# Analysis of Sediment Nutrient Pollution Characteristics of Enclosed Fish Ponds in Baiyangdian Lake

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**Abstract: In order to solidly promote the governance and protection of the ecological environment of Baiyangdian Lake, taking the bottom sediment of the enclosed fish ponds in three areas of Baiyangdian Lake as the research object, the plane and vertical distribution characteristics of nutrients such as total nitrogen (TN), total phosphorus (TP) and organic matter in different layers (0~60cm) in the bottom sediment were analyzed with Nemerow index method, and the pollution degree of sediment in each area was evaluated. The results showed that the TN concentration of the fish pond bottom sediment in the Shaochedian area was 1020.0mg/kg~2101.7mg/kg, the TP concentration was 267.7 mg/kg~787.2 mg/kg, the organic matter content was 2.7%~9.5%, and the pollution degree of the fish pond was mainly light and moderate. The TN concentration of the fish pond bottom sediment in Zaolinzhuang area was 502.3 mg/kg~1996.7mg/kg, the TP concentration was 292.1mg/kg~5465.3mg/kg, the organic matter content was 2.9%~10.8%, the pollution degree of the fish pond was mainly light and moderate. The TN content of the fish pond bottom sediment of the fish pond in the Wanloudian area was 470.8mg/kg~2075.0mg/kg, TP concentration was 128.0mg/kg~705.8mg/kg, the organic matter content was 3.4%~9.6%, and the pollution degree of fish pond was mainly moderate and heavy. From the perspective of the vertical distribution of pollutants, the organic matter content and TN of the bottom sediment of the fish pond in each area showed a gradual decreasing trend from the surface layer (0~10cm) to the bottom layer (50~60cm), and the removal of the surface sediment was the key to the reduction of endogenous pollution in the fish pond in Baiyangdian Lake, while the TP had no obvious regularity.**

**Keywords: Baiyangdian Lake; Fish Pond; Nutrient Pollution; Nemerow Index**

## 1. Introduction

Baiyangdian Lake is the largest freshwater wetland system in both Xiong'an New Area and North China, playing a critical role in climate regulation, groundwater replenishment, and biodiversity conservation. Known as the "Pearl of North China" [1], it holds a key position in the ecological security system of Xiong'an New Area. The total area of Baiyangdian Lake spans approximately 366 km², and the lake is divided into 143 ponds of varying sizes and shapes by more than 3,700 ditches and 120,000 acres of reed beds. Historically, large-scale embankment construction for aquaculture was implemented in the lake during the 20th century. As a result, the lake now contains numerous types of ponds, including fish ponds, lotus ponds, marsh ponds, and field ponds. According to 2019 statistics, there are over 1,200 such ponds within the lake. To restore and protect Baiyangdian Lake, since the establishment of Xiong'an New Area in 2017, the Hebei Provincial Government and the Xiong'an New Area Administrative Committee have made substantial efforts to advance an integrated approach focusing on "water replenishment, pollution control, and flood prevention". These efforts have included a series of water ecological restoration projects around the lake, leading to the phased-out removal of aquaculture activities. Consequently, the lake's water surface area has expanded by approximately 160,000 km², with the overall water quality being stabilized at Class III surface water standards. However, the accumulation of historical pollutants and the isolation of the ponds by embankments has resulted in a lack of connection between the polluted water within these ponds and the surrounding water bodies. This disconnection has led to stagnation in the water flow throughout the lake area, which, in turn, presents a significant threat to the water environment and the overall aquatic ecosystem of Baiyangdian Lake.

Research on Baiyangdian Lake is extensive, with previous studies mainly focusing on hydrodynamics, water quality, and the distribution of biological communities [2-4]. Additionally, large-scale analyses have been conducted on sediment pollution characteristics across the entire lake or its watershed. For instance, Fu Changfeng et al. [5] performed nearly 10,000 physical and chemical analyses of sediment samples and found that sediment-covered areas and non-sediment-covered areas accounted for 68.8% and 31.2% of the total lake area, respectively. They also examined the vertical distribution of various nutrients within the sediment. Fu L. [6] assessed the potential risks of target pollutants, such as parabens, triclosan, and bisphenol A, from both human health and ecological perspectives. Zhang L. [7] employed various methods to characterize the structure and composition of organic particulate matter in the lake's water, investigating the impact of different extraction forms of organic particles on water quality. Yin Dechao [8] conducted systematic surveys on nitrogen and phosphorus nutrient salts, evaluating pollution levels and analyzing the TN and TP contents, as well as the total reserves in both the sediment and transition layers of the lake. However, there has been no research specifically addressing the investigation, monitoring, and pollution characteristics of the enclosed fish ponds within Baiyangdian Lake. This study focuses on typical enclosed fish ponds in the lake, analyzing nutrient pollution in the sediment through detailed monitoring. The goal is to provide technical support and a reference framework for future ecological dredging of the ponds and for the broader ecological restoration of Baiyangdian Lake.

