Effect of constructed wetland system on aquaculture wastewater by ecological treatment

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Abstract. In this study, an integrated ecological system was constructed to treat small scattered aquaculture wastewater in southern rural areas of China. The water outlet of 4 level wetlands was continuously monitored from July to December in 2017. Results showed the average concentrations of total nitrogen (TN), ammonia nitrogen (NH₄⁺-N), nitrate nitrogen (NO₃-N), total phosphorus (TP) and chemical oxygen demand (COD) were 43.64mg/L, 17.53mg/L, 1.71mg/L, 1.66mg/L and 51.39mg/L in the average effluent concentration of grade I wetland, respectively, and 8.35mg/L, 4.42mg/L, 0.24mg/L, 0.26mg/L, 21.32mg/L in the average effluent concentration of grade IV wetland, respectively. The removal rates were 81%, 75%, 86%, 85% and 59% for TN, NH₄⁺-N, NO₃-N, TP and COD in the integrated ecological system, respectively. The effluents from the integrated ecological system met the requirements of "Discharge Standard of Pollutants for Livestock and Poultry Breeding" (GB 18596-2001) and achieved "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant" (GB 18918-2002) the center two levels to discharge the standard. Obviously, the integrated ecological system could work efficiently in treating the rural scattered aquaculture wastewater, and also possess merits of low construction and operation costs and simple management method, which will be benefited to its application in the southern rural regions of China.

1 Introduction

At present, seven major water systems have been polluted to varying degrees in China, and the problem of water eutrophication has become increasingly prominent [1]. According to a report in the "Second National Pollution Source Census Bulletin" in 2020, the amount of nitrogen and phosphorus emitted by livestock and poultry breeding is reached to 1.025 million tons and 160 thousand tons, respectively, accounting for 22% and 37.9% of the total environmental emissions of nitrogen and phosphorus in the country. The environmental pollution caused by the poultry breeding industry has exceeded the industrial pollution, and the environmental problems caused by it have attracted great attention in China [2]. Farming sewage has the characteristics of high content of organic matter, nitrogen, phosphorus and other pollutants, and direct discharge will pollute the water source and pose a certain threat to the safety of drinking water [3]. In recent years, constructed wetlands have been widely used in rural sewage treatment with many advantages, such as low investment, stable effluent strong impact resistance, low quality. energy consumption, and easy management. The results of constructed wetlands for rural sewage treatment have achieved certain effects [4-10]. In general, farms are built in suburbs or rural areas, and their topography and

geographic environment are suitable for constructing wetlands. Therefore, the use of artificial wetlands for aquaculture wastewater treatment has great application advantages in rural areas [11-12]. This paper introduces an ecological combination treatment technology for sewage treatment in small-scale farms in rural areas, in order to provide technical support for solving pollution control of livestock and poultry breeding in rural areas in China.

2 Materials and methods

2.1 Basic situation of constructed wetlands

The construction site of the constructed wetland system is located in the Laowu Group, Kaihui Town, Changsha County. The substrate bottom mud is paddy soil, and precast concrete baffles are built around the wetland. The constructed wetland system is divided into 4 levels according to the original topography. The levels are connected by precast concrete pipes with a diameter of 200mm. The total construction area is $3421m^2$ and the water area is $2675m^2$. Among them, the left of wetland I is $268m^2$ and the right of wetland I is $196m^2$, wetland II is $232m^2$, wetland III $689m^2$, and wetland IV $1290m^2$ (Figure 1). wetland I and pool depth 0.70m, water depth 0.20 - 0.30m; grade II wetland pool depth 0.80m, water

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depth 0.30 - 0.40m; wetland III pool depth 0.90m, water depth 0.40 - 0.45m; wetland IV pool is 1.0m deep, and the water depth is 0.45-0.60m. The wetland water at all levels flows to the downstream wetland step by step using the natural drop. The main source of pollution in the project area is the breeding wastewater of about 850 pigs from the four pig farms. The aquaculture wastewater is digested by a biogas digester and a straw substrate pool, and then collected through pipelines and collected into a constructed wetland for treatment. The left first-level ecological wetland receives 350 pigs wastewater, and the right first-level ecological wetland receives 500 pigs wastewater.



