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Pollution Characteristics of Surface Sediments in Luhun Drinking Water Reservoir in the Middle China

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ABSTRACT

The pollution status of surface sediments in the Luhun drinking water reservoir in the central of China was analyzed and evaluated, and three sampling points were selected for this study. The results showed that the organic matter content of the Luhun reservoir was as high as 5.2%, which was at a high level. The analysis of nitrogen, phosphorus, and their components showed that the total nitrogen (TN) and total phosphorus (TP) pollution in Luhun reservoir was in the medium pollution level, among which the ion-exchange state of nitrogen component and the strong-alkali extraction state of phosphorus component accounted for a relatively high risk of release into the overlying water. The results showed that the bioavailability index of Pb and Cr was as high as 0.73 and 0.62, which was of big pollution risk. Generally speaking, the sediment of Luhun reservoir had a high risk of pollution to the overlying water. The results of this study can provide a theoretical basis for urban safe water supply and provide support for water quality improvement.

INTRODUCTION

In recent years, with the aggravation of groundwater pollution, the water quantity is not enough to meet the needs of urban development. So more and more reservoirs gradually have become the drinking water source of big cities (Zhou et al. 2017a, Zhang et al. 2017, Tang et al. 2014), for example, Xi'an, Beijing, and Shenzhen. However, as a semi-natural water body, the water exchange capacity of the reservoir is weak, so the hydraulic retention time is long, and the artificial pollution intensifies, which leads to the gradual decline of water quality of the reservoir (Gu et al. 2020, Zhang et al. 2017, Li et al. 2015, Guo et al. 2018). Some researchers pointed out that sediment was the source of pollutants in reservoir water, and its pollution degree directly affected the water quality of overlying water. Heavy metals, nitrogen, phosphorus, and organic matter are the main pollutants in sediments, and heavy metals have attracted more and more researchers' attention due to their ecological toxicity (Zhou et al. 2020, Huang et al. 2021, Gao et al. 2020).

Studies on heavy metals in sediment majorly focus on Mn, Cr, Al, and Pb. These metal elements are also the compounds with the highest concentration in sediment, which have a significant impact on the safety of water supplies. For deep water source reservoirs, the water at the bottom of the reservoir has entered an anaerobic state (due to the dual oxygen consumption of the water body and sediment, the dissolved oxygen concentration of the bottom water body is less than 2 $mg.L^{-1}$, even 0 $mg.L^{-1}$). At this time, metal elements, nitrogen, phosphorus, and other pollutants in the sediment easily change into a reduction state, and then enter the overlying water body, causing water pollution (Wang et al. 2019a, Zackary et al. 2016, Dadi et al. 2016). The metal elements in sediment are complex. According to different extraction methods, the metal elements in sediment are generally divided into five components, F1, F2, F3, F4, and F5 (Zhou et al. 2017b). The metal contamination level in sediment may be analyzed using quantitative statistics based on the percentage of different components, and then the threat to safe water supply can be assessed.

The central drinking water reservoir (Luhun reservoir) was taken as the research object, and three representative monitoring points, S1, S2, and S3 (Fig. 1) were selected for analyzing the different contents of sediment components, especially heavy metal elements, and evaluating the pollution status by using safety evaluation method. This study can provide a scientific basis for water quality protection and guarantee of the reservoir, and provide a theory for water quality improvement of reservoir support.

MATERIALS AND METHODS

Sampling Sites and Sampling Methods

Luhun reservoir is 67 km away from Luoyang City, and the control basin area is 3492 m^3, accounting for 57.9% of the basin area. The annual average runoff at the dam site is 1.025 billion cubic meters (1951-1968), with an annual average flow of 32.5 $m^3.s^{-1}$.

The annual average sediment transport is about 3 million tons, the average sediment content is 3.2 $kg.m^{-3}$, and the sediment concentration is more than 90% in flood season from July to October, and there is clear river bottom during the non-flood period. The peak discharge of the 1000 year return period is 12400 $m^3.s^{-1}$, the peak discharge of the 10000 year return period is 17100 $m^3.s^{-1}$, and the flood peak discharge of dam protection (20% of the flood peak plus 20% of the flood peak in the 10000 year return period) is 20520 $m^3.s^{-1}$.

In this study, three representative sampling points were selected, namely, the tail of the reservoir, the middle of the reservoir, and the area in front of the dam. The basic distribution was shown in Fig. 1.

