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Research Article

Ecological Treatment and Resource Utilization of Wastewater from a Chicken Transfer Station

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Research was conducted at a chicken transfer station to assess ecological treatment and resource utilization. The study examined three aspects: wastewater ecological treatment, resource utilization maximization, and process optimization. Process design and operation monitoring were carried out to treat and reuse wastewater from a chicken feeder station over two periods. The first period was operated in 2014, adopting the mode of pretreatment plus a constructed wetland. Results show that the relevant indicators basically meet the regulatory requirements at that time. The second period carried out in 2017 improved upon the results obtained during the first period. On the basis of strengthening the pretreatment and constructed wetland functions, full recycling of tailwater and zero discharge of wastewater was achieved. The aquatic plant water celery used for wetland wastewater purification function also reached the standard of safe vegetable consumption, producing systematic ecological and economic benefits. The second phase of the project has high promotion and application value in the wastewater treatment of the chicken transfer station. This study demonstrates an improved approach to poultry production wastewater treatment by transforming wastewater into an agricultural product while achieving wastewater reuse and environmental pollution control.

1. Introduction

Wastewater from poultry breeding operations is one of the main sources of agricultural nonpoint source pollution in China [1]. Poultry breeding wastewater contains high concentrations of organic matter, ammonia nitrogen, suspended matter, and other pollutants. If discharged directly without treatment or used for agriculture, serious environmental pollution or human health events occur [2]. A very high proportion of poultry breeding in China occurs in the chicken industry. Wastewater generated by chicken industry operations cause environmental pollution and resource waste.

At present, the main methods of intensive poultry breeding wastewater treatment in China can be divided into three categories: physicochemical methods, biological methods, and ecological methods [2]. Physicochemical methods mainly include a flocculation method and an electrochemical method. Biological methods mainly include anaerobic and aerobic digestion, among which anaerobic digestion is the

most widely used technology for aquaculture wastewater [3]. Ecological methods include constructed wetlands and oxidation ponds [4]. Constructed wetlands for treating livestock and poultry breeding wastewater has developed rapidly in recent years. Studies on the removal of chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), total phosphorus (TP), and engineering applications of constructed wetlands have been published [5, 6]. Current research on constructed wetlands emphasize the removal of pollutants, but do not fully consider the utilization of water resources and nitrogen and phosphorus nutrients. In addition, most research focus on the treatment of chicken farm wastewater, chicken manure fermentation wastewater, chicken claw processing wastewater, and broiler slaughtering wastewater [7–10]. Studies on the ecological treatment and resource utilization of chicken transfer station wastewater are very limited.

Compared with the common livestock and poultry breeding wastewater, the characteristics of wastewater from chicken breeding transfer stations differ from common

livestock and poultry breeding wastewater. Chicken breeding transfer stations do not involve feed feeding. The structure of related pollutants is relatively simple creating favorable conditions for recycling. The nitrogen and phosphorus in the wastewater of the chicken transfer station are classified as pollutants from the perspective of environmental protection [11]; from a resource perspective, nitrogen and phosphorus are necessary nutrients for plant growth.

Resource utilization of nutrients is possible through the cultivation of organic agricultural products during wastewater treatment, transforming waste into an agricultural product in addition to water pollution control. Water celery is a perennial herb economic vegetable crop with dense roots. The biological filter bed formed by its roots in the water body has good adsorption, absorption, and retention effects on pollutants, so as to purify the water [12]. Water celery has a good purification effect on low concentration organic wastewater [13]. The water celery used in this study is from Anhui Shanquan Aquatic Vegetable Research Institute, which is a perennial plant. It has good pollution control characteristics even in winter. It can be harvested many times a year and can continuously and stably absorb wastewater nutrients which cause eutrophication. It is an ideal species of artificial wetland plants.

The research reported here was conducted at the Hesheng chicken breeding transfer station in Xianning. Research on the ecological treatment and resource utilization of wastewater and its optimization was carried out in a two-stage process design and operation. In the first stage of the project, the A^3/O+two-stage water celery constructed wetland technology mode was adopted. Considering the improvement of water quality and utilization rate of water resources, the physicochemical+A/O+two-stage water celery constructed wetland technology mode was adopted in the second stage of the project to transform the first-stage treatment process. By comparing the operation effect of the two phases of the project, the removal rate of wastewater pollutants in the chicken transfer station by different pretreatments and water celery constructed wetlands was explored. The project provides a theoretical reference for improving the livestock and poultry production wastewater treatment processes. This project also provided technical support for the chicken transfer station in the actual production process of wastewater treatment.

