Strategy Evaluation and Suggestions for Taihu Lake Following the 2007 Cyanobacterial Bloom Outbreak

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Abstract: Taihu Lake, the third largest freshwater lake in China, is located in the lower reaches of the Yangtze River and serves as an important water source for the surrounding areas. The waters of Taihu Lake have experienced eutrophication for four decades, with frequent cyanobacteria blooms that have caused serious water use problems in the surrounding areas. The most recent was in 2007. This paper analyzed the management of cyanobacteria in the past decade based on the situation of cyanobacteria management since the 2007 outbreak, summarized the past experience and future development direction of cyanobacteria management in Taihu Lake, and analyzed the effects of different measures. Results show that the causes of cyanobacteria outbreak were analyzed, and the corresponding management suggestions were put forward. The governance of the past decade has mainly included physical, chemical and ecological approaches. Physical and chemical methods can kill algae quickly and effectively, but there are problems of high cost and secondary pollution. Ecological approaches are more promising, such as deep water purification by establishing ecosystems dominated by aquatic plants. In addition, emerging algae treatment technologies also show high potential, such as algae AIO recovery technology and resource disposal technology, which can effectively alleviate the problem of cyanobacteria and realize resource utilization.

1 INTRODUCTION

Taihu Lake is the third largest freshwater lake in China, located in the lower reaches of the Yangtze River. The waters of Taihu Lake have experienced eutrophication, with frequent outbreaks of cyanobacteria blooms. Large algal blooms can cause water quality to deteriorate, depleting the water of oxygen and killing fish. In addition, algal toxins released by cyanobacteria death can inhibit the growth of other algae and aquatic plants, reduce the predation intensity of zooplankton and fish, and stimulate their own rapid growth to form a large number of cyanobacteria blooms (Gao and Xie, 2011).

The process of cyanobacteria management in Taihu Lake can be traced back to the late 1980s and early 1990s. During this period, the urbanization process of Taihu Lake accelerated, and the intervention of human activities on the water body became less and less. By 2007, the lake had a massive cyanobacteria outbreak covering 970 square kilometers. This left people near the lake without clean water to drink, causing serious impacts on people and the environment. Eutrophcation in Taihu Lake is caused by human activities that lead to a large amount of nitrogen, phosphorus and other nutrients into the water, resulting in the rapid proliferation of phytoplankton. Water eutrophication can lead to deterioration of water quality and a decrease in dissolved oxygen, which can lead to the death of large numbers of fish and other organisms.

In order to cope with the sudden cyanobacteria outbreak, the treatment after the 2007 cyanobacteria outbreak in Taihu Lake mainly included the following measures: guiding the Yangtze River water into Taihu Lake to improve the cleanliness and stability of the water quality of Taihu Lake, and promoting the exchange and renewal of the water body. Measures have been taken to shut down pollution and control discharge to reduce the amount of inferior water entering Taihu Lake, thus reducing the pollution burden of Taihu Lake. Monitoring points should be added, monitoring frequency should be increased, and daily tracking monitoring and inspection should

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be carried out to timely grasp the changing trend of water situation, water quality and cyanobacteria (Lyu, 2007). However, the intensity of cyanobacterial blooms in Taihu Lake from 2016 to 2019 was significantly higher than that from 2010 to 2015 (Wu, Zhu and Zhu, 2021. It can be seen that the problem of cyanobacteria in Taihu Lake has not been completely solved until recent years.

In this paper, according to the situation of cyanobacteria management in the past ten years since the outbreak of cyanobacteria in 2007, the methods and effects of cyanobacteria management are discussed. Different governance methods include physical methods, chemical methods and ecological methods. Physical methods include deep aeration, mechanical algae removal, electronic algae removal and so on. The chemical method mainly uses algae removal agents such as copper sulfate, chlorine dioxide and ozone (Gao and Xie, 2011).

2 CAUSES OF CYANOBACTERIAL BLOOM IN TAIHU LAKE

First of all, the root cause of the cyanobacterial outbreak in Taihu Lake is the eutrophization of Taihu Lake (Zhang, Zeng and Chen, 2016). Water eutrophcation refers to the phenomenon that under the influence of human activities, nutrients such as nitrogen and phosphorus required by living things enter the water body in large quantities, causing rapid reproduction of algae and other plankton, decline of dissolved oxygen in the water body, deterioration of water quality, and mass death of fish and other organisms. However, the causes of cyanobacteria outbreaks and the difficulty in managing them are related to human factors and natural factors in Taihu Lake.