Methods for Determination of Chemical Indicators of Sediments

The surface 5 mm sediment samples of each sampling point were collected by Peterson grab sampler, and the mud was taken 3 times at each sampling point and mixed as the sediment samples at this point. The samples were transported back to the laboratory, were grounded and sieved after freeze-drying, and stored in sealed bags for standby.

Pb, Cr, Al, and Mn in sediment were determined by the Tessier extraction method (Deng et al. 2016, Dubravka et al. 2014). The loss of fire technique was used to assess the amount of organic matter (OC) in sediment. The potassium persulfate technique was used to detect TN in sediment, whereas the SMT method for phosphorus separation in freshwater sediment was developed under the auspices of the European Standard Test Committee (Zhou et al. 2020), and the extraction and determination of nitrogen and phosphorus components were determined according to relevant literature reports (Kwak et al. 2018, Jin et al. 2013). The metal elements were extracted by Tessier continuous extraction method, which mainly included the following five forms: exchangeable state (F1), carbon binding state (F2), iron-manganese oxide binding state (F3), organic compound state (F4), and residue state (F5). The sediment samples were first digested with an $HCl-HNO_3-HF-HClO_4$ mixture, and then gradually extracted. The metal concentration of the extract was determined by ICP-MS.

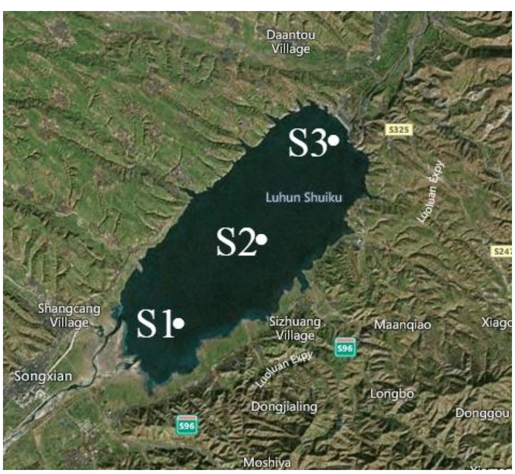

Fig. 1: Distribution of sampling points in LH water source reservoir.

RESULTS AND DISCUSSION

Analysis of Physicochemical Composition of Sediments

The branches, gravel, small stones, and other substances in the collected sediment samples were removed, and then the sediment was freeze-dried, grounded, and mixed for determination. The test results were shown in Table 1. In the three monitoring points, silt was the main component of sediment, accounting for 85.7% on average. Clay was the second most abundant element in the sediments of the S1, S2, and S3 monitoring stations, accounting for 10.1 percent, 9.8 percent, and 6.5 percent, respectively. Gravel, with an average content of 5.8 percent, was the least sediment component, owing to the low fluidity of the water body in the area in front of the dam and the deposition of big particles in the area at the reservoir's tail.

The water content of sediment was the ratio of the weight of moisture in the wet sample to the total weight of sediment, which indirectly reflected the level of dissolved oxygen in sediment (Li & Zhang 2019). As shown in Table 1, the average water content of sediment in the Luhun reservoir was 79.7%. The higher water content of sediment indicated that the sediment texture in front of the Luhun reservoir dam was very loose, and it was easy to resuspend under disturbance. The loss of ignition of sediments reflected the organic matter composition in sediments. The average loss on ignition of sediments in Luhun reservoir was 5.2%, which was higher than that of the same type of reservoirs in China

Table 1: Physicochemical composition of surface sediment in LH reservoir.

Component	S1	S2	S3
silt [%]	83.6	84.4	88.1
Clay [%]	10.1	9.8	6.5
gravel [%]	6.3	5.8	5.4
Moisture content [%]	80.1	82.4	76.5
Loss on ignition [%]	4.8	5.2	5.5

(Zhu et al. 2004, Zhang et al. 2019b, 2019c, Yu et al. 2019), indicating that the organic matter pollution of sediments in front of Luhun reservoir dam was serious. The redox and microbiological conditions at the sediment-water interface, for example, vary, and the contaminants in the sediment are easily released into the overlying water, resulting in contamination of the overlying water (Ma et al. 2015).