2. Research Materials and Methods

2.1. Overview of Research Station. The Hesheng Wenshi livestock and chicken breeding transfer station is located in Heshengqiao Town, Xian'an District, Xianning City. The research area is shown in Figure 1. The station covers an area of about 9700 m^2, including a 4000 m^2 sales platform, 700 m^2 of a first-stage constructed wetland, and 1400 m^2 of a second-stage constructed wetland. There are more than 40000 broilers transferred and sold in the chicken transfer station every day, with a daily wastewater output of 80-100 tons. The content of COD, NH$_3$-N, and TP in the wastewater is 307-712.63 mg/L, 13.60-46.11 mg/L, and 8.36-15.91 mg/L,

respectively. The wastewater mainly comes from the washing of the sales platform. The concentration of the three indicators is lower than that of the chicken farm wastewater, and the wastewater does not contain feed additives. After the three indicator concentrations are reduced by pretreatment, it can be used as a nutrient for the growth of aquatic vegetables. The engineering application of wastewater treatment at a chicken transfer station was carried out. Phase I of the project adopted the technical mode of "A^3/O pretreatment+two-stage constructed wetland depth treatment"; phase II of the project adopted the technical mode of "physicochemical +A/O pretreatment+two-stage constructed wetland depth treatment."

2.2. Engineering Technology Pattern Design

2.2.1. Technical Route of Phase I Project. In the initial stage of the experiment, the A^3/O pretreatment+two-stage constructed wetland depth treatment technology is adopted in the first phase of the project. The specific engineering processes applied are shown in Figure 2. Chicken manure generated in the chicken breeding transfer station was cleaned and collected to make organic fertilizer. Wastewater generated from table cleaning enters into the water collection pool. After the large volume of solid waste is removed through the coarse grille, it enters into the three-stage anaerobic tank for anaerobic nitrification and then into the aeration tank to increase the dissolved oxygen in the water. At the same time, the gas produced by the anaerobic fermentation of the water is released. The two-stage constructed wetland further absorbs the pollutants in the tailwater after pretreatment. Reclaimed water is pumped back to the platform after advanced treatment in the water celery constructed wetland.

The design capacity of the phase I wastewater treatment project is less than the actual wastewater output. Wastewater remains in the anaerobic tank for a short time, and the concentration of each index of the effluent pretreated by the A^3/O biological method is high. The tailwater is purified by the water celery constructed wetland. The concentration of ammonia nitrogen in the water is still high, resulting in a peculiar smell, which is not conducive to the long-term recycling of the transfer station. Based on the above difficulties, phase I of the project was transformed from the process technology route to focus on sewage treatment facilities and equipment. Rainwater was separated from wastewater in the plant area. Rainwater is discharged into the ecological pond for purification, reducing the pretreatment load. The high-efficiency physicochemical+A/O pretreatment technology replaced the original A^3/O pretreatment technology; ozone disinfection equipment was added to ensure the safety of reclaimed water.

2.2.2. Technical Route of Phase II Project. The phase II project adopted the technical mode of the physicochemical+A/O pretreatment+constructed wetland depth treatment. The technical process of the phase II project is shown in Figure 3. The cleaning wastewater from the transfer sales platform is removed by the coarse grille and solid-liquid

Figure 1: Overview of the research area.

separator and treated by anaerobic aerobic biochemistry, alum coagulation, and PAM flocculation. After ozone disinfection, it is discharged to the two-stage constructed wetland water celery for further absorption and repair. The water quality of the effluent is tested to meet the needs of production water in the chicken transfer station. The treated water is returned to the platform for reuse, completing the chain of water treatment and water resource recycling. Continuous recycling of tailwaters results in zero liquid discharge of pollutants.

2.3. Water Quality Monitoring and Data Processing. The three indexes of COD, NH$_3$-N, and TP in the two phases of the project are monitored regularly and irregularly. The dichromate method (HJ 828-2017) is used for COD determination, Nessler's reagent spectrophotometry (HJ 535-2009) is used for NH$_3$-N determination, and the ammonium molybdate spectrophotometric method (GB 11893-89) is used for TP determination. Original 2018 software is used for data processing.