## 2. Research Scope and Methodology

### 2.1 Research Scope

The scope of this study encompasses three major regions—Shaochedian, Zhaolinzhuang, and Wanloudian—each containing a number of enclosed fish ponds, totaling 73 ponds. These ponds are surrounded by embankments, reed-covered fields, or elevated areas within the lake, forming independent aquatic units. The distribution of these ponds across the study area is illustrated in Figure 1.

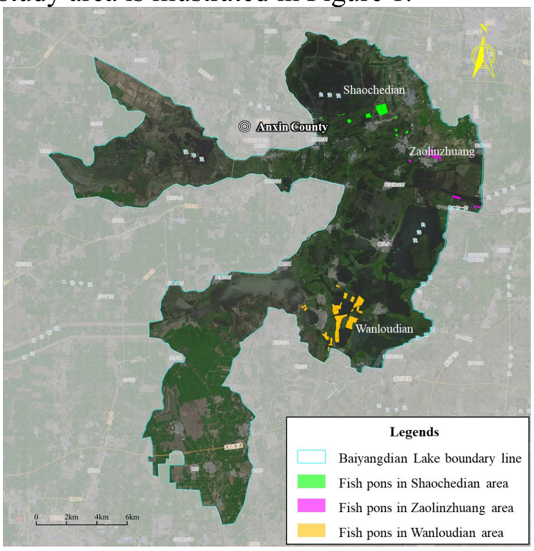



**Figure 1. Fish Pond Distribution Plan of The Study Area**

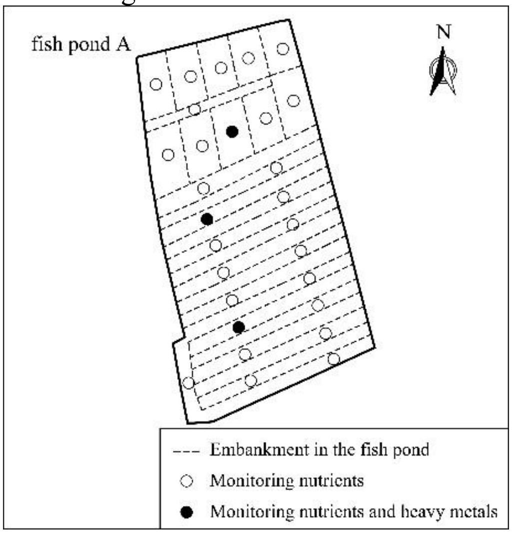
Shaochedian area has 15 ponds, covering a total area of 646,500 m², with an average pond size of 43,000 m². The typical water depth at normal water levels ranges from 1.2 m to 3.0 m. Zhaolinzhuang area possesses 29 ponds, covering a total area of 310,800 m², with an average pond size of 11,000 m². The typical water depth at normal water levels ranges from 1.0 m to 3.2 m. Wanloudian area holds 29 ponds, covering a total area of 2,031,000 m², with an average pond size of 70,000 m². The typical water depth at normal water levels ranges from 1.8 m to 5.8 m.

### 2.2 Monitoring Point Setup

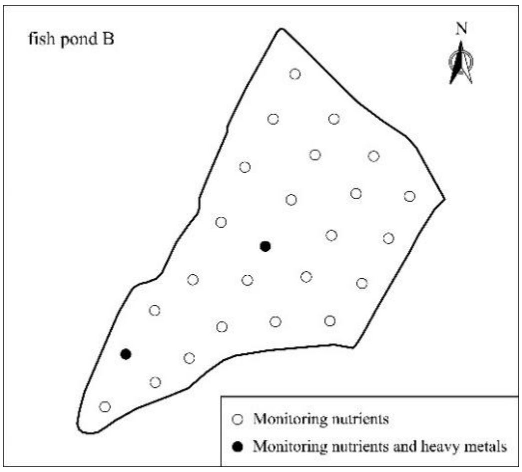
Based on preliminary survey results, this study established a total of 351 monitoring points within the 73 fish ponds mentioned above, distributed as follows: 75 points in the Shaochedian area, 52 points in the Zhaolinzhuang area, and 224 points in the