Figure 1. Process flow chart of ecological treatment technology aquaculture wastewater

2.2 Planting of plants in constructed wetland system

Plants in the constructed wetland system are mainly plants with strong absorption capacity of nitrogen, phosphorus, COD and other pollutants also taking into account the landscape. A total of six plants including *Myriophyllum, Barracuda grass, Thalia dealbata, Canna, Lotus root,* and *Water Lily* were selected, and the constructed wetland system performed well during operation (Figure 2).

The selected plants were planted in late April, the Myriophyllum sp. is used for seeding, and other five plants were planted. In order to maximize the absorption of pollutants, plants with high biomass are planted on the wetland I and wetland II, mainly including Barracuda grass, Canna and Myriophyllum, Barracuda grass and Canna planting plants in 3 rows apart, with a plant spacing of 0.5m, and a unit spacing of 1.0m. Wetland III mainly plant Thalia dealbata, Canna and Myriophyllum. The planting density of Thalia dealbata and Canna are the same as wetlands I. Wetlands IV are planted with Thalia dealbata, Canna, Water Lilies, Myriophyllum and Lotus roots. Canna, Water Lilies, and Lotus roots are planted with round ornaments. After the plants survive at all in the wetlands, seed Myriophyllum sp. between the plants. The constructed wetlands receive sewage after the plants have closed the entire water surface. During the operation period, Myriophyllum and Barracuda were harvested in the constructed wetland was carried out in early July and mid-September.



Figure 2. Effect of constructed wetland system during operation

2.3 Sample collection and water quality indicators

From mid-July 2017 to early December 2017, 1L water sample was collect at various wetland outlets every month with white bottle. A total of 11 water samples and 44 water samples were collected. Five water quality indicators, including total phosphorus (TP), total nitrogen (TN), nitrate nitrogen (NO₃-N), ammonia nitrogen (NH₄⁺-N), and chemical oxygen demand (COD), were measured for each water sample. The water samples were determined in accordance with "Water and Wastewater Monitoring and Analysis Method (the Fourth Edition)".

3 Results and Analysis

After being treated by the wetland ecosystem, the TN concentration of aquaculture wastewater showed a gradually decreasing trend (Figure 3). The TN concentration of the left of wetland I outlet and the right of wetland I outlet is 3.69 - 115.71mg/L, 4.22 - 256.12mg/L, respectively, and the TN concentration at the outlet treated by wetland II, III, and IV is 1.46 - 47.32mg/L, 1.39 - 44.47mg/L, 0.17 - 32.79mg/L, respectively, the corresponding TN removal rate is 54%, 25%, 45%, respectively.



Figure 3. Changes in total nitrogen concentrations at wetland exports in mid-July ~ early December

After the aquaculture wastewater is treated by wetland I-IV, the monthly TN removal rate from July to December is 99%, 58%, 86%, 90%, 84%, 32%, , respectively, and the treatment effect in July is obviously better than others. The treatment effect was the worst in December.

After treatment by the wetland ecosystem, the concentration of NH_4^+ -N in aquaculture wastewater showed a gradual decrease (Figure 4). The aquaculture wastewater with the NH_4^+ -N concentration of 3-27.94 mg/L and 3.84-59.81mg/L in the left of wetland I outlet and the right of wetland I outlet is treated by the wetland II, III, and IV, the outlet NH_4^+ -N concentration is 1.11-29.96mg/L, 0.21-22.58mg/L, 0.03-16.36mg/L, respectively, the corresponding NH_4^+ -N removal rate is 20%, 36%, 51%, respectively.

After the aquaculture wastewater is treated by wetland I-IV, the monthly NH_4^+ -N removal rate from July to December is 99%, 99%, 91%, 91%, 49%, 40%, respectively, and the wetland ecosystem is in July and August. The removal rate of NH_4^+ -N in summer months is significantly higher than that in November and December.