Analysis of Nitrogen and Phosphorus in Sediments

The nitrogen and phosphorus components in the surface sediment of the Luhun reservoir were measured. The results are shown in Fig. 2. The total nitrogen concentration of surface sediment was between 1.21-1.58 $mg.g^{-1}$ and the total nitrogen pollution degree of Luhun reservoir sediment was in the middle level compared with the same type reservoir (Wang et al. 2019b, Fang et al. 2019, Li 2019, Wen et al. 2019). The proportion of ion-exchange nitrogen in the total nitrogen component was significant, accounting for 37.2 percent at the S1 sampling point and 45.6 percent at the S3 sample point. The ion-exchange nitrogen had a relatively easy transformation form in all nitrogen components. The increased ion-exchange nitrogen in the sediments of the Luhun reservoir implies that nitrogen components in the sediments were easily transferred to the overlying water. Strong alkali-exchange nitrogen was second to ion-exchange nitrogen in terms of percentage, accounting for 23.8 percent on average.

Among the four phosphorus components, the strong base extracted phosphorus was more likely to migrate and transform than other forms. The ratio of concentration to total phosphorus concentration was called the bioavailability of phosphorus, which can be used to evaluate the risk of phosphorus pollution. The average concentration of total phosphorus in the surface sediment of Luhun reservoir was 1.06 $mg.g^{-1}$, and the proportion of four phosphorus components was not significant. The concentration of P extracted from strong alkali was 0.257 $mg.g^{-1}$, 0.304 $mg.g^{-1}$ and 0.312 $mg.g^{-1}$ respectively, which accounted for 22.4%, 28.9% and 28.7% respectively in each sampling point. The bioavailability of phosphorus in the sediment of sample locations S2 and S3 was found to be greater than that of sampling point S1.

Generally speaking, the average content of total nitrogen in the surface sediment of Luhun reservoir is 1.39 $mg.g^{-1}$, with a larger proportion of ion exchangeable nitrogen in the components, posing a significant danger of migration and transformation. The average content of total phosphorus in sediment was 1.06 $mg.g^{-1}$, and the average proportion of strong alkali extracted phosphorus in its components was 26.7%, indicating that the bioavailability index of phosphorus is 26.7%, which had a high risk of migration and transformation.

Analysis of Heavy Metals in Sediments

Surface sediments from three sample stations in the Luhun reservoir were continually extracted and examined for the four metals Pb, Cr, Al, and Mn. The results are shown in Fig. 3. The average concentrations of the four metals in sediments were 15.0 $mg.kg^{-1}$, 13.4 $mg.kg^{-1}$, 982.3 $mg.kg^{-1}$ and 1132 $mg.kg^{-1}$ respectively. Among the five components, F1 is exchangeable. When the redox conditions, microbial conditions, and water disturbance of the overlying water change, it is easy to transfer and transform at the mud water interface, which causes water quality pollution in the overlying water. The exchangeable metal concentration reflects the risk of pollution to water.

The bioavailability factor (BF) BF = Cbio/total, where C_{bio} is the sum of F1, F2, F3, and F4 components, and C_{Total} is the total metal concentration (Frémion et al.2016, Aleksandra et al. 2013). It can be seen that the bioavailability

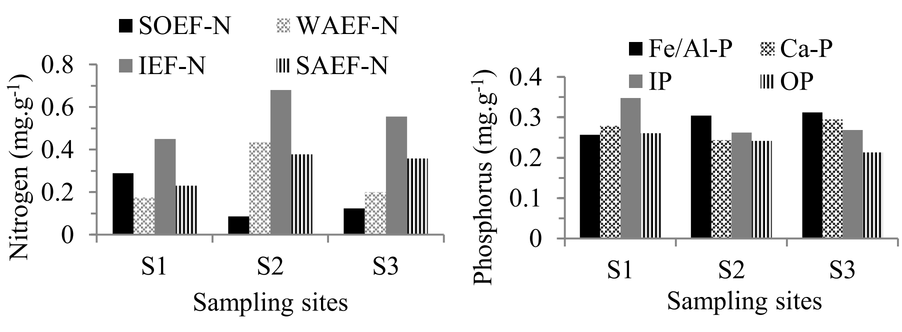

Fig. 2: Components of nitrogen and phosphorus in the sediments of 3 sampling points of LH reservoir (SOEF-N: strongly oxidized extracted nitrogen, WAEF-N: weakly acid exchangeable nitrogen, IEF-N: ion exchangeable nitrogen, SAEF-N: strongly alkali exchangeable nitrogen; Fe/ Al-P: strongly alkali extracted phosphorus, Ca-P: strongly acid extracted phosphorus, IP: inorganic phosphorus, OP: organic phosphorus).