3. Results and Discussion

3.1. Comparative Analysis of Pretreatment Effect. Pretreatment is a key process to remove pollutants from wastewater. Results of pretreatment studies are shown in Figure 4.
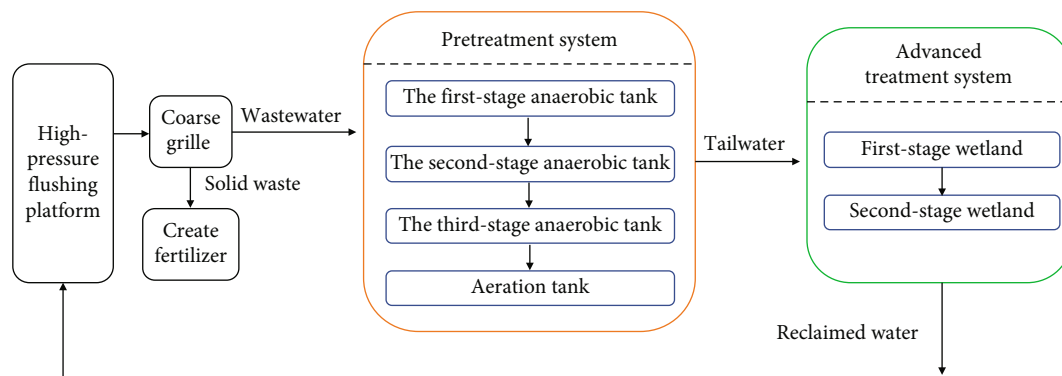
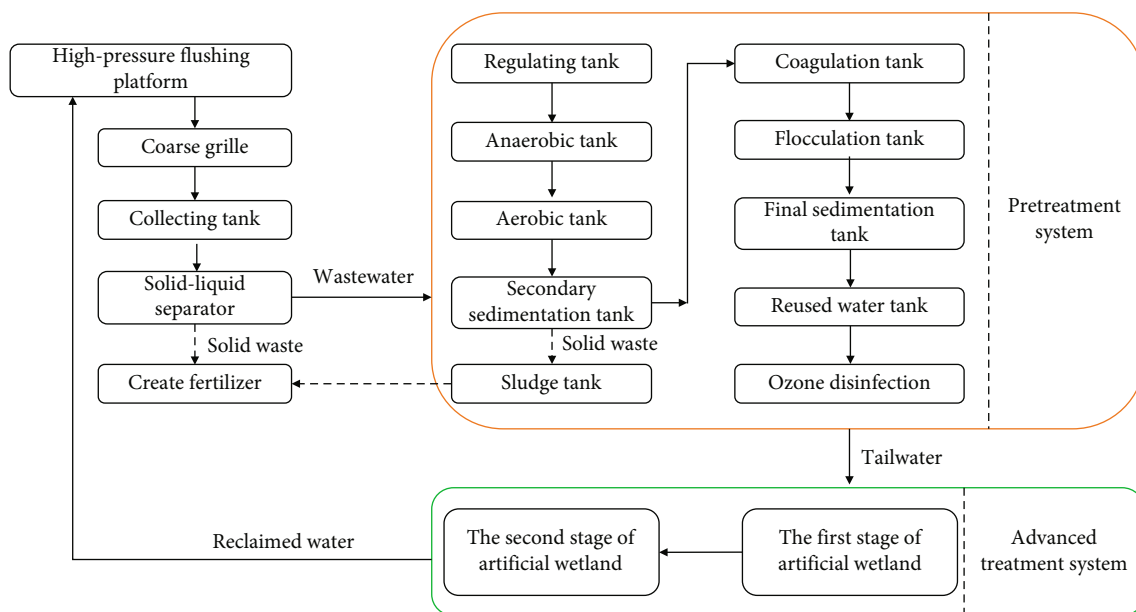FIGURE 2: Technical flow chart of the phase I project.

FIGURE 3: Technical flow chart of the phase II project.

Wastewater from the chicken transfer station has good biodegradability. Biological methods were used in both pretreatment processes, which is suitable for the treatment of livestock and poultry wastewater with its high removal efficiency and low treatment cost [14]. The A^3/O process was adopted for the pretreatment of the phase I project; three-stage anaerobic fermentation+aeration and nitrifying bacteria and photosynthetic bacteria are added. In the process of multistage anaerobic fermentation, particles are hydrolyzed, which can significantly reduce the content of solid matter and COD in water [15]. The effluent concentrations of COD, NH_3-N, and TP in the first project pretreatment were 118-178 mg/L, 18.8-24.33 mg/L, and 2.56-4.35 mg/L, respectively, with average removal rates of 67.49%, 29.96%, and 68.91%, respectively. From March to July, the COD removal rate increased with the increase of influent concentration, mainly due to the rise of temperature, high biological activity, and good decomposition effect of pollutants. Ammonium ions (NH_4^+) and free ammonia (NH_3) produced by biodegradation of nitrogen-containing substances are both directly or

indirectly inhibited in the anaerobic digestion system [16], resulting in low removal rate of NH_3-N. The effluent concentration of the first project pretreatment is greatly affected by the influent concentration, and the pollutant removal rate fluctuates greatly. The low temperature leads to the inhibition of enzyme activity in the bacterial body, and the metabolism speed is slow [17]. The pollutant removal effect of the two project's pretreatment process in winter is slightly lower than that of other seasons.