Figure 4. Changes of ammonia nitrogen concentration in mid-July ~ early December of each wetland outlet

After treatment by the wetland ecosystem, the concentration of NO₃-N in aquaculture wastewater showed a gradual decrease (Figure 5). The NO₃-N concentration of the left I wetland outlet and the right I wetland outlet are 0.04 - 6.07mg/L, 0.12 - 4.07mg/L, the outlet NO₃-N concentration is 0.01 - 3.3mg/L, 0 - 2.05mg/L, 0 - 1.34mg/L respectively, after being treated by the wetland II, III, and IV, the corresponding NO₃-N removal rate is 45%, 42%, 55%, respectively.

After the aquaculture wastewater is absorbed by wetland I-IV, the monthly NO₃-N removal rate from July to December is 98%, 83%, 99%, 91%, 78%, 85%, respectively, and the NO₃-N removal rate in December relatively low.



Figure 5. Changes of nitrate concentration in mid-July \sim early December of each wetland outlet

After treatment by the wetland ecosystem, the TP concentration of aquaculture wastewater showed a gradually decreasing trend (Figure 6). After the aquaculture wastewater with the TP concentration of 0.4 - 2.92mg/L and 1.18 - 3.4mg/L at the left of wetland I outlet and right of wetland I outlet is treated by wetland II, III, and IV, the TP concentration at the outlet is respectively 0.06 - 1.86mg/L, 0.09 - 1.09mg/L, 0.02 - 0.82mg/L, respectively, the corresponding TP removal rate is 31%, 52%, 53%, respectively.

After the aquaculture wastewater is absorbed by wetland of grade I-IV, the monthly TP removal rate from July to December is 95%, 82%, 82%, 90%, 72%, 87%, respectively, and the TP removal rate in December relatively low.



Figure 6. Changes in total phosphorus concentrations in mid-July - early December of each wetland outlet

After treatment by the wetland ecosystem, the COD concentration of aquaculture wastewater showed a

gradually decreasing trend (Figure 7). The aquaculture wastewater with a COD concentration of 12.36 - 154.69mg/L and 16.54 - 121.67mg/L at the left of wetland I outlet and the right of wetland I outlet is treated by the wetlands II, III, and IV, the outlet COD concentrations are 11.14 - 47.16mg/L, 10.99 - 49.05mg/L, 9.14 - 46.95mg/L, respectively, the corresponding COD removal rate is 43%, 14%, 15%, respectively.

After the aquaculture wastewater is absorbed by wetlands I-IV, the monthly COD removal rates from July to December are 36%, 50%, 45%, 77%, 62%, and 14%, respectively. The wetland ecosystem is in 9, 10, and 14%. The removal efficiency of COD in wastewater in the autumn months such as November is better than that of other months, and the COD removal rate in December is the lowest.



Figure 7. Changes in COD concentrations at wetland exports in mid-July ~ early December

4 Discussion

Different processes have different ways and properties to treat sewage. Li et al. and others researched the use of biological filters, constructed wetlands, and stabilization ponds to treat rural dispersed sewage, and the removal rates of NH4+-N, TN, TP, and COD were 98%, 97%, 97%, and 88%, respectively [13]. The stable and lasting removal of pollutants relies on the joint action of wetland system plants and composite substrates, among which plants play an important role in constructed wetlands [14, 15]. Sediment adsorption and sedimentation are the main ways for plant combination wetland phosphorus removal, which accounts for 72.44% to 75.62% of the wetland phosphorus removal, but plant combination is beneficial to delay the sediment adsorption saturation time and increase the phosphorus absorption rate of plants [16]. Therefore, wetland plants play a major role in the removal of pollutants. In this study, the concentration of the five water quality indicators showed a gradually decreasing trend after the