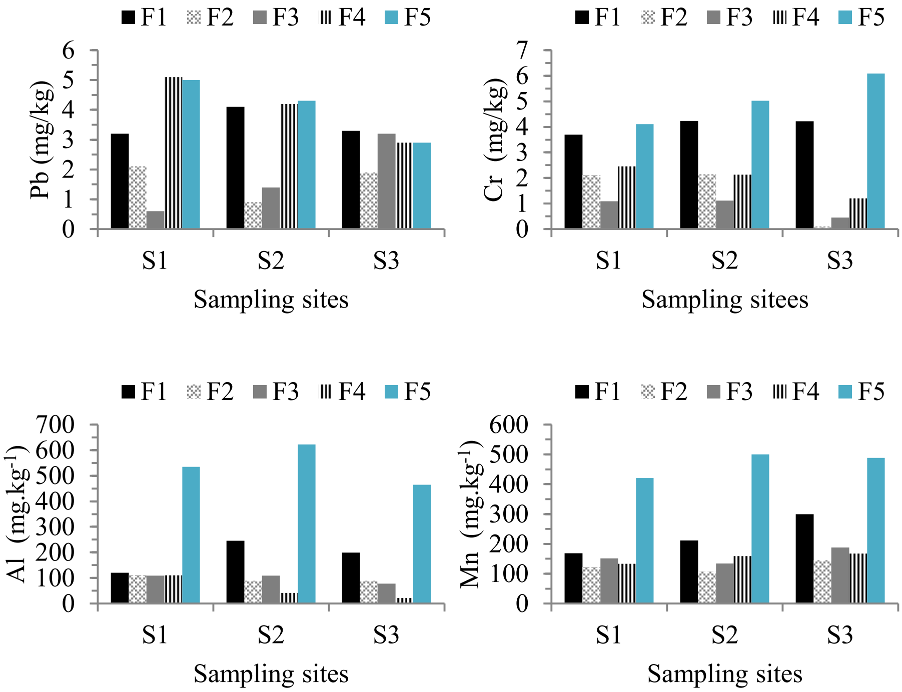

Fig. 3: Pb, Cr, Al, and Mn components in sediments of 3 sampling points in LH reservoir.

index of Pb in the surface sediments of the Luhun reservoir was 0.69, 0.71, and 0.79 respectively, and the BF average value of Pb was 0.73. BF of Pb indicated that Pb migration and transformation ability in sediment was strong, and there was a high pollution risk. The bioavailability index of Cr at three sampling points was 0.69, 0.66, and 0.50 respectively, and the BF average value of Cr was 0.62. BF of Cr indicated that Cr migration and transformation ability in sediment was stronger than Pb, but there was still a high risk of pollution. The bioavailability index of Al at three sampling points was 0.46, 0.44, and 0.45 respectively, and the BF average of Al was 0.45. BF of Al showed that the migration and transformation ability of Al in sediment was lower than that of Pb and Cr, and the pollution risk was low. The bioavailability index of Mn at three sampling points was 0.58, 0.55, and 0.62 respectively, and the BF average value of Mn was 0.58. BF of Mn indicated that Mn migration and transformation capacity in sediment was lower than Pb and Cr, and pollution risk was low.

According to the above analysis, compared with other similar reservoirs in China (Jiang & Zeng 2019, Zhu 2019, Zhang et al. 2019a), Pb, Cr, Al, and Mn concentrations in Luhun reservoir sediment were basically at the middle level; through the analysis of bioavailability index, it was found that the migration and transformation capacity of Pb and Cr in the sediments of Luhun reservoir was strong and the pollution risk was high.

CONCLUSION

(1) The results showed that the average loss on ignition was 5.2%, which indicated that the pollution of organic matter in the reservoir sediments was serious, and the pollution in the area in front of the dam was the most serious.

(2) The average concentration of total nitrogen in the surface sediments of Luhun reservoir was 1.39 $mg.g^{-1}$, in which the most active ion-exchange nitrogen accounted for 45.6%, the average concentration of total phosphorus was 1.06 $mg.g^{-1}$, and the strong alkali-extracted phosphorus accounted for 26.7%, indicating that the change of redox conditions and microbial conditions at the sediment-water interface was easy to cause nitrogen and phosphorus pollution in the overlying water.

(3) The overall amounts of Pb, Cr, Al, and Mn in the Luhun reservoir's surface sediments were comparable to those found in similar reservoirs in China. The bioavailability index of Pb and Cr was high, and there was a higher risk of water pollution of Pb and Cr.

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