The pretreatment of the second phase project adopts the combination process of alum coagulation, PAM flocculation physicochemical method, and A/O biological method. A solid-liquid separator is added in the second phase project, which can effectively reduce the pressure of subsequent treatment [18]. The A/O biological method is the main method of urban sewage treatment in China. Through the anaerobic aerobic process, microorganisms decompose and transform macromolecular pollutants which are removed using alum coagulation and PAM flocculation, The effluent concentration of COD, NH_3-N, and TP in the second phase project
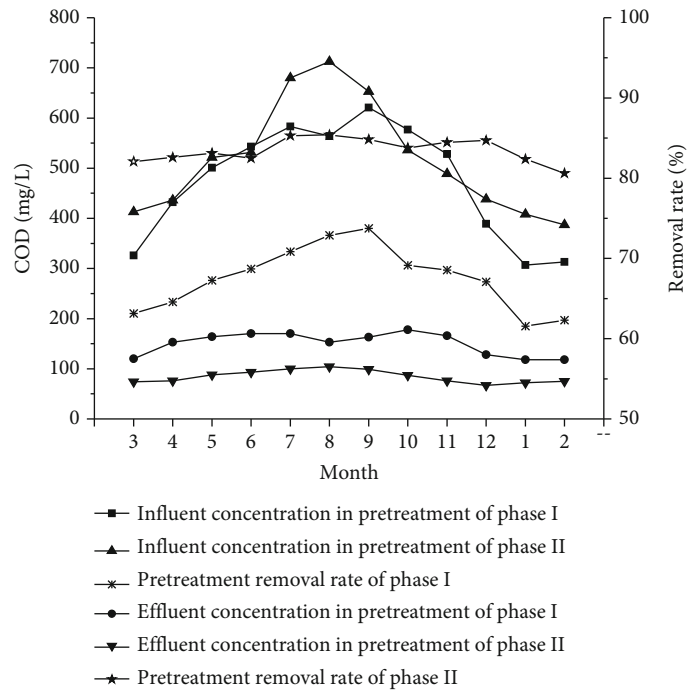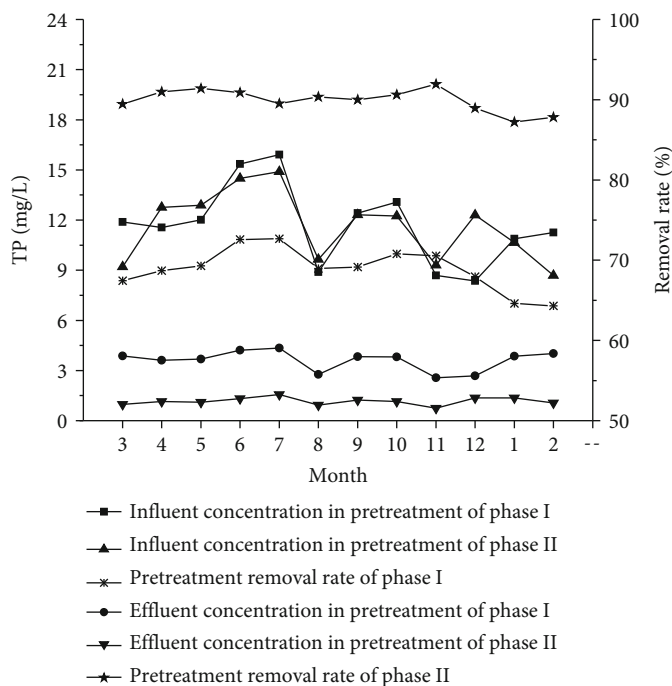
(a) The influent/effluent concentration and removal rate of COD
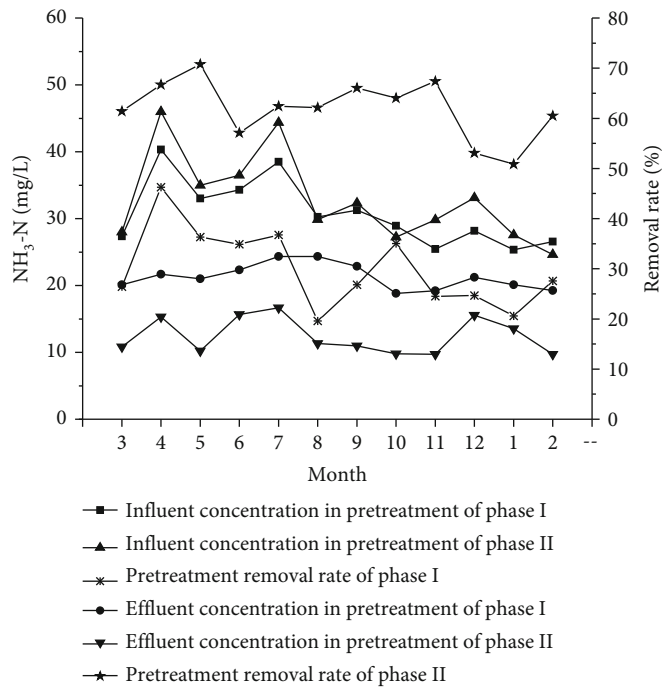
(b) The influent/effluent concentration and removal rate of NH$_3$-N

