Study on Temporal and Spatial Distribution of Biogenic Elements of Sediment in Baiyangdian Lake

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Abstract. Baiyangdian Lake is the largest macrophyte-dominated shallow lake in North China and the most important ecological barrier area in the Xiong’an New Area. Since the 1980s, the surface water of Baiyangdian Lake has been in a state of eutrophication for a long time due to high nitrogen and phosphorus content. Under the background of the gradual implementation of the New Area Planning Outline, the load of nitrogen and phosphorus from exogenous sources into the lake has been gradually controlled, and the nitrogen and phosphorus enriched in the sediment has increasingly become the main factor affecting water quality. Therefore, this study focused on the vertical and lateral distribution differences of total organic carbon, total nitrogen and total phosphorus contents in Baiyangdian Lake sediments. Meanwhile, combined with sedimentary years, the enrichment characteristics of nitrogen and phosphorus in different ages and their consistency with the change of total organic carbon content were analyzed. The study can provide some scientific reference for controlling the accumulation of nitrogen and phosphorus in Baiyangdian sediment and scientifically and orderly dredging.

1. Introduction

Lake sediments are reservoirs of biogenic elements. The contents, distribution characteristics and changes of total organic carbon, total nitrogen, total phosphorus and other elements in sediments can not only objectively reflect the biogeochemical process of the lake, but also reflect the impact of human activities on the lake ecosystem to a certain extent (Qin et al., 2006). Among them, the total organic carbon content in sediments can reflect the change of the accumulation of biological residues. The contents of nitrogen and phosphorus in sediments can reflect the storage of nutrients and potential endogenous release capacity. The C/N ratio and C/P ratio can reflect the source of nutrient elements (Zhu et al., 2005).

Baiyangdian Lake is the largest shallow lake in North China. Due to the disturbance of human activities, there is a strong exchange between the Baiyangdian sediment and the overlying water. On the premise that the exogenous pollution is gradually controlled, the nutrient elements enriched in the sediments may gradually become the main endogenous pollution factors affecting the water quality of Baiyangdian Lake. The Planning Outline for the Xiong’an New Area in Hebei Province, released in April 2018, it was clearly stated that "the advantages of natural background should be utilized to carry out ecological dredging", "reasonably demarcate dredging scope, scientifically and orderly implement dredging, eliminate endogenous pollution and restore the ecological environment of aquatic animals at the bottom of the water". In this context, it is of great significance to analyze the enrichment regularity...
and spatiotemporal distribution characteristics of biogenic elements in Baiyangdian Lake sediments for controlling endogenous pollution through dredging.

2. Materials and methods
In May 2020, sediment samples were collected from 7 typical sediment zones in the study area (3 berths were collected in each zone, and the average value of the 3 berths sample data represented the zone data of Baiyangdian Lake). The hand-drill gravity dredge was used to collect sediments at 0-50cm below the mud-water interface, and the samples were collected and stored in a cold storage environment at 0-4 °C. For the collected sediment samples, plant residues, sand and gravel and other impurities were first removed with forceps. Then the samples were dried naturally in a cool and ventilated place. Then, they were ground into powder with a mortar and passed through a 100-mesh sieve for analysis. According to the Soil Physical and Chemical Analysis compiled by Nanjing Institute of Soil Science, Chinese Academy of Sciences to measure the physical and chemical indexes in the sediments, and the bulk density was determined by cutting ring method. The sediment samples for chemical analysis were digestible by sulfate oxidation, and the total nitrogen and total phosphorus were determined by ultraviolet spectrophotometry and molybdenum-antimony anticolorimetry, respectively. The organic matter was determined by potassium dichromate volumetric method. Statistical analysis of the data was performed in SPSS and ORIGIN2017 software.

3. Results and Discussion
3.1. Spatial Distribution Characteristics of Biogenic Elements in Surface Sediments
The soil around and inside Baiyangdian Lake is clayey or loamy lacustrine meadow swamp soil and artificial stacked meadow swamp soil with lacustrine sediments as parent material. The average particle size of sediments is 2120μm, and the range is 430~5400μm, among which the particles in 400-800μm account for more than 90%.

