Analysis of Correlation between Channel Sediment Nutrition and Aquatic Plant Biomass in Pishihang Irrigation District

Yongsheng Zhang\textsuperscript{1,2,*}, Haiying Li\textsuperscript{1,2}, Ruina Fan\textsuperscript{3}, Zhan Li\textsuperscript{4}, Zhong Hong\textsuperscript{4}

\textsuperscript{1} China Institute of Water Resources and Hydropower Research, Beijing 100038, China
\textsuperscript{2} State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, Beijing 100038, China
\textsuperscript{3} Beijing waterworks group CO.,LTD., Beijing 100038, China
\textsuperscript{4} Shenzhen Water Planning and Design Institute co. LTD, Shenzhen Guangdong, 518000, China

*Corresponding author’s e-mail: yszsunny@163.com

Abstract: To study sediment dredging in Pishihang Irrigation District, the largest irrigation district in China, this paper collected aquatic plants and sediment in the channel to analyze the biomass and nutrient distribution. The results were as follows: in April, the biomass at Point 3 peaked at 21.9 kg/m\textsuperscript{2} while in July and September, the biomass at Point 4 was the highest at the level of 25.1 kg/m\textsuperscript{2} and 25.6 kg/m\textsuperscript{2} respectively. The nutrient factor in sediment at Point 4 and 5 was higher than those at other points. The correlation coefficients of aquatic plant biomass with ammonia nitrogen and nitrate nitrogen were 0.81, 0.65 and 0.51 respectively. The nutrients in the sediment affecting the growth of aquatic plants mainly consisted of ammonia nitrogen, nitrate nitrogen and inorganic phosphorus. The eco-dredging project in the canal of Pishihang Irrigation District for weeding was about 20-30cm in thickness.

1. Introduction

Located in Anhui Province and Henan Province, Pishihang Irrigation District covers Pihe Irrigation District, Shihe Irrigation District, Hangbu River Irrigation District and Meishan Irrigation District in Henan Province\textsuperscript{[1-3]}. It has been operating for more than half a century since its establishment in 1958. As the irrigation district is located in Dabie Mountain that suffers from serious soil erosion, sediment depositing at the bottom of the channel provides ideal conditions for the overpopulation of aquatic plants\textsuperscript{[4,5]}. The compromised water conveyance capacity and flood control function have seriously affected the performance of the irrigation districts\textsuperscript{[6]}. Exploring the distribution of nutrients in the sediment is of great significance for removing aquatic plants in the channel and reducing water eutrophication.

Sediment nutrient is an important factor affecting the growth of aquatic plants. The composition of sediment nutrient is determined by the type and density of aquatic plants\textsuperscript{[7]}, which could effectively inhibit the release of nitrogen, phosphorus, nitrate nitrogen, ammonia nitrogen, heavy metals and other substances in sediment\textsuperscript{[8,9]}. Canna can absorb up to 75.97 g/m\textsuperscript{2} and 13.52 g/m\textsuperscript{2} of nitrogen and phosphorus in sediment, and regular harvesting can significantly improve the removal rate of nitrogen and phosphorus in wetland sediment\textsuperscript{[10]}. The concentrations of nitrogen, carbon and phosphorus in the
sediment of eastern Taihu Lake where aquatic plants are densely growing are lower than those in the area where plants are scattered \cite{11}. The phosphorus of sediment is removed by eichhornia crassipes through absorption and assimilation \cite{12}. Rational allocation and planting of aquatic plants can enhance the absorption and release of phosphorus \cite{13}. These studies have clarified the mechanism regulating the transformation of sediment nutrient and aquatic plants as well as interactions between the two, but most of the studies focus on nutrient distribution and form transformation in lake and river sediment \cite{14-16} while there are few studies on nutrient distribution in channel sediment of irrigation district.

Most irrigation districts in our country were built long ago, with huge demands for sediment dredging in the channel \cite{3,4}. However, the existing sediment dredging projects mainly aim at environmental protection and removal of pollutants \cite{17,18}, with few efforts in eco-dredging scheme to remove aquatic plants.

Based on the above situation, this study investigated the distribution of sediment nutrient and biomass of aquatic plants in the channel of Pishihang Irrigation District, and discussed the dredging thickness of the channel based on the root length of aquatic plants in the channel, serving as references for channel dredging in other irrigation districts of China and laying foundation for greater ecological and economic benefits in the irrigation districts.