Figure 4: Continued.

(c) The influent/effluent concentration and removal rate of TP

FIGURE 4: Different pretreatment inlet and outlet water concentrations and removal rates.

was 67.01-120 mg/L, 9.73-16.67 mg/L, and 0.75-1.56 mg/L, respectively; the COD concentration in July-September is slightly higher than the secondary discharge standard of "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant," and the NH_3-N and TP concentration reached the second level standard; the average removal rates of the three indexes are 83.14%, 61.87%, and 89.93%, respectively. Compared with the first-stage pretreatment process, the second-stage pretreatment process has a more stable removal rate and effluent concentration.

3.2. Analysis on Treatment Effect of Constructed Wetland. In recent years, constructed wetlands have been widely used because of their advantages of high treatment efficiency, low investment cost, and good landscape. Constructed wetlands can remove nitrogen and phosphorus pollutants through plant root absorption and microbial transformation [19–21]. The absorption and transformation of the pollutants in the tailwater by the constructed wetland further reduces the concentration of the pollutants in the water. The aquatic plant water celery used in this study can absorb the pollutants for its own growth. It has been identified by the food safety appraisal agency and reached the qualified food standard. The influent concentration and removal rate of the two phases of constructed wetland are shown in Figure 5.

The removal rate of pollutants in constructed wetlands changed significantly with the seasons, and the removal rate increases from March to June. During the high temperature period from July to August, with the increase of water consumption, the wastewater stays in the constructed wetland for a short time, and the constructed wetland does not adequately treat the pollutants, resulting in a downward trend

of removal rate, but the total amount of pollutants removed by the constructed wetland is large. From September to October, the removal rate increased with the decrease of temperature but decreased with the slow growth of plants in winter. Although the removal rate is low in winter, the total amount of wastewater is less than that in summer, and the pollutant removal per unit area is higher than that in summer.

The average removal rates of COD, NH_3-N, and TP were 39.83%, 42.03%, 27.54%, 70.95%, 32.16%, and 38.35%, respectively. The difference of influent concentration between the two constructed wetlands is large, but the removal effect of COD and TP by the constructed wetlands is not significant, which shows that the water celery has a wide range of adaptability to the purification effect of water pollutants. The purification effect of water celery on ammonia nitrogen fluctuates obviously, from high concentration to general condition; even at a low concentration, it can play a better role.

The apoptosis and decay of plants in winter lead to the reduction of the purification effect of the constructed wetland and even secondary pollution of water bodies. The selection of plants in the constructed wetland should not only consider the purification effect, economic value, and landscape performance of plants but also consider the overwintering performance of plants. The overwintering performance of plants greatly determines the sustainable development of the constructed wetland.