According to the analysis and test results, the horizontal distribution characteristics of total carbon, total nitrogen and total phosphorus in the surface sediments of Baiyangdian Lake are shown in the figure below: among them, the total organic carbon content in order from high to low: Caiputai > Shaochedian > Wangjiazhai > Nanliuzhuang > Duancun > Quantou > Zaolinzhuang; the total nitrogen content in order from high to low: Shaochedian > Nanliuzhuang > Wangjiazhai > Quantou > Caiputai > Duancun > Zaolinzhuang; the total nitrogen content in order from high to low: Nanliuzhuang > Wangjiazhai > Quantou > Duancun > Caiputai > Shaochedian > Zaolinzhuang.

![Figure 1](image.png)

Figure 1. The transformation rules of biogenic element in column surface sediment samples of different lakes.

(Meaning of English letters: SC Shaochedian; WJ Wangjiazhai; NL Nanliuzhuang; QT Quantou; CP Caiputai; ZL Zaolinzhuang; DV Duancun)
It can be seen from the above figure that the content of organic carbon in surface sediment samples from Caiputai and Shaochedian sites was significantly higher than that from other sites. These two areas were also the most abundant and biomass of aquatic plants in Baiyangdian Lake. In recent years, with the gradual banning of seine cultivation in the lake, local farmers no longer harvest aquatic plants as fish bait, and the decay of aquatic plants has gradually accumulated in the sample sites. That may be the main reason for the high total organic carbon content in these two sites.

Compared with the total organic carbon content, the total nitrogen content in the surface sediments had a certain spatial difference, but the change was not significant. The order of total nitrogen content between different sample sites was close to total organic carbon, and the total nitrogen content was relatively low in the sample sites with few aquatic plants. Correlation analysis also showed that TOC content is significantly correlated with TN content ($r=0.76$, $P<0.01$), indicating that the sediment was a "sink" of organic matter and total nitrogen.

In the surface sediments, Nanliuzhuang and Wangjiiazhai had the highest total phosphorus content, followed by Quantou, while Caiputai and Zaolinzhuan had the lower total phosphorus content. The spatial distribution characteristics of phosphorus mainly depend on the geographical location of each zone in Baiyangdian Lake. Nanliuzhuang is the first station from the Fuhe River to the Lake. When the water reaches the site, the surface area of the water is open and the flow rate slows down. The dissolved phosphate carried by the water reacts with the original water body in the lake, and reacts with the sediment, lakeside zone and platform soil for the calcium ion exchange. Combined with the blocking and absorption of large aquatic plants, phosphorus is fixed and deposited on the bottom of the lake, forming a rich area. Wangjiiazhai and Nanliuzhuang are very similar; Quantou is in third place. This is because Quantou is the main aquaculture producing area of Baiyangdian Lake, the large amount of aquaculture bait will undoubtedly increase the content of total phosphorus in the sediment. Both Caiputai and Shaochedian are densely distributed areas of aquatic plants, and their contents are relatively low, and there is no significant difference between them. Zaolinzhuan is located at the mouth of the lake where the inflow of water carries a low total phosphorus content. In addition, Zaolinzhuan itself belongs to hard sand and gravel substrate, which is not easy to adsorb and exchange with total phosphorus.

According to the above analysis, several characteristics of biogenic elements distribution in Baiyang Lake surface sediments can be summarized as follows: the first is the obvious deposition of phosphorus in surface sediments. Nitrogen can be replenished by nitrogen fixation, whereas phosphorus deposition in the geochemical cycle makes phosphorus limitation of lakes more common. Second, the spatial distribution of organic matter content is quite different, which may be related to the accumulation characteristics of aquatic plant residues in different areas.