2. Material and Methods

2.1 Research site
Pishihang Irrigation District is located in Anhui and Henan Province, covering Pishe Irrigation District, Shihe Irrigation District, Hangbu River Irrigation District and Meishan Irrigation District in Henan Province. It is the largest irrigation district in China, which was founded in 1958 for rice irrigation and drinking water supply to Liu'an and Hefei. The irrigation system includes 2 general main canals, 11 main canals and 19 sub-canals, with a total length of 1384km \cite{1-3}.

2.2 Site for investigation
To fully understand the distribution of sediment nutrients of irrigation channels, three collection sites of sediment were selected in the general main canals and main canals respectively (Table 1).

| Canal          | Point | Characteristics                      |
|----------------|-------|--------------------------------------|
| general main canals | 1     | bay in Pi River, low flow rate       |
|                | 2     | straight channel segment in Pi River |
|                | 3     | downstream of regulating brake       |
| main canals    | 4     | downstream of Jidong River           |
|                | 5     | midstream of Jidong River            |
|                | 6     | upstream of Jidong River             |

2.3 Sampling Time
The aquatic plants were collected in April, July and September of 2018 for separate investigation. Field sediment sampling was conducted in July 2018.

2.4 Collection Method
Aquatic plant collection: 3 sample plots sized 2m*2m were taken from each sampling site. As
sediment nutrients mainly works on submerged plants and emergent plants, only the two were collected in each sample plot using methods described in relevant documents[19,20].

Sediment collection: Sediment samples were collected using a vertical gravity-driven sediment coring device with an inner diameter of 60mm. Then the sediment at the thickness of 2.0cm was transferred to a sealed bag and then put into an incubator for cold storage. Three parallel samples were collected at each sampling point, where the average values of relevant indexes were taken and recorded.

2.5 Measurement

The fresh weight of aquatic plants, measured when the sample did not drip, was used to measure the biomass of aquatic plants. The general main canal and main canals of Pishihang Irrigation District extend for miles with uneven distribution of aquatic plants, posing the possibility of greater errors in estimating the total amount of aquatic plants in the canals. This paper selected areas with abundant aquatic plants and measured the biomass of aquatic plants using fresh weight per unit area.

The biomass of aquatic plants per unit area is given by:

\[ m_f = \frac{m_1}{A} \]

where \( m_f \)—biomass of aquatic plants per unit area, kg/m\(^2\);
\( m_1 \)—fresh weight of samples, kg;
\( A \)—sample coverage, m\(^2\).

The biomass of aquatic plants per unit area is given by the average value of multiple weighing.

Total nitrogen, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, total phosphorus, inorganic phosphorus and organic phosphorus were measured in the laboratory. Total nitrogen was determined using semi-micro Kjeldahl method (GB/T 7173-1987) while nitrate nitrogen, nitrite nitrogen and ammonia nitrogen were measured by potassium chloride solution plus spectrophotometry (HJ 14256-2003. The total phosphorus was determined by alkali fusion molybdenum antimony ant spectrophotometry (GB 632-2011), and the inorganic phosphorus was measured by SMT method.

2.6 Data processing

The sediment and aquatic plants samples were monitored for 3 times to acquire the average values. The correlation analysis was processed by SPSS 16.0, where P<0.05 meant significant correlation and P<0.01 was extremely significant correlation.

3. Results and Analysis

3.1 The biomass of aquatic plants

In Pishihang Irrigation District, the biomass at the 6 sites in April was 3.3 kg/m\(^2\), 16.5 kg/m\(^2\), 21.9 kg/m\(^2\), 16.4 kg/m\(^2\), 12.5 kg/m\(^2\) and 0 kg/m\(^2\) respectively while in July, the numbers were 4.8 kg/m\(^2\), 21.1 kg/m\(^2\), 17.8 kg/m\(^2\), 25.1 kg/m\(^2\), 19.5 kg/m\(^2\) and 0.09 kg/m\(^2\) respectively. In September, the biomass was 4.5 kg/m\(^2\), 21.7 kg/m\(^2\), 18.1 kg/m\(^2\), 25.6 kg/m\(^2\), 19.7kg/m\(^2\) and 0.11 kg/m\(^2\) at the 6 sites. In April, the biomass at Point 3 was the highest, while in July and September, Point 4 had the highest value.