Many kinds of plants have been used for water purification research, mainly *Canna* and *Cyperus alternifolius L.* [22]. Plants have a good purification effect and have a certain economic value in the appropriate season, but near winter,
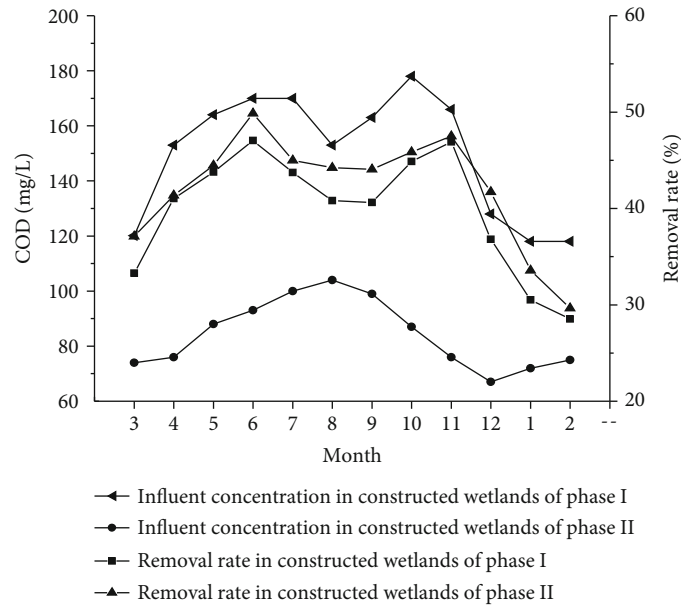
(a) The influent concentration and removal rate of COD
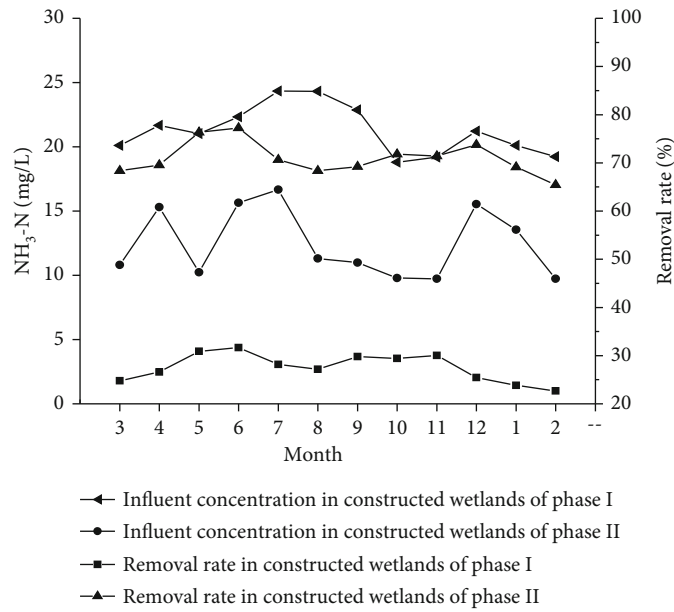
(b) The influent concentration and removal rate of NH₃-N

Figure 5: Continued.

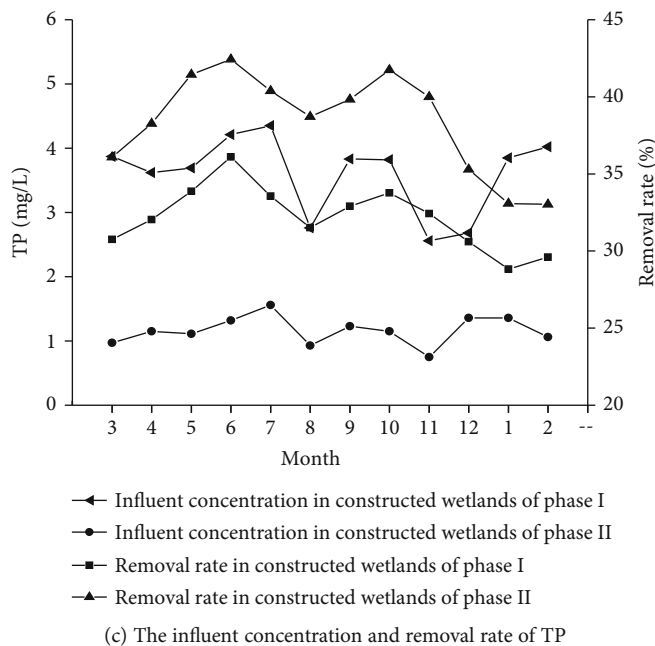(c) The influent concentration and removal rate of TP