Table 1 gives the biophysical element content of surface sediments in Taihu Lake, Hongze Lake, Poyang Lake, Nansi Lake, Chaohu Lake, Dongping Lake and other similar shallow lakes (Li, 2008). From the horizontal comparison, the average content of organic matter in the surface sediments of Baiyangdian Lake is in the middle. The total nitrogen content is much higher than that in Hongze Lake, Chaohu Lake, Poyang Lake and Nansi Lake, while the total phosphorus content is lower than that in Taihu Lake, Dongting Lake and Ulansuhai Nur, and higher than that in Nansi Lake and Chaohu Lake.

| Lakes/Elements | TOC  | TN   | TP   |
|----------------|------|------|------|
| Taihu Lake     | 31.9 | 1.68 | 0.857|
| Hongze Lake    | 16.8 | 0.723| 0.642|
| Poyang Lake    | 10.4 | 1.57 | 0.385|
| Nansi Lake     | 55.6 | 0.686| 0.68 |
| Chaohu Lake    | 3.8  | 0.31 | 0.223|
| Dongping Lake  | 29   | 0.938| 0.771|
| Ulansuhai Nur  | 32   | 1.328| 0.562|
| East Taihu Lake| 28.4 | 1.14 | 0.631|
3.2. Vertical Distribution of Total Organic Carbon

The amount of organic matter in sediments depends on the input and output of organic matter. The input mainly comes from the mineralization of organic matter in sediments and the return of animal and plant residues in water, while the output mainly includes the degradation of organic matter. In general, the organic matter content in the sediments of the study area showed a high spatial difference. The organic matter content of Shaochedian Lake has been maintained in a high range and has no great fluctuation, with the mean value and the value range being 41.5±4.32mg/g and 15-45.31mg/g, respectively. In the sediment column samples from Zaolinzhuang, the high organic matter content appeared at 0-20cm depth and ranged from 10-20 mg/g. In the sediment column samples from Caiputai, the content of organic matter above 25cm depth was higher. There was no obvious change rule of total phosphorus. In the sediment column samples from Wangjiazhai, the organic matter increased significantly above 25cm. The change rule of Quantou was similar to that of Wangjiazhai. Most of the berths in Nanliuzhuang District was in the state of algal turbidity, and its total carbon content was the smallest among the six sample sites. The depth change along the column was not obvious, and there was no obvious accumulation peak.

According to the research results of Cui et al. (2017), the average annual deposition increase in Baiyangdian District is about 2.6cm. Therefore, the 50cm sediment column can represent the deposition process of the last 20 years, i.e., 2000-2020. According to the chronological order, the sample can be approximately divided into five different periods, namely: 50-40cm, corresponding to 2000-2004; 40-30cm, corresponding to 2004-2008; 30-20cm, corresponding to 2008-2012; 20-10cm, corresponding to 2012-2016; 10-0cm, corresponding to 2016-2020. In most sediment samples from the district, the organic carbon content of 20cm in the surface layer is higher than that in the bottom layer, indicating that the earlier the deposition age is, the lower the organic carbon content is, and vice versa (Fig. 2).

![Figure 2. The transformation rules of TOC in typical lake columnar sediment samples.](image)

3.3. Vertical Distribution of Total Nitrogen and Total Phosphorus

The contents of total nitrogen and total organic carbon showed significant consistency. In terms of time, the later the deposition age, the higher the total nitrogen content ($R^2=0.71$, P<0.001). Shaochedian, Zaolinzhuang, Caiputai and Quantou all showed this rule (Fig. 3).
The consistency of the distribution of carbon and nitrogen in sediments can be explained from two perspectives. One is the ratio of carbon to nitrogen: when the ratio of carbon to nitrogen (C/N) in the sediments is between 14-30, it can be considered that the organic matter in the lake mainly comes from external sources. When C/N is less than 6, it means that organic matter is mainly endogenous. Endogenous organic matter can be further divided into two types: algal and grass. Among them, the C/N ratio in algal lake sediments is generally between 4-10, while the C/N ratio of aquatic vascular plants is greater than 20. The C/N values of the whole columnar samples are all between 8.8 and 10.6, and the fluctuation is small. This indicates that the source of organic matter in the sediments is stable, and the organic matter is mainly lacustrine, including aquatic plants, algae and the remains of some animals. While the nitrogen mainly comes from the nitrogen-containing compounds in the above organic matter, and is less affected by external input. In addition, significant nitrogen degradation did not occur during early diagenesis (Emmeis, 2000). Besides, the analysis results showed that the C/N values of a few samples were higher, which may be due to the fact that the sampling sites were close to the lakeside zone and are greatly affected by the external input. Or nitrogen-containing proteins were preferentially released during organic matter degradation. The granular structure of the sediments may also affect degradation. The content of fine particles in sediment samples was positively correlated with the content of total nitrogen. This is because its pores are small and in anoxic level, which is not conducive to microbial activities and slows down the process of organic matter and organic nitrogen (Chen, 2008).