Wanloudian area. The arrangement of monitoring points adhered to the principle of a grid-like distribution, with the distance between two adjacent points ranging from 75 m to 100 m [9]. For each independent aquatic unit within the fish ponds, at least one sediment monitoring point was established. For example, the layout of sediment monitoring points in typical fish ponds A and B in the Shaochedian and Wanloudian areas is shown in Figure 2:




(a) Distribution of sediment monitoring points in Fish Pond A




(b) Distribution of sediment monitoring points in Fish Pond B

**Figure 2. Layout Diagram of Typical Fish Pond Sediment Monitoring Points**

## 2.3 Sampling Methods and Detection Indicators

Using a handheld GPS device, the sampling points were precisely located. The sampling method employed was core sampling, with a sampling depth of 1 meter. The top 60 cm of the sediment was sampled, with mixed samples collected in 10 cm increments. These samples were placed in polyethylene self-sealing bags, frozen, and transported back to the laboratory for drying, grinding, and sieving before analysis. The key indicators for detection included organic matter, total nitrogen (TN), and total phosphorus (TP), representing the primary nutrient salts. The results of these analyses were used to assess the distribution characteristics of nutrient salt pollution in both the horizontal and vertical profiles of the fish pond sediments.

## 2.4 Evaluation Methods for Nutrient Salt Pollution

The assessment of nutrient salt pollution in the sediment of closed fish ponds in the wetland area was carried out using the Single Factor Index method and the Nemerow Pollution Index method. The Single Factor Pollution Index method is commonly used to identify the main pollutant factors in a sample [10]. This method is relatively simple, where a smaller index indicates light pollution, while a larger index corresponds to heavier pollution. The formula for calculation is as follows:

$$PI_i = C_i^m / C_i^S \quad (1)$$

Where,

- $PI_i$ is the cumulative pollution index for pollutant $i$.

-When $PI_i \leq 1.0$, the pollution level is classified as "no pollution".

-When $1.0 < PI_i \leq 2.0$, it is classified as "slightly polluted".

-When $2.0 < PI_i \leq 3.0$, it is classified as "mildly polluted".

-When $3.0 < PI_i \leq 5.0$, it is classified as "moderately polluted".

-When $PI_i > 5.0$ it is classified as "heavily polluted".

- $C_i^m$ is the measured value of pollutant $i$.

- $C_i^S$ is the background value of pollutant $i$, where the background value of TN is 670 mg/kg and TP is 440 mg/kg, based on relevant literature.

The Nemerow Pollution Index method takes into account both the individual pollution indices of all measured parameters and the most heavily polluted factor. It is a multi-factor environmental quality index that reflects the effects of all pollutants on the sediment while highlighting the impact of high-concentration pollutants. This method is widely applied in soil quality and water quality assessments. The formula is as follows:

$$P_j = \sqrt{\frac{{PI_j^{ave}}^2 + {PI_j^{max}}^2}{2}} \quad (2)$$

Where,

- $P_j$ is the Nemerow Pollution Index value for pollutant category j.
- When $P_j \leq 0.7$, the pollution level is "uncontaminated".
- When $0.7 < P_j \leq 1.0$, the pollution level is "no contamination ".
- When $1.0 < P_j \leq 2.0$, it is "slightly polluted".
- When $2.0 < P_j \leq 3.0$, it is "moderately polluted".
- When $P_j > 3.0$, it is "heavily polluted".
- $PI_j^{ave}$ is the average single pollution index for pollutant category j.
- $PI_j^{max}$ is the maximum single pollution index for pollutant category j.

## 3. Results and Analysis

### 3.1 Nutrient Salt Pollution Characteristics

#### 3.1.1 Plane distribution characteristics

The plane distribution characteristics of nutrient salt pollution are shown in Figures 3 to 5. Overall, the sediment TN concentrations in the fish ponds of the Shaochedian area ranged from 1,020.0 mg/kg to 2,101.7 mg/kg (with the average concentration of 1,461.6 mg/kg based on six sediment layers), while TP concentrations ranged from 267.7 mg/kg to 787.2 mg/kg, with an average of 481.8 mg/kg. The organic matter content ranged from 2.7% to 9.5%, with an average of 6.2%. In the Zaolinzhuang area, TN concentrations in the fish pond sediments ranged from 502.3 mg/kg to 1,996.7 mg/kg, with an average of 1,195.0 mg/kg; TP concentrations ranged from 292.1 mg/kg to 5,465.3 mg/kg, with an average of 939.9 mg/kg. The organic matter content ranged from 2.9% to 10.8%, with an average of 6.2%. In the Wanloudian area, TN concentrations in the fish pond sediments ranged from 470.8 mg/kg to 2,075.0 mg/kg, with an average of 1,350.3 mg/kg; TP concentrations ranged from 128.0 mg/kg to 705.8 mg/kg, with an average of 425.5 mg/kg. The organic matter content ranged from 3.4% to 9.6%, with an average of 5.7%.