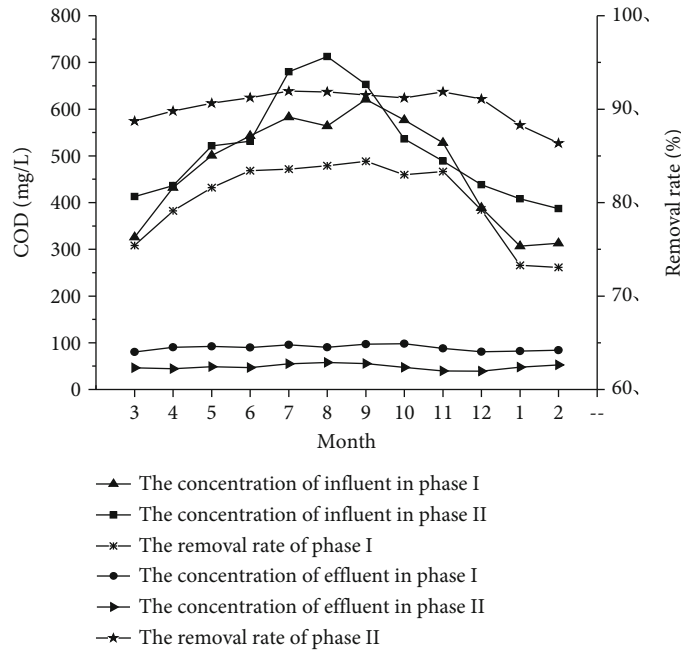Figure 5: Influent concentration and removal rate of constructed wetland.

they are basically in a withered state, so the purification effect on water quality is greatly reduced. The four-season water celery used in this study is a cold-loving and temperature-tolerant plant, which is evergreen all year round and evergreen in winter. It can also survive at -5°C and has a strong overwintering ability. At 0°C, there are new white roots growing in the creeping roots of the water body. Although the stem grows slowly in winter, the roots are still full of vitality and play the role of pollution control. In winter, there are dense root-like sponge blankets, with a longitudinal height of more than 0.5 m, and a single root length of 0.8 m. Plant roots release oxygen to the rhizosphere environment and provide a large attachment area for microorganisms [23]. Roots also provide a good living environment for microorganisms, enabling the constructed wetland to purify pollutants in winter. Water celery does not die in winter, can grow continuously, and does not need to be replanted, which reduces the operation and maintenance cost of the constructed wetland. At the same time, with the temperature rising, the root system began to grow vigorously, thus supporting the stem and leaf to turn green rapidly [12].

3.3. Comparative Analysis of Operation Effect of Two Phases of the Project. The influent concentration, effluent (reclaimed water) concentration, and corresponding removal rate of COD, NH_3-N, and TP in the two projects are shown in Figure 6. It is stipulated in the standard of "The Reuse of Urban Recycling Water-Water Quality Standard for Urban Miscellaneous Water Consumption" that the concentration of NH_3-N shall not exceed 10 mg/L for cleaning and vehicle washing and COD and TP shall not be required. In the first phase of the project, the influent concentration of COD is 307-621 mg/L, with an average value of 473.67 mg/L, the average concentration of reclaimed water is 89.08 mg/L, with an average removal rate of 80.28%. The concentration of

reclaimed water reaches the secondary standard of pollutant discharge of pollutants for municipal wastewater treatment plants. The influent concentration of NH_3-N was 25.33-40.32 mg/L, with an average value of 30.78 mg/L, and the average concentration of reclaimed water is 15.39 mg/L, with an average removal rate of 49.13%. The concentration of reclaimed water is higher than "The Reuse of Urban Recycling Water-Water Quality Standard for Urban Miscellaneous Water Consumption" and at a higher level, resulting in water body odor during recycling. The TP inlet concentration is 8.36-15.91 mg/L, with an average value of 11.69 mg/L, and the average value of reclaimed water concentration is 2.44 mg/L, and the TP overall reaches the secondary standard, with an average removal rate of 78.87%. The first phase of the project removed COD, NH_3-N, and TP, but the removal rate is unstable and volatile. Removal rates were significantly affected by the influent concentration, and the low temperature resistance is weak. In winter, the removal rate of pollutants is greatly reduced. The first phase of the project met the requirements of wastewater treatment that year but not the requirements for reclaimed water reuse.