3.2 Distribution of Sediment Nutrients

(1) Total Nitrogen

In terms of horizontal distribution, the concentration of total nitrogen at Point 1, Point 2 and Point 3 was not significantly different, and there was not much difference in the concentration at Point 4 and point. The concentration of total nitrogen at point 6 was lower than that at Point 4 and Point 5, but higher than that at Point 1, 2 and 3, suggesting that the concentration of total nitrogen in the general main canal is significantly lower than that of the main canals.

In terms of vertical distribution, there was no significant difference in the concentration of total nitrogen at Point 1, 2 and 3, which ranged between 639 and 688mg/kg. At Point 4 and Point 5, the content of total nitrogen in sediment at the depth of 0-2cm and 2-4cm was significantly higher than
that in other layers of sediments. The total nitrogen at the depth of 0-2 cm and 2-4 cm at Point 4 was 1115 mg/kg and 988 mg/kg respectively, and 1086 mg/kg and 981 mg/kg respectively at Point 5. However, there was no significant difference in the total nitrogen concentration between Point 4 and Point 5 at the depth of 4-20 cm. The total nitrogen concentration at the 4-20 cm of Point 4 was 921-988 mg/kg, and 956-981 mg/kg at the same depth of Point 5.

(2) Nitrogen Nitrate
Horizontally, there was no significant difference at Points 1, 2 and 3 while the concentration of nitrate nitrogen at Point 4 was higher than that at Point 5. Point 6 had a lower concentration than Points 4 and 5, but slightly higher than Points 1, 2 and 3. The distribution of nitrate nitrogen showed that the concentration of nitrate nitrogen in the general main canal was significantly lower than that in main canals. In addition to significant difference in the concentration of nitrate nitrogen between the general main canal and main canals, the nitrate nitrogen showed a gradual increase from the upstream to the downstream.

Vertically, there was no significant difference in the concentration of nitrate nitrogen at Points 1, 2 and 3, which ranged between 181.20 and 229.11 mg/kg. The concentration of nitrogen nitrate at point ranged from 341.49 to 398.43 mg/kg, showing a gradual downward trend at the depth of 0-20 cm. The value at Point 5 was about 312.82-399.48 mg/kg, also showing a gradual downward trend at 0-20 cm.

(3) Nitrogen Nitrite
Horizontally, there was no significant difference in the concentration of nitrite nitrogen at Points 1, 2 and 3. The content of nitrite nitrogen at Points 4 and 5 was not significant, but significantly higher than that at Points 1, 2 and 3. The concentration of nitrite nitrogen at Point 6 is lower than that at Points 4 and 5 but slightly higher than that at Points 1, 2 and 3.

Vertically, the distribution of nitrogen nitrite content at the 6 sites showed a downward trend from 0 cm to 20 cm. However, the concentration at Points 1, 2 and 3 decreased relatively slow while point 4 and 5 were much faster.

(4) Ammonia Nitrogen
The horizontal distribution of ammonia nitrogen at the 6 sites was consistent without much difference in the concentration of ammonia nitrogen except for Points 4 and 5 that had a higher surface sediment concentration.

Vertically, the content of ammonia nitrogen in the surface layer of sediment at Points 4 and 5 was relatively high, which reached 58.32 mg/kg and 55.08 mg/kg, in the surface layer of 0-2 cm and 2-4 cm at Point 4, and 56.08 mg/kg and 52.12 mg/kg at Point 5.

(5) Total Phosphorous
Horizontally, there was no significant difference in total phosphorus between Points 1, 2 and 3, and no significant difference between Points 4 and 5. The concentration of total phosphorus at Point 6 was lower than that at Points 4 and 5, but higher than that at Points 1, 2 and 3, suggesting a lower concentration of total phosphorus in the main canal than that in the other canals.

There was no significant difference in the vertical distribution of total phosphorus at the 6 sites. At Points 4 and 5, the content of total phosphorus in the sediment layer 0-2 cm and 2-4 cm was significantly higher than that in other layers, which reached 585.11 mg/kg and 576.00 mg/kg at Point 4 and 573.68 mg/kg and 570.24 mg/kg at Point 5. However, there was no significant difference in total phosphorus in sediment layers from 4-20 cm. The total phosphorus concentration in the sediment layer of 4-20 cm was 921-988 mg/kg at Point 4, and 956-981 mg/kg at Point 5.