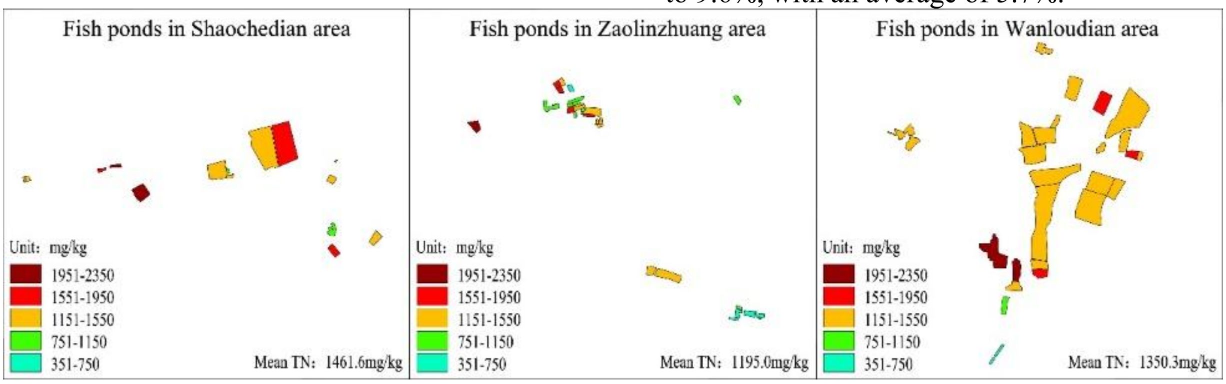



**Figure 3. Plane Distribution of Average TN Concentration in the Bottom Sediment of Fish Ponds in Different Areas**

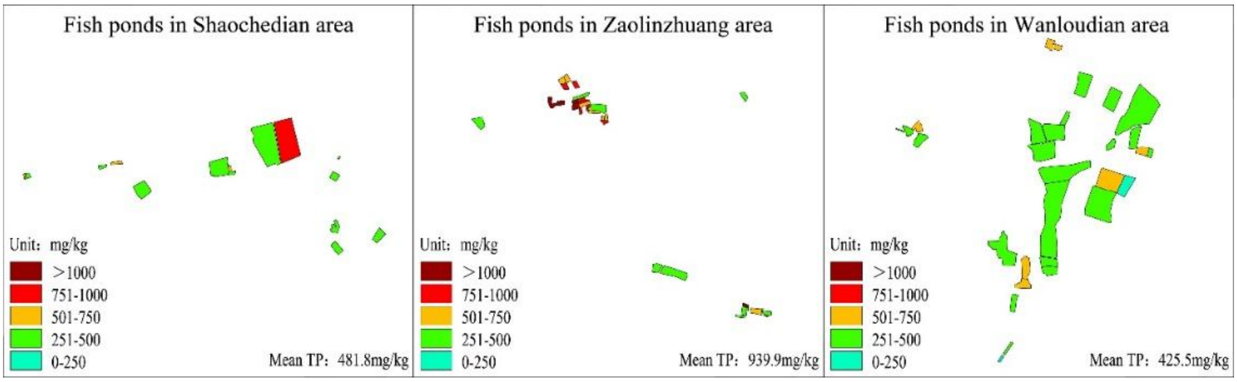



**Figure 4. Plane Distribution of Average TP Concentration in the Bottom Sediment of Fish Ponds in Different Areas**

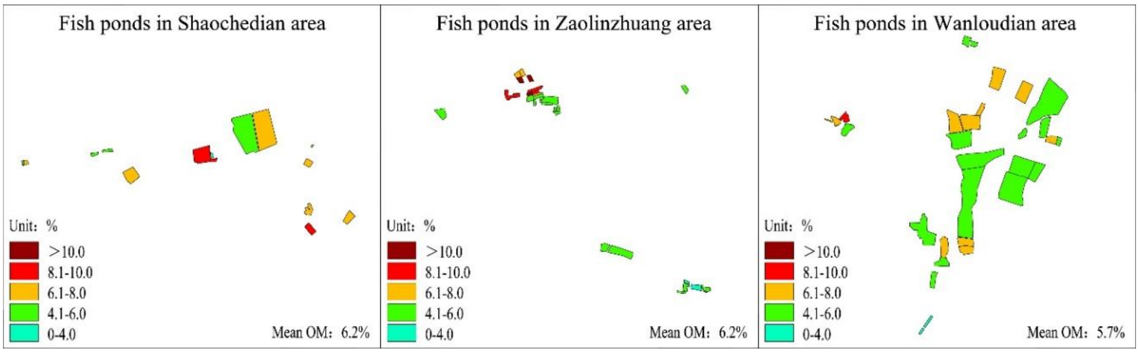



**Figure 5. Plane Distribution of Average Organic Matter Concentration in the Bottom Sediment of Fish Ponds in Different Areas**

Taking Fish Pond A from the Shaochedian area and Fish Pond B from the Wanloudian area as examples, the plane distribution characteristics of nutrient salt concentrations in the sediments were analyzed, as shown in Figures 6 and 7. As indicated in the figures, there were notable differences in the sediment pollution levels across different regions within the same fish pond. For Fish Pond A, TN concentrations ranged from 570 mg/kg to 1,920 mg/kg, with the highest concentration observed in the northern region. TP concentrations varied between 570 mg/kg and 1,920 mg/kg, with elevated levels in the northern and southern areas, while other areas exhibited relatively lower concentrations. The organic matter content ranged from 2.75% to 13.60%, and it was relatively evenly distributed throughout the pond. For Fish Pond B, TN concentrations ranged from 290 mg/kg to 1,550 mg/kg, with the highest concentration in the eastern region. TP concentrations ranged from 240 mg/kg to 1,220 mg/kg, peaking in the southern area, while other regions had concentrations below 600 mg/kg. The organic matter content ranged from 3.00% to 12.10%, with a general pattern of higher values in the west and lower values in the east.