2.1 Human Factors for the Continuous Deterioration of Water Quality in Taihu Lake

The direct reason for the deterioration of lake water quality is that the total amount of pollution discharge seriously exceeds the standard. Taihu Lake Basin is the core area of the Yangtze River Delta economic circle. However, the more extensive development mode and economic structure have brought about increasingly serious environmental pollution problems for a long time. First, there is a serious imbalance between sewage volume and runoff, which seriously exceeds the carrying capacity of the water ecological environment in the basin. Second, the discharge of pollutants into the lake seriously exceeds the standard, far exceeding the carrying capacity of the basin waters and the Taihu Lake water body. However, in the face of huge sewage discharge, sewage treatment capacity is seriously insufficient. At the beginning of the cyanobacteria outbreak in 2007, the number of municipal sewage treatment units around Taihu Lake was seriously insufficient. Even if the tail water is discharged after treatment, the accumulation of eutrophics in Taihu Lake is accelerated because most sewage treatment plants do not have dephosphorization and nitrogen removal devices. In addition, a large amount of exogenous pollution enters the lake along with the rivers that enter the lake, and in addition, the large-scale lake enclosure culture and Seine culture formed in the East Taihu Lake for a long time have led to the increasing accumulation of pollutants, phosphorus and nitrogen in the lake (Lyu, 2007).

2.2 The Geographical Defects of Taihu Lake Lead to the Deterioration of Water Quality

From the perspective of water flow, the Taihu Lake Basin is a typical plain river network area, and the environmental degradation of its river network system is serious. There are 215 rivers around the lake, most of which enter the lake with poor quality water. Due to the self-purification function of the lake, the quality of the water flowing from the lower reaches of Taihu Lake is higher, which inevitably leads to the accumulation of a large number of pollutants in the lake, resulting in a vicious cycle. In addition, Taihu Lake belongs to the Yangtze River system, and the drainage system between Taihu Lake and the Yangtze River is not smooth. For a long time, there is no main river communication, and there is only one drainage channel of Taipu River. The single drainage channel is not suitable for the complex lake structure, resulting in poor water exchange in the lake. Moreover, Taihu Lake is a shallow lake. Due to the low and flat terrain in the region, the water exchange period is as long as 309 days, the hydrodynamic conditions are poor, the dilution and degradation efficiency of pollutants is low, and the self-purification ability of the water in the lake is poor. Taihu Lake is also a lake with complex flow patterns. In addition to the main lake area, there are

many pock-shaped lakes, and the water bodies do not flow or exchange for many years, so pollutants are easy to gather and accumulate (Lyu, 2007), which leads to the accelerated deterioration of the water ecological environment and threatens the safety of water supply in the water source.

3 CONTROL MEASURES AND RESULTS OF CYANOBACTERIAL BLOOM IN TAIHU LAKE

After the cyanobacteria outbreak, the government took immediate remedial measures. These measures mainly include the control of the discharge of pollution sources and the transfer of clean water from the field. After achieving certain results, measures were taken to maintain the ecological stability of Taihu Lake in order to stabilize it. In addition to continuing to control pollution sources, people are actively looking for ways to actively remove algae and use methods such as introducing aquatic plants for ecological management.

3.1 Control Measures and Results Shortly after Cyanobacterial Bloom in 2007

In response to the outbreak of cyanobacteria ecological hazards in Taihu Lake, the water conservancy department has taken a series of emergency control measures. These measures are aimed at mitigating the damage of cyanobacteria to the ecological environment of Taihu Lake and ensuring the security of local water supply. The main measures include water transfer and drainage, gate closure and pollution interception, discharge control, and strengthening monitoring and early warning. Water transfer and drainage is one of the key measures. Through Changshu Hub and Meiliang Lake pumping station, the Yangtze River water is guided into Taihu Lake to improve the cleanliness of Taihu Lake water. This not only helps to stabilize the water quality, but also promotes the exchange and renewal of water bodies, effectively improving the water quality of Taihu Lake. Secondly, shutting down pollution and controlling emissions are also important prevention and control measures. In view of the water quality of the main rivers entering the lake and the nearby ports, the quantity of inferior water entering the lake has been successfully reduced by shutting down pollution and controlling discharge, thus reducing the pollution burden of the Lake and preventing the growth of cyanobacteria. In addition, during the emergency management period, the hydrological department added monitoring points, increased the monitoring frequency, and carried out daily tracking monitoring and inspection, so as to timely grasp the change trend of water situation, water quality and cyanobacteria (Lyu, 2007).

