroke and the Ganjiang river, Xinjiang, Lean river,FuHe river, less than, research indicated that may be with the area surrounding terrain and water is a mixture of various water bodies and other factors (Li et al.2016), On the other hand, non-point source pollution and exogenous pollution in agricultural production and life are less, and the forest land in the drainage basin is covered by a large area with strong pollution carrying capacity and repair capacity, so the accumulation degree of heavy metal pollution is relatively light (Li et al.2011). Similar to the distribution characteristics shown by interpolation spatial distribution law, the main sources of Cu, Zn, Pb and Cr are shangrao Lead-zinc mine, Dexing copper mine mining, smelting of Shangyongping copper mine, a tributary of Xinjiang River, and industrial wastewater generated in cities (Zhang et al.2023;Li et al.2016;Jian et al.2014;Yang et al.2018). Studies show that Part of Pb derived traffic pollution, vehicle emissions and tire wear (Hou et al.2019;Al-Rajhi et al.1996), and As mainly comes from new pesticides, fertilizers and agricultural production activities (Hudson-Edwards et al.2004). The characteristic value of the second principal component is 1.62, and the contribution rate is 20.26%. Cd and Hg are the main factors, and the correlation between them is significant (P<0.01). The coefficient of variation is large, and the distribution in the lake area is uneven, and the pollution source is mainly human activities (Martin et al.2013;Zhou et al.2018;Zhang et al.2021). The characteristic value of the third principal component is 0.88, and the contribution rate is 10.96%. Its main factor is Ni, and its distribution concentration in Poyang Lake area is 112.89 mg/kg, partly from metal smelting wastewater (Manno et al.2006;Krishna et al.2009), mineral development and other industrial activities (Gao et al.2019). The other part may come from the natural activity products of rock and soil structure changes (Li et al.2016;Wang et al.2014). It can be seen that the heavy metals in the sediments of Poyang Lake area mainly come from the mining of mineral resources attached to tributaries, the smelting wastewater of heavy metals, the human influence of urban development and agricultural production and life.

Table 4. Rotational load description of the principal components of heavy metal elements in the sediments of Poyang Lake(%)

Item	Component 1	Component 2	Component 3
Characteristic value	3.21	1.62	0.88
Variance contribution rate	40.15	20.26	10.96
Cumulative contribution rate	40.15	60.41	71.37
As	**0.794**	-0.241	-0.060
Cd	0.103	**0.809**	**0.303**
Cr	**0.648**	-0.442	-0.312
Cu	**0.857**	-0.126	0.015
Ni	0.027	-0.562	**0.779**
Pb	**0.783**	0.056	0.011
Zn	**0.777**	**0.300**	**0.269**
Hg	0.447	**0.536**	-0.073

Three principal component factors were screened out successively. The principal component rotation loading factors of heavy metals in surface sediments of Poyang Lake are shown in Figure.(4). Through the discrete degree of heavy metal elements in the picture, can further reflect the correlation among the elements and the homologous (Zhang et al.2016), the figure.(3) shows that the As, Cr, Cu, Pb, Zn and As the first principal component, with the heavier load, have the same source, main source for the mining and smelting and other agricultural production activities and urban industrial wastewater; Hg and Cd are the second principal components, which have heavy loads. They come from similar sources and are mainly caused by human activities. As the third principal component, Ni has a heavy load, which is mainly caused by mineral resources exploitation and natural rock and soil structure changes.