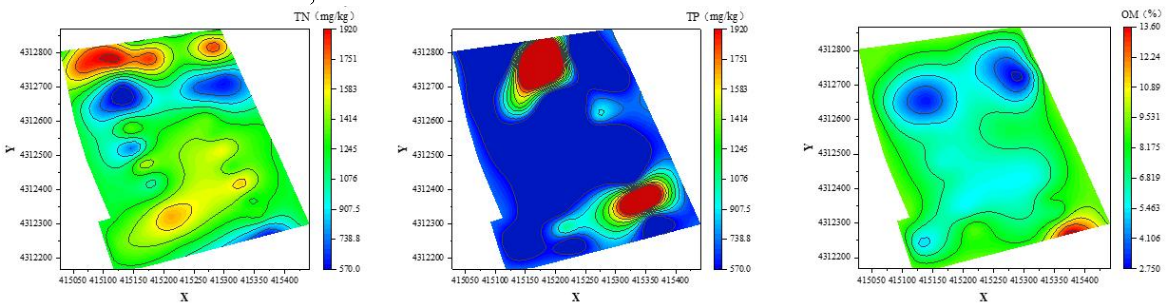



**Figure 6. Characteristics of Nutrient Pollution Plane Distribution in Sediment of Fish Pond A**

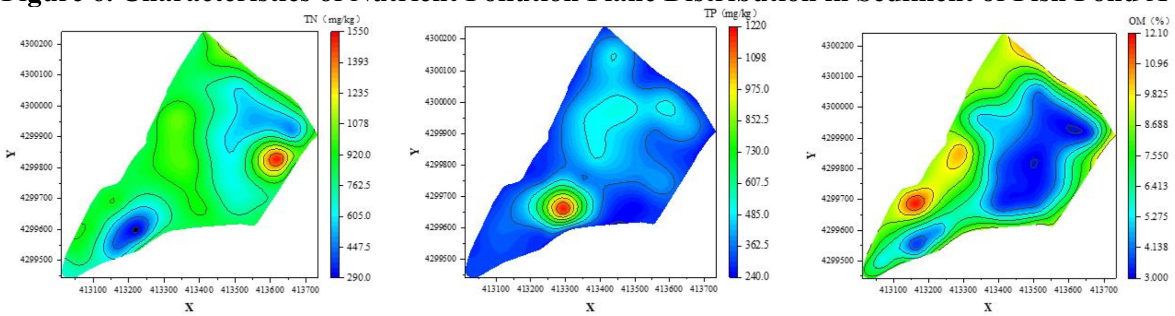


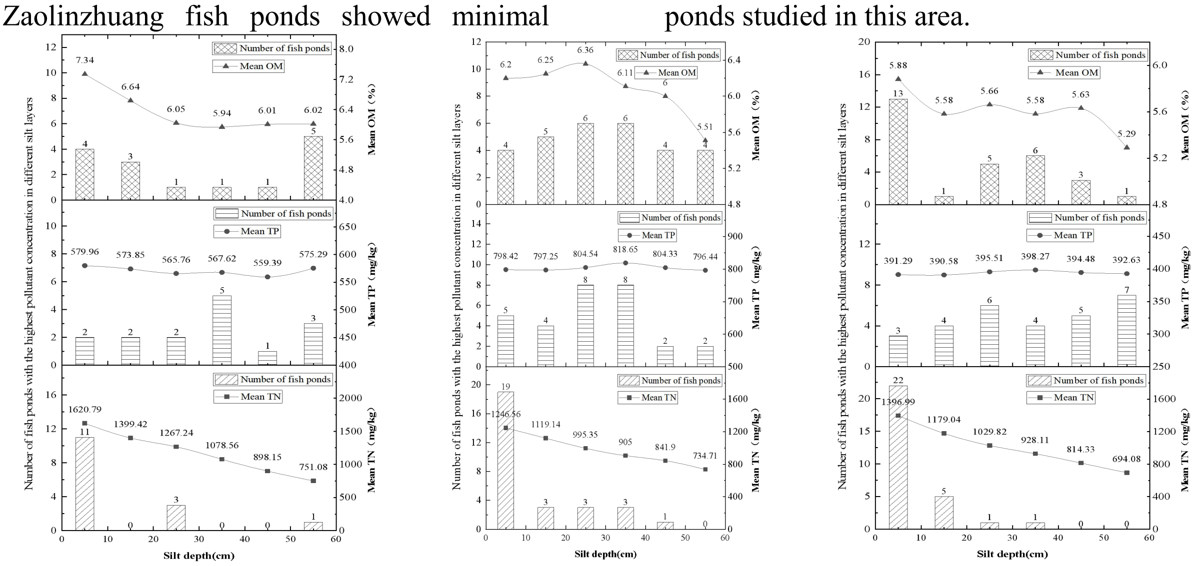

**Figure 7. Characteristics of Nutrient Pollution Plane Distribution in Sediment of Fish Pond B**

3.1.2 Vertical distribution characteristics

From the specific sediment layer monitoring results (as shown in Figure 8), the organic matter content in the sediment of the fish ponds in the Shaochedian area generally showed a gradual decrease from the surface to the bottom layer. The highest average organic matter content, reaching 7.34%, was observed in the 0–10 cm layer. After decreasing to 6.05% in the 20–30 cm layer, the organic matter content tended to stabilize in the 30–60 cm layers. In most fish ponds, the organic matter content was higher in the 0–20 cm sediment layer, which is attributed to the fact that the surface sediment is primarily humus, which contains relatively high organic matter. The TP concentrations in the sediment layers of the Shaochedian fish ponds showed minimal variation, indicating that the TP concentration is not directly related to the sediment depth, and in most fish ponds, the TP concentration was not highest in the surface layer. The TN concentration in the sediments of the Shaochedian fish ponds showed a decreasing trend with increasing sediment depth. From the 0–10 cm layer to the 50–60 cm layer, the average TN concentration decreased from 1,620.79 mg/kg to 751.08 mg/kg. In addition, in most fish ponds, the highest TN concentration was found in the 0–10 cm sediment layer, accounting for 73.33% of the ponds studied in this area. This suggests that the removal of surface sediments is key to reducing TN levels in the sediment.

In the Zaolinzhuang area, the organic matter content in the sediments of the fish ponds exhibited an initial increase followed by a decrease with increasing depth. The highest average organic matter content, 6.36%, was found in the 20–30 cm sediment layer, while it decreased to 5.51% in the 50–60 cm layer. Similar to the Shaochedian area, the TP concentrations in the sediment layers of the Zaolinzhuang fish ponds showed minimal variation, indicating that the TP concentration is not directly related to sediment depth. The TN concentration in the sediments of the Zaolinzhuang fish ponds showed a gradual decrease with increasing depth, from 1,246.56 mg/kg in the 0–10 cm layer to 734.71 mg/kg in the 50–60 cm layer. In most fish ponds, the highest TN concentration was found in the 0–10 cm layer, accounting for 65.52% of the ponds studied in this area.