The vertical distribution of total phosphorus in the 8 sampling sites was shown in Fig. 4. Compared with carbon and nitrogen, the vertical variation rule of phosphorus in the columnar sample was more complex, but some obvious variation characteristics could still be summarized. To be specific, the total phosphorus content in Nanliuzhuang decreased sharply with the increase of depth, indicating that the accumulation of phosphorus mainly occurred in recent years, so it can be judged that the phosphorus load in the district was gradually increasing. In Shaochedian Lake, the trend was opposite to that in Nanliuzhuang, and the phosphorus content in the surface sediments was lower, which might be due to the harvest of aquatic plants by farmers. The change trend of phosphorus at the other sites was similar with the depth, which basically showed little change from the bottom to within 10cm of the surface layer, and the content of phosphorus increased slightly within 5cm of the surface layer. Another rule can be obtained from the figure 4, that is, with the increase of depth, the content of phosphorus at each site tended to the same value, which can also be considered as the background value of phosphorus in the Baiyangdian sediment, which is about 0.062%.
3.4. Analysis of Biogenic Elements Deposition

Linear regression was conducted for the total nitrogen and total carbon contents of all stratified sediment samples. The results showed that there was a significant positive linear correlation between them, and the correlation coefficient was high: $\text{TN}(\%) = 0.0541 \times \text{TOC} (\%) - 0.0233$ ($R^2 = 0.5776$, $P<0.01$) (Fig. 5). This indicated that the deposition of biological organic matter was accompanied by the deposition of total nitrogen, and bioaccumulation mineralized a large amount of organic nitrogen into the sediments. Different from the distribution of total nitrogen, there was no significant correlation between total phosphorus content and total organic carbon content in sediments. This suggested that phosphorus entering the sediment was not dependent on bioaccumulation, but mainly through sedimentation, adsorption and ion exchange. But even so, the abundant distribution of aquatic plants, especially emergent plants, can still promote the deposition of phosphorus and inhibit re-suspension, thus increasing the deposition of phosphorus.

Figure 5. Correlation between organic matter content in sediment samples and (a) TN content, (b) TP content.

4. Conclusion

The distribution characteristics of biogenic elements in the surface and columnar sediments are the...
direct reflection of lake biogeochemical processes. The analysis results of element content in the samples showed that the biogenic elements such as carbon, nitrogen and phosphorus showed obvious spatial heterogeneity in both vertical and surface. The distribution of total organic carbon and total nitrogen in sediments was consistent. The later the deposition age, the higher the contents of the two elements in the samples. The bioaccumulation of aquatic plant residues may be the main source of organic carbon and total nitrogen in the Baiyangdian Lake sediments. The total phosphorus content in the sediments decreased significantly from northwest to southeast. The total phosphorus concentration in the surface sediments of the lake from the entrance of the Fuhe River to the Nanliuzhuang area was higher than that in the eastern and southern areas. There was no significant correlation between the contents of total phosphorus and total organic carbon in the sediments, suggesting that the phosphorus mainly came from outside the lake, and the biological accumulation was not the main source of phosphorus.

Acknowledgement
This paper is one of the periodical results of the operating expenses for basic scientific research of "Research on the mechanism of rapid restoration of aquatic vegetation disturbed by dredging" (WE0145B422019), funded by the IWHR Research & Development Support Program.

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