aquaculture wastewater was treated by the wetland ecosystem. After studying the period from early July to early October, the main pollutants of aquaculture wastewater and farmland drainage were absorbed by wetlands I to IV, the total nitrogen concentration was between 0.17 - 1.68mg/L, and the ammonia nitrogen concentration was between 0.03 - 0.49mg/L, total phosphorus concentration is between 0.02 - 0.41mg/L, COD concentration is between 9.14 - 26.42mg/L. Compared with the environmental quality standards of surface water, the corresponding indicators basically meet the water quality standards of Class II - Class V. Zhao et al. [17] believe that annual harvesting of plants not only promotes the direct and indirect effects of plants on pollutants in constructed wetlands, but also increases the ability of the constructed wetland matrix to remove pollutants, thereby improving the effect of nitrogen and phosphorus removal in constructed wetlands. During the operation period, the concentration of the four water quality indicators decreased in the summer and early autumn after the four-level wetland treatment of the aquaculture wastewater. This is related to the ability of plants to absorb pollutants, and is also related to the harvesting of Myriophyllum and Barracuda. Plants are affected by the growth pattern, which further affects the absorption of pollutants by plants.

According to research in a year, the concentration of the five water quality indicators at the outlets of wetland I were higher, which may be affected by surface runoff after rainfall. The drainage channels on both sides of the wetland merged into the constructed wetland. It has a greater impact on the retention time of the water body, and the washing time of hog ring is generally 9 am. and 5pm. Individual farmers do not wash the hog ring during this time period, resulting in large fluctuations in the data of some water samples, causing some data distortion affects the overall data analysis and conclusions. Although the concentration of the five water quality indicators generally declined in a year, the export concentration of wetland IV was still relatively large. Compared with the environmental quality standards of surface water, all indicators did not belong to Grade V water quality. The reason for this is that the plants grown in the constructed wetland in the demonstration area are generally growing except for Barracuda grass and Canna, but Canna, Thalia dealbata, and Water Lily have withered, and the growth of Myriophyllum sp. with large biomass has basically stopped. In addition, because functional microbial communities help to effectively remove nitrogen from wetlands, surface runoff and wetlands have poor heat preservation effects under low temperature conditions in winter, and the number and activity of microorganisms are easily affected, which affects the ability of wetlands to absorb nitrogen [18-20]. Therefore, the results of this study reveal that the constructed wetland has certain limitations in absorbing aquaculture wastewater and farmland drainage. In some seasons when plants are growing well, the effect of absorption is obvious, but in seasons when plants are growing poorly, the effect is average. At the same time, the pollutant absorption effect of the constructed wetland is also affected by the dilution of aquaculture wastewater.

The elevation of the channel on the demonstration area is lower than that of the channel on the right. The farmland drainage in the demonstration area basically flows into the constructed wetland system from the channel on the left. The aquaculture wastewater in the first-class wetland is diluted, and the plants on the first-class wetland are growing well. However, during the rainy season of the wetland, there is channel water to dilute the aquaculture wastewater. In other periods, there is basically no water from the right channel to enter the wetland system. And because the left of wetland I only accepts wastewater from 350 pigs from substrate digestion pool 1, and the right of wetland I receives wastewater from 500 pigs from substrate digestion pool 2 - 4, the total amount of aquaculture wastewater received is greater. The absorption capacity of plants planted in wetlands has caused the plants in this level of wetlands to die. In the next stage, it is necessary to increase the connecting culvert between the right of wetland I and the wetland II to shorten the residence time of aquaculture wastewater in the right of wetland I. The environmental carrying capacity of plants also needs to be considered.

5 Conclusion

Using constructed wetlands to treat aquaculture wastewater, the average removal rate of total nitrogen, ammonia nitrogen, nitrate nitrogen, total phosphorus, and COD is 81%, 75%, 86%, 85%, 59%, respectively, and the effluent quality reaches the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant" (GB 18918-2002) effluent secondary standard. The whole process has the characteristics of environmental protection, cleanliness, safety, long-term effect, simple and convenient operation, economic effect, ecological environmental protection effect and broad promotion prospects.

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