In the Wanloudian area, the organic matter content in the sediments of the fish ponds exhibited a decreasing trend from surface to bottom. The maximum value, 5.88%, was found in the 0–10 cm sediment layer, while the minimum value, 5.29%, was observed in the 50–60 cm layer. The highest organic matter content was found in the 0–10 cm layer in the majority of the fish ponds. Like the other two areas, the TP concentration in the sediment layers of the Wanloudian fish ponds did not show a direct relationship with sediment depth. Similarly, the TN concentration in the sediments of the Wanloudian fish ponds showed a gradual decrease with increasing depth, from 1,396.99 mg/kg in the 0–10 cm layer to 694.08 mg/kg in the 50–60 cm layer. In most fish ponds, the highest TN concentration was found in the 0–10 cm layer, accounting for 75.86% of the ponds studied in this area.




(a) Shaochedian Area (b) Zaolinzhuang Area (c) Wanloudian Area

**Figure 8. Relationship Between Sediment Pollutant Content and Silt Depth in Fishponds in Different Areas**

In summary, for pond dredging treatment, considering the entire fish pond as a single treatment unit is not entirely reliable. For larger ponds, it is recommended to further delineate dredging areas and depths based on sediment monitoring results from different locations and depths.

### 3.2 Evaluation of Nutrient Salt Pollution

According to the analysis results using the TN single-factor index method (as shown in Table 1), the average TN single-factor pollution accumulation index values for the fish ponds in the Shaochedian, Zaolinzhuang, and Wanloudian areas were 1.7, 1.5, and 1.5, respectively. The sediment pollution levels in all three areas were primarily classified as mild, accounting for 55.5%, 55.1%, and 87.6% of the samples from each area, respectively.

**Table 1. Statistical Table of TN Single-Factor Pollution Level**

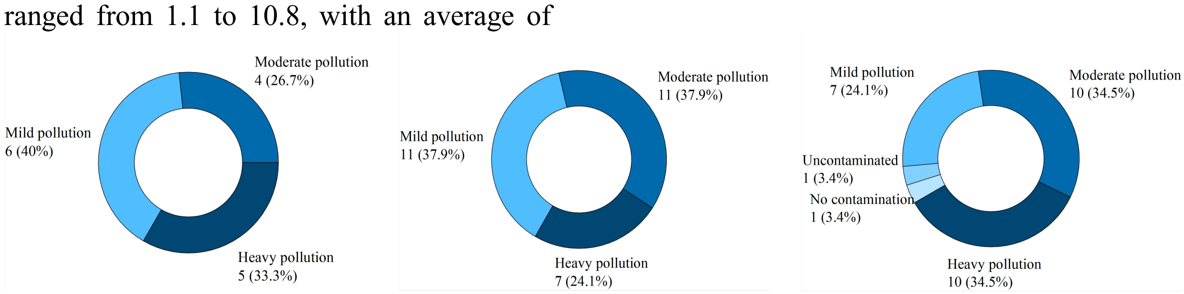
| Area Name | Number of Sediment Samples with Different Pollution Levels | | | | | PI Value | Average Value |
|---|---|---|---|---|---|---|---|
| | No Pollution | Light Pollution | Mild Pollution | Moderate Pollution | Heavy Pollution | | |
| Shaochedan | 72 | 250 | 87 | 37 | 4 | 0.5~5.6 | 1.7 |
| Zaolinzhuang | 87 | 172 | 44 | 7 | 2 | 0.3~6.0 | 1.5 |
| Wanloudian | 339 | 756 | 182 | 58 | 9 | 0.2~6.9 | 1.5 |
| Total | 498 | 1178 | 313 | 102 | 15 | 0.2~6.9 | 1.5 |

According to the analysis results using the TP single-factor index method (as shown in Table 2), the average TP single-factor pollution accumulation index values for the fish ponds in the Shaochedian, Zaolinzhuang, and Wanloudian areas were 1.3, 1.8, and 0.9, respectively. In the Shaochedian and Wanloudian areas, the sediment pollution levels were predominantly classified as uncontaminated, accounting for 60.9% and 68.2% of the samples in each area, respectively. In the Zaolinzhuang area, the sediment pollution levels were predominantly mild, accounting for 44.5% of the samples, followed by uncontaminated samples, which accounted for 30.8%.