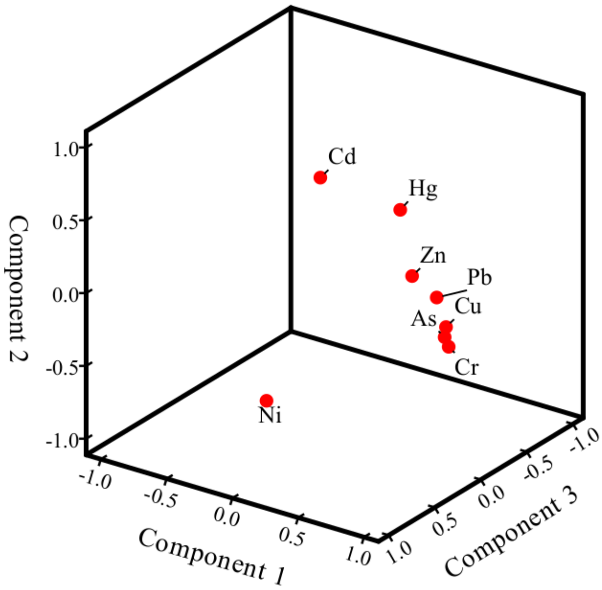
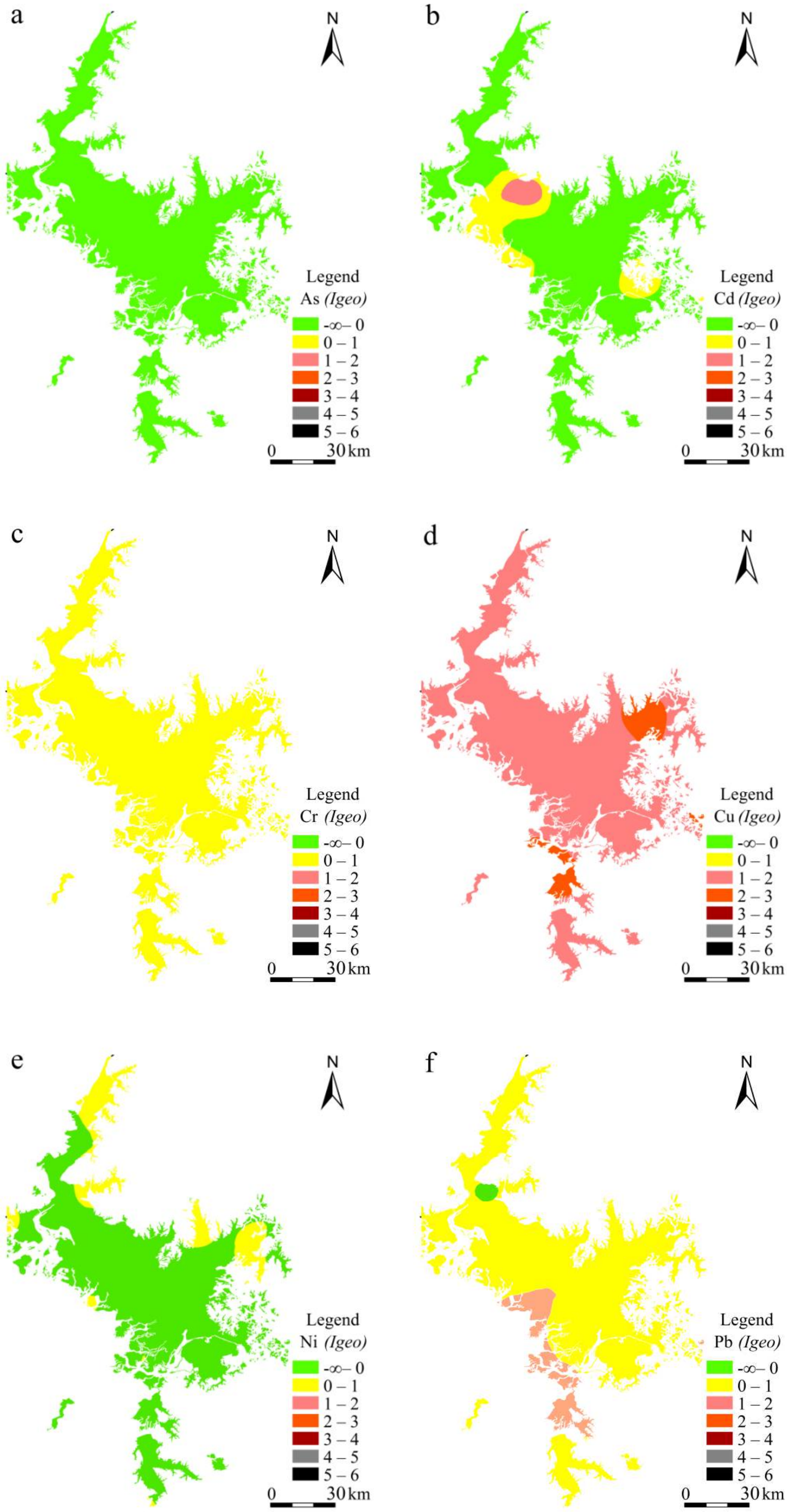