(6) Inorganic Phosphorus
There was no significant difference in the horizontal distribution of inorganic phosphorus between Points 1, 2 and 3. Points 4 had a higher concentration than Point 5 except for the surface layer of 0-2 cm, while the concentration of inorganic phosphorus at Point 6 was lower than Points 4 and 5, but slightly higher than that at Points 1, 2 and 3. The distribution of inorganic phosphorus showed that the concentration of inorganic phosphorus in the general main canal was significantly lower than that in main canals at sediment layers, which was presented in a gradual growing trend from upstream to downstream.
There was no significant difference in the vertical distribution of inorganic phosphorus at Points 1, 2 and 3, which ranged between 191.77 and 231.10 mg/kg. The concentration of inorganic phosphorus at Point 4 ranged from 317.65 mg/kg to 427.68 mg/kg, with a gradual decrease from 0 cm to 20 cm. The concentration at Point 5 was about 331.35-409.16 mg/kg, showing a gradual downward trend from 0-20 cm.

Figure 1  Distribution of Sediment Nutrients in Sediment

3.3 Correlation between Biomass and Sediment Nutrients

According to the correlation analysis of aquatic plant biomass and related sediment nutrients (Tables 2), the aquatic plant biomass was significantly correlated with ammonia nitrogen with a correlation coefficient of 0.81. The biomass of aquatic plants was positively correlated with total nitrogen, nitrate nitrogen, total phosphorus and inorganic phosphorus, with correlation coefficients of 0.41, 0.65, 0.50 and 0.51, respectively. The biomass of aquatic plants was negatively correlated with nitrite nitrogen, with correlation coefficients of -0.62 and -0.42. The correlation analysis showed that the main nutrient factor affecting the growth of aquatic plants included ammonia nitrogen, followed by nitrate and inorganic phosphorus. Therefore, the removal of nitrogen and phosphorus is the key to grass control.
4. Discussion

4.1 Distribution of Sediment Nutrients
Pishihang Irrigation District has been operating for more than half a century since its establishment, with enormous sediment deposition in the canal\textsuperscript{[1-3]}. In this study, it was found that the horizontal and vertical distribution of total nitrogen and total phosphorus in sediment of Pishihang Irrigation District were similar.

There was no significant difference between the concentration of total nitrogen and total phosphorus between the six sites of general main canals and main canals, probably because sediments from the general main canals and main canals exchanged under hydrological dynamic conditions before depositing at Point 6.

There was no significant difference in the vertical distribution of total nitrogen and total phosphorus in sediment layers, probably because the sediments were not formed by deposits from the main and sub canals, but rather developed by mud and sand in the channel in a short period of time. The upstream of the channel in Pishihang Irrigation District is in the Dabie Mountain that suffers from serious soil erosion, which provides sources of sediment for the channel.

At Points 4 and 5 of the sub canals, the total nitrogen and total phosphorus in the sediment layer of 0-4cm had relatively high concentration probably due to the presence of rotten aquatic plants on the surface of sediment layer, thus elevating the concentration of total nitrogen and total phosphorus. This study also found that Point 4 and Point 5 were located in the upper and middle streams of the main canal, with lush aquatic plants in the canal, and Point 6 had the most aquatic plants among the 6 sites.

4.2 Dredging based on distribution of sediment nutrients
Sediment are accumulating in the general main canal and main canal of Pishihang Irrigation District all the year round. According to the ecological status of the canal in Pishihang Irrigation District, aquatic plants in the canal are over-propagated\textsuperscript{[1-5]}, with sediment as the most directly available nutrients for aquatic plants. Therefore, it would be most effective to determine the dredging depth of aquatic plants based on the distribution of sediment nutrients. However, it was found in the study that there was no significant difference between the sites in the vertical distribution of sediment nutrients except for Points 4 and 5 which showed a decreasing trend. Therefore, the dredging projects at Points 4 and 5 were shallower than that at other points. Since there was no significant difference in the vertical distribution of nutrients at each point, the dredging thickness should be determined by the distribution of sediment nutrients in combination with the root length of aquatic plants. Except for aquatic plants with adventitious roots, the roots of most aquatic plants are about 20-30 cm in length \textsuperscript{[21]}, namely the thickness of eco-dredging in Pishihang Irrigation District is only 20-30 cm.

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