**Table 2. Statistical Table of TP Single-Factor Pollution Level**

| Area Name | Number of Sediment Samples with Different Pollution Levels | | | | | PI Value | Average Value |
|---|---|---|---|---|---|---|---|
| | No Pollution | Light Pollution | Mild Pollution | Moderate Pollution | Heavy Pollution | | |
| Shaochedan | 274 | 136 | 13 | 15 | 12 | 0.1~13.0 | 1.3 |
| Zaolinzhuang | 96 | 139 | 46 | 13 | 18 | 0.3~13.5 | 1.8 |
| Wanloudian | 917 | 372 | 36 | 19 | 0 | 0.2~4.4 | 0.9 |
| Total | 1287 | 647 | 95 | 47 | 30 | 0.1~13.5 | 1.1 |

The Nemerow Pollution Index for each fish pond in the three areas was calculated, and the pollution levels of the fish ponds in each area were evaluated, as shown in Figure 9. In the Shaochedian area, the Nemerow index ranged from 1.4 to 4.1, with an average of 2.5. The analysis indicated that the sediment in the fish ponds of this area was contaminated to varying degrees, with 40.0%, 26.7%, and 33.3% of the ponds being classified as mild, moderate, and heavy pollution, respectively. In the Zaolinzhuang area, the Nemerow index ranged from 1.1 to 10.8, with an average of 2.8. The analysis revealed that the sediment in the fish ponds of this area was also contaminated to varying degrees, with 37.9%, 37.9%, and 24.1% of the ponds being classified as mild, moderate, and heavy pollution, respectively. In the Wanloudian area, the Nemerow index ranged from 0.6 to 5.0, with an average of 2.6. The evaluation indicated that 3.4%, 3.4%, 24.1%, 34.5%, and 34.5% of the fish ponds were classified as uncontaminated, no contamination, mild, moderate, and heavy pollution, respectively.




(a) Shaochedian Area (b) Zaolinzhuang Area (c) Wanloudian Area

**Figure 9. Pie Chart of the Sediment Pollution Level of Fish Ponds in Each Area**

## 4. Conclusions

(1) In the Shaochedian area, the average TN concentration in fish pond sediments is 1,461.6 mg/kg, the TP concentration is 481.8 mg/kg, and the organic matter content is 6.2%.

In the Zaolinzhuang area, the average TN concentration is 1,195.0 mg/kg, the TP concentration is 939.9 mg/kg, and the organic matter content is 6.2%. In the Wanloudian area, the average TN concentration is 1,350.3 mg/kg, the TP concentration is 425.5 mg/kg, and the organic matter content is 5.7%.

(2) In the Shaochedian area, organic matter content in the sediments decreases progressively from the surface to the bottom, while TN concentration declines as sediment depth increases. Similarly, in the Wanloudian area, both organic matter content and TN concentration decrease gradually with depth. In contrast, the Zaolinzhuang area shows an initial increase in organic matter content, followed by a decrease from the surface to the bottom, with TN concentration also decreasing with increasing depth. However, no significant correlation is observed between TP concentration and sediment depth in any of the areas. Notably, sediment pollution levels vary considerably across different regions within the same pond. Therefore, for large fish ponds, it is recommended to further subdivide the area to determine specific dredging ranges and depths.

(3) The results from the single-factor index analysis reveal that the TN pollution levels in the sediments of all three areas are predominantly mild, with over 50% of the samples in each area falling into the mild pollution category. In the Shaochedian and Wanloudian areas, most of the sediments are classified as uncontaminated, comprising 60.9% and 68.2% of the samples, respectively. In the Zaolinzhuang area, mild pollution predominates, accounting for 44.5% of the samples.

(4) The results from the Nemerow pollution index analysis indicate that fish pond sediments in the Shaochedian area experience varying levels of pollution, with 40.0% of ponds classified as mildly polluted, 26.7% as moderately polluted, and 33.3% as heavily polluted. In the Zaolinzhuang area, 37.9% of ponds are mildly polluted, 37.9% moderately polluted, and 24.1% heavily polluted. In the Wanloudian area, the pollution levels are distributed as follows: 3.4% uncontaminated, 3.4% no contamination, 24.1% mildly polluted, 34.5% moderately polluted, and 34.5% heavily polluted.

(5) Given that Baiyangdian is a crucial ecological wetland within the Xiong'an New Area, the protection of its environment is of paramount importance. For historically polluted fish ponds, it is essential to develop tailored remediation strategies based on the scope, severity, and vertical distribution of sediment pollution. A "one pond, one strategy" approach should be adopted for precise remediation efforts. Additionally, during the implementation phase, strict pollution prevention measures must be enforced in construction areas to prevent secondary contamination, safeguarding the water quality of surrounding wetland regions.

**Acknowledgments**

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