Figure 4. Rotational load factor of the principal components of heavy metal in the surface sediments of Poyang Lake

2.4. Accumulation characteristics and ecological risk analysis of heavy metals in surface sediments

The spatial distribution of heavy metal pollution indices in the overall surface sediments of Poyang Lake is has been shown in Figure.(5) through rendering by Arcgis software. As can be seen in Figure.(5) (a), there is no accumulation of As content in surface sediments, indicating that the lake area is not polluted by As in general. It can be seen from Figure.(5) (b) that there is mild and moderate pollution of heavy metal Cd in Xiushui River and Duchang as well as Xinjiang River and Le 'an River. As can be seen from Figure.(5) (c), Cr is generally slightly polluted, but there is extremely strong pollution at the mouth of the lake and in the repair area. There are a large number of mineral resources and ceramic smelting process in tributaries of Poyang Lake area, and tailings and washing wastewater in the production process indirectly bring Cu pollution factors (Hu et al.2011). As can be seen from Figure.(5) (d), Cu is moderately accumulated, and moderate intensity pollution occurs in Changjiang river, Fuhe River and Ganjiang River. The sources of Ni are different from other heavy metals, and their pollution sources are caused by by-products of industrial and smelting heavy metals (Li et al.2018;Luo et al.2019).Figure.(5) (e) shows that the study area is slightly accumulated. Previous studies have shown that Pb pollution comes from many sources and is evenly distributed in the whole lake (Ma et al.2019). Figure.(5) (f) shows that Pb in the study area is slightly polluted as a whole, but moderately polluted in the whole Ganjiang River basin and the entrances of Nanjishan, Kangshan and Fuhe Lakes. Zn is a trace element required by animals, plants and microorganisms. As can be seen from Figure.(5) (g), Zn is in mild accumulation in the study area, and there is no pollution in some areas, which is in a healthy state. The physical and chemical properties of Hg are relatively unstable, and previous studies have shown that Hg mainly comes from human production and life (Zhang et al.2021;Feng et al.2017). As can be seen from Figure.(5) (h), the cumulative distribution characteristics are obvious, mainly at the mouth of Ganjiang river and Fuhe river and Xinjiang river, with slight accumulation near the urban area, and no accumulation in other places. It can be seen that the accumulation degree of As, Cd, Cr, Cu, Ni, Pb, Zn and Hg in surface sediments of Poyang Lake is mostly mild to moderate, and very few are strong. The pollution of Cr, Cu, Pb, Zn and Hg is more serious in the study area, followed by Cd and Ni.

The potential ecological risk and pollution load index of heavy metals in surface sediments of Poyang Lake are shown in Figure.(6). The results of the total ecological risk index showed that the study area was classified as mild and moderate, and the overall analysis showed that the study area was at moderate risk level, and most of these areas were distributed in the mouth of each tributary lake. P_{Fi} showed that Poyang Lake was slightly polluted as a whole, and some study areas were moderately polluted, mainly near the tributaries of Ganjiang River and the entrance of Fuhe and Xinjiang River. It can be seen that pollutants such as industrial production and life, agriculture and mineral smelting are collected in Poyang Lake due to various tributaries. Poyang Lake has been storing water all the year round, and the water in the middle of the lake stays for a long time. As a result, the sediment at the bottom of the lake is in a state of compression, which leads to the accumulation of heavy metals, thus causing serious harm to the ecological environment (Wang et al.2017;Yao et al.2022).