After months of emergency treatment measures such as water transfer and drainage, gate closure and pollution interception, monitoring and early warning, as well as the coordination and cooperation of local governments and environmental protection departments, obvious results have been achieved. The reasons for the effectiveness of this measure are as follows: First of all, the water supply safety of Taihu Lake water source has been successfully guaranteed. By diverting water from the Yangtze River into Taihu Lake and then diverting it rationally, two flow fields in the lake area are formed, which accelerates the exchange and renewal of water bodies in the water source and improves the main water quality indicators. Secondly, the environmental capacity of the Taihu Lake body has been improved. The diversion of water from the river resulted in an increase in the total water inflow into the lake, with a net increase of 1.52 billion cubic meters of storage water (Lyu, 2007).

3.2 Control Measures and Progress in Recent 10 Years

After the initial control of the cyanobacteria outbreak in 2007. The management of Taihu Lake is mainly to stabilize the healthy ecosystem, actively remove excess cyanobacteria in the lake and reduce pollution emissions. The control of pollution sources mainly involves raising the lake basin, removal and aging capacity of sewage treatment plant, the development of scientific fertilization technology to reduce farmland light and phosphorus loss, and to reduce the amount of domestic sewage production from the policy. When the nutrient level of the lake drops to a certain level, the cyanobacteria bloom could disappear and the healthy ecosystem dominated by deep-water plants would be gradually rebuilt (Gao and Xie, 2011). From July 2007 to December 2015, the production and discharge of all kinds of pollution increased significantly, but the amount into the lake showed a decreasing trend. This is because sufficient

sewage treatment capacity has been built in the upper and middle reaches of the basin, and the domestic and industrial pollution loads have been greatly reduced. Livestock and poultry in the basin dominated by large-scale centralized breeding have become important point sources in the basin. By adjusting the scale and breeding layout, scientific and reasonable disposal of breeding sewage and waste, the pollution load of livestock and poultry has been greatly reduced in the basin. In addition, all kinds of domestic and industrial pollution sources and other non-point sources (including planting, aquaculture, waste and ground runoff) have been strictly controlled (Ma et al., 2017).

Beside the above measures, a lot of efforts have been made to catch cyanobacteria. Until 2015, a total of 18 algae-water separation stations have been built in various basins of Taihu Lake, and the algae-mud obtained from them has been basically utilized as resources. This measure controlled the degree of cyanobacteria outbreak and resource utilization to a certain extent. At the same time, a large amount of sludge produced by algae was removed from the bottom of Taihu Lake (Ma et al., 2017). In addition, people also use physical methods and chemical methods to actively remove algae. Chemical methods include the use of copper sulfate, chlorine dioxide, ozone and other jujube removal agents. Physical methods include deep aeration, mechanical algae removal, and electronic algae removal (Gao and Xie, 2011). Because of the growth of algae, a large amount of oxygen consumption underwater, some organisms died due to lack of oxygen. Increasing the content of dissolved oxygen in the water is beneficial to the growth of other organisms.

In addition, ecological restoration is another important method to control cyanobacteria in Taihu Lake, including the establishment of an ecosystem dominated by aquatic plants. Aquatic plants can absorb and assimilate nutrients such as nitrogen and phosphorus in lake water and sediment during growth (Gao and Xie, 2011), which plays an important role in reducing nutrient levels in lake water and preventing eutrophication. In addition, aquatic plants can inhibit wind and waves, retain sediment, and inhibit algae, thus improving water transparency, providing an excellent habitat for economic aquatic animals. In addition, the constructed wetland sewage purification technology can capture the insoluble pollutants in the water through the precipitation and filtration of the wetland, and then be used by microorganisms. Soluble pollutants in water can be decomposed and removed through the adsorption of plant root biofilm and microbial metabolic degradation process. Constructed wetlands can effectively intercept non-point source pollution and reduce nutrients entering lake channels, thus improving lake water quality (Gao and Xie, 2011).