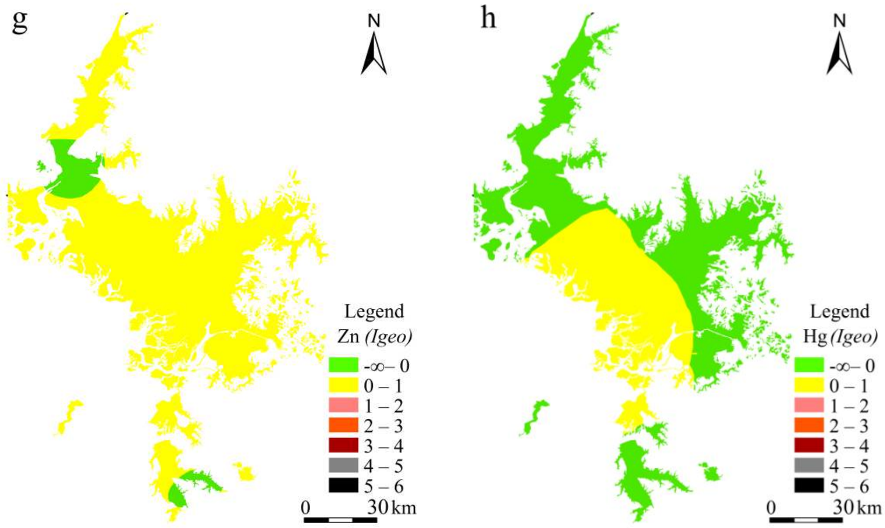


Figure.5 Overview of the accumulation of heavy metals in the surface sediments of the study area

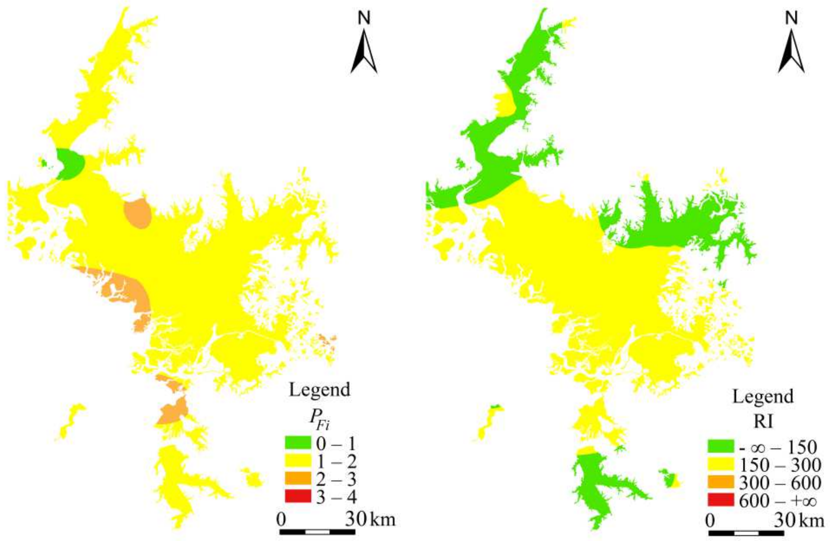


Figure.6 Distribution of heavy metals RI and PFi in the surface sediments of the study area

3. Conclusion

The areas with high contents of As, Cd, Cr, Cu, Ni, Pb, Zn and Hg in the surface sediments of Poyang Lake are mainly distributed in the south of Poyang Lake, and the pollutants in the surface sediments of Poyang Lake are primarily transported into the tributaries of the lake mouth. Cu was the main pollution factor, and the super-background value rate was 98.76%. The accumulation degree of eight heavy metals was Cu>Pb>Cr>Zn>Cd>Hg>Ni>As.

The principal component and correlation analysis results show that the first principal component is As, Cr, Cu, Pb and Zn, and the correlation is significant. The main sources of pollution are agricultural production activities such As mining and smelting and industrial wastewater generated in cities. The second principal components were Hg and Cd, with significant correlation and a large variation coefficient. The high concentration area was located in the south and southwest of Poyang Lake, and the pollution source was mainly human activities. The third principal component is Ni, and its pollution sources are mainly mineral resources exploitation and natural rock and soil structure change.

The analysis of pollution status shows that the overall ecological risk in the study area is at a moderate level, and some of them have a slight risk. The pollution load coefficient revealed that the main body of Poyang Lake was slightly polluted, and some of the study areas were moderately polluted, mainly in the vicinity of the tributaries of Ganjiang

River and the entrance of Fuhe River and Xinjiang River. Therefore, the ecological and environmental harm caused by heavy metal pollution can not be underestimated.

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Compliance with ethical standards

Conflicts of Interest: The authors declare that they have no conflict of interest.

Consent to participate: All authors were participated in this work

Consent to publish: All authors agree to publish.

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