4 DISCUSSION

4.1 Current Situation

The lake has long been plagued by severe eutrophication and pollution. According to the analysis of the current situation of water pollution around Taihu Lake, the water quality of Taihu Lake is moderately polluted, mainly affected by total nitrogen (TN), total phosphorus (TP), heavy metals and chemical oxygen demand (COD) and other factors. From 2007 to 2020, due to the strengthening of the management of Taihu Lake, the environmental capacity increased, and the density of cyanobacteria continued to increase, resulting in a continuous downward trend of TN in Taihu Lake, with the mean value of the whole Taihu Lake decreasing from 2.35mg/L to 1.48mg/L, a reduction of 37%. At the same period of time, TP is basically flat. Among them, the average annual TP from 2008 to 2012 was lower than 0.074mg/L in 2007, and from 2015 to 2019 was higher than that in 2007 (Wu et al., 2022). During the period from 2012 to 2018, the maximum annual load into the lake around Taihu Lake, the western Taihu region and the western Zhejiang region all occurred in 2016, which were 53 278.10, 34 983.30 tons and 14 729.20 tons, respectively. As a result, the TN load of these two areas into Taihu Lake also increased significantly. The minimum annual load in the lake around Taihu Lake and the west Lake area occurred in 2013, which were 33 600.16 tons and 22 752.05 tons, respectively, but not in other water resources zones, which further indicated that the inter-annual variation of load in the Lake around Taihu Lake was largely dependent on the variation in the west Lake area (Li et al., 2023). In the 13 years, the TP load of the river into the lake was greater than 01.84 million tons in 2007 for 10 years, and reached 0.25 million tons in 2011 and 2016, with an increase of 36% (Wu et al., 2022). What's more, the pollution situation in the northern part of Taihu Lake is particularly serious, especially Hg pollution is significantly higher than other areas, which has exceeded the chronic benchmark limit value of freshwater aquatic organisms. The overall Hg

concentration in Taihu Lake was (0.34±0.17) μg·L-1, ranging from 0.16 to 0.70 μg·L-1, while the mean Hg concentration in the northern coast reached 0.52 mg·L-1. In addition, cyanobacteria bloom and other phenomena still exist, especially in the three northern bays and the western lake area (Liu et al., 2020). From the above data, although some water quality barely meets the standard, overall, the pollution situation of Taihu Lake has not improved significantly.

The changes of TN loading and concentration in different water resources around Taihu Lake showed different characteristics. The annual average concentration of TN in Taihu Lakehu is significantly higher than that out of Taihu Lakehu, especially in the western region of Taihu and Zhejiang. In each year, the TN load into the western part of the lake contributed the most to the TN load into the lake, while the contribution of the Taicpu River to the TN load out of the lake was the most significant (Li et al., 2023). In addition, the characteristics of TN loading into the lake during cyanobacteria outbreaks were similar to those at the annual scale, but there were some differences among regions. Among them, the change of water quality of East Taihu Lake near Suzhou is also the focus of people's attention. The change of water quality in East Taihu Lake is not optimistic. The biomass of cyanobacteria has gradually increased, the area and volume of aquatic plants have shown a downward trend, the silt problem at the bottom of the lake is serious, and the influence of hydrological conditions on the aquatic ecological environment has become more significant in recent years. In particular, the water ecological environment of East Taihu Lake has weakened its ability to conserve water resources, which is difficult to meet the local demand for water resources. The gap between the water ecological and environmental protection status of East Taihu Lake and the average level of Taihu Lake basin is narrowing, and some water quality indicators have even been lower than the average level of Taihu Lake, and the TP concentration continues to rise (Guo, Tan and Wang, 2023). Compared with 2007, the TP of East Taihu Lake in 2020 increased by 20% (Wu, Zhu and Zhu, 2021).

4.2 Suggestions for Cyanobacterial Bloom Management

The traditional physical and chemical methods were more commonly used, faster and more effective, and can effectively kill algae, but they are expensive, but also prone to secondary pollution, and most physical methods cannot fundamentally solve the problem of water eutrophication. Therefore, ecological methods are currently preferred. The following is an evaluation of the existing methods.

The design of ecological restoration system and the purification effect of aquatic plants is more effective. In terms of ecological restoration and deep purification of drinking water source quality, the threat of cyanobacteria outbreak to drinking water source safety has been effectively solved through the construction of water source ecological purification project and the use of aquatic plants as part of the natural ecosystem. The designed three-stage purification system, including reed wetland, submerged plant area and water conservation area, forms a cascade purification system and improves the water purification effect (Fan, 2020). In terms of the combination of ecological restoration with dredging and flood control and dredging projects, the silt accumulation is made shallower by implementing ecological dredging. In addition, water plants are used for wetland restoration, and the excavation site is deepened into deep water area or flood discharge channel, which solves the problem of dredging and silting treatment in Taihu Lake and reduces the dredging cost (Ma et al., 2017).

Aquatic plant plays an important role in ecological restoration. They directly absorb nutrients in water, such as phosphorus and COD, and have a good purification effect on eutrophic water (Gao and Xie, 2011). At the same time, grass-type aquatic plants have the effect of inhibiting algae growth, which can reduce the amount of algae in the water, thus reducing the occurrence of bloom. The wave elimination effect of wetland system also helps to reduce sediment in water body and further improve water quality (Gao and Xie, 2011). In addition, the effect of water temperature on P release should be considered for ecological restoration. By planting large aquatic plants, such as reeds, the water surface temperature can be lowered and the rate of phosphorus release from sediment can be slowed down, thus reducing the degree of eutrophication (Fan, 2020). Controlling water depth is also an effective means to reduce the concentration of nutrients in water.

Emerging algal treatment technologies are highly anticipated. Among them, the successful application of cyanobacteria AIO salvage technology（All－Weather, Intelligence, Offshore） and resource disposal technology has relieved the pressure of cyanobacteria in Taihu Lake. AIO recovery technology can obtain algae mud with a moisture

content of less than 50% after disposal by automatic collection, algae water separation and high temperature pressing facilities, and then produce organic fertilizer through fermentation of algae mud and straw. Or further produce algae powder with a moisture content lower than 10% and a higher value through the low-temperature evaporation and drying system of solar composite membrane. The treatment of algal sludge and the market application of the final product have broad prospects, and have been successfully promoted in several cyanobacterium outbreak areas in China, forming a sustainable, low-cost, market-oriented ecological recycling system. This technology not only fills the gap in the field of cyanobacteria treatment in China, but also achieves the goals of efficient salvage, stable treatment, harmless treatment, reduction and resource utilization, and effectively reduces the secondary pollution problem (Qian and Xie, 2023). In the future, with the continuous upgrading of technology and the application of new processes, this technology is expected to be applied to the management of more lakes to achieve efficient and green development of lake management.

5 CONCLUSION

The management of cyanobacteria in Taihu Lake has been a tricky task since the outbreak of cyanobacteria in 2007. Taihu Lake is highly eutrophication, resulting in frequent cyanobacteria blooms and declining water quality. Human activities, such as excessive pollution discharges and improper wastewater treatment, are the main causes of eutrophication. In addition, the geographical features of Taihu Lake, including shallow water and complex flow patterns, exacerbate the accumulation of pollution. The immediate response after the 2007 cyanobacteria outbreak included water transfers from the Yangtze River and pollution source control measures. The long-term strategic focus is on pollution source control, algae removal, and ecological restoration. Longstanding measures have improved water quality and reduced cyanobacteria biomass. Although initial progress has been made in the management of cyanobacteria in Taihu Lake since 2007, the pollution situation in Taihu Lake is still worrying, with continuous cyanobacteria blooms and deteriorating water quality, and high levels of nitrogen and phosphorus in the lake, especially in the northern and eastern regions. In order to cope with the continuous growth of cyanobacteria and the eutrophication of the lake water, ecological restoration, combined with innovative technologies, offers hope for long-term management of cyanobacteria, in addition to physics-based algae removal methods and chemical-based algae removal agents.

What's more, the development of algal recovery and resource utilization technologies, such as AIO recovery technology, provides sustainable and cost-effective solutions for cyanobacteria management. These innovations relieve pressure on Taihu and provide opportunities for wider application in other lake management contexts. With the progress of cyanobacterial control technology in the future, the efficiency and effect of cyanobacterial control can be improved by combining advanced technologies such as remote sensing with traditional management methods. Moreover, emphasis on sustainable and adaptive management practices, as well as stakeholder engagement and policy support, is essential to achieve lasting improvements in the ecological health and water quality of Taihu Lake. By drawing on past experiences, embracing technological advancements, and adopting ecosystem-based strategies, Taihu can move toward a more sustainable and resilient future that ensures the well-being of the environment and local communities.

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