The concentrations of COD, NH_3-N, and TP in the influent water of the second phase project were 387-712.63 mg/L, 24.63-46.01 mg/L, and 8.69-14.89 mg/L, respectively; the average values of the concentration of the reuse water are 48.47 mg/L, 3.59 mg/L, and 0.72 mg/L, respectively, and the average removal rates of the three indexes are 90.37%, 88.91%, and 93.76%, respectively. The concentration of COD and TP in the reuse water reached the level-B standard, the concentration of NH_3-N reached the level-A standard, and it is far lower than the water quality standard of urban miscellaneous water. The quality and removal rate of reuse water in phase II greatly improved compared with the phase I project, and the removal rate of pollutants is more stable than in phase I. After physicochemical+A/O pretreatment
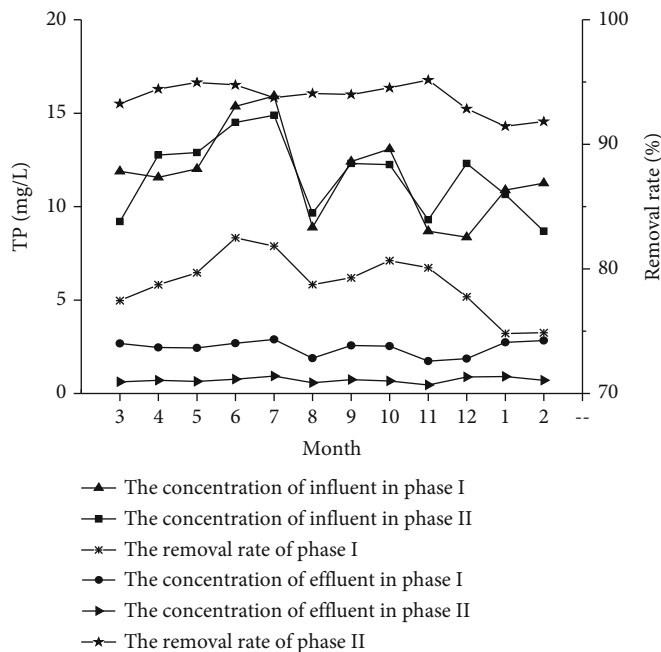
(a) The influent/effluent concentration and removal rate of COD
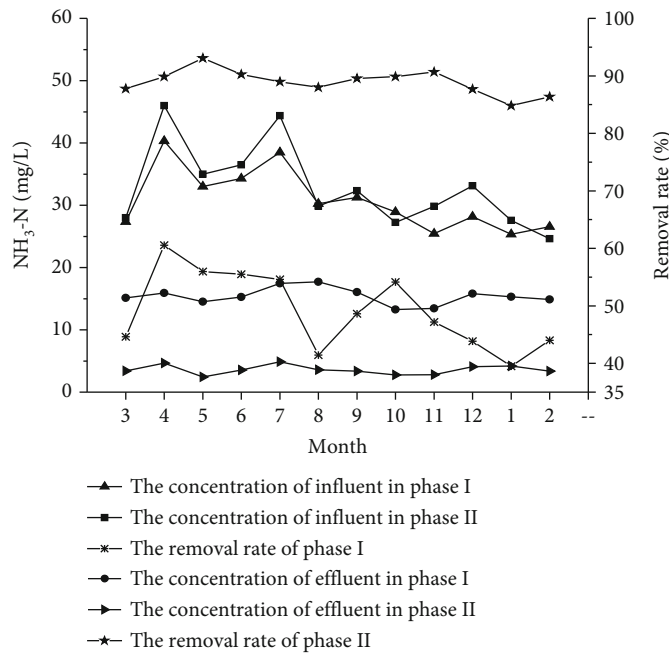
(b) The influent/effluent concentration and removal rate of NH$_3$-N

FIGURE 6: Continued.

(c) The influent/effluent concentration and removal rate of TP

FIGURE 6: In and out water concentration and removal rate in two phases.

and constructed wetland advanced treatment, reclaimed water had no peculiar smell, and water quality met the needs of the production water of the station. Reclaimed water recycling achieved zero discharge of pollutants and recycling of water resources.

3.4. Project Benefit Analysis. The second phase of the project integrated wastewater treatment and resource utilization. Wastewater concentrations were greatly reduced after pretreatment. The tailwater advanced treatment and water fertilizer integrated resource utilization with the four-season water celery constructed wetland. The purified and restored tailwater resources met the water quality requirements of the platform, realized the recycling of tailwater resources, and accompanied high-quality organic vegetables, while achieving zero pollutant discharge of wastewater. The ideal goal of water treatment is in line with the current national strategic needs of environmental protection and resource utilization. The average daily output of wastewater in the chicken transfer station is about 100 tons. The annual water saving is about 32000 tons after treatment of the existing operation project and the deduction of plant absorption and natural evaporation of the artificial wetland. According to the calculation of 2.6 yuan per ton of the operation water in Xian'an District, Xianning City, the annual water cost can save about 83000 yuan; the annual output of water celery per mu $(667 \, m^2)$ is 13000-150000 kg, and the water surface area of the first- and second-stage artificial wetlands is $2100 \, m^2$. The effective planting area of watercress is about 2 mu, the annual biomass of watercress can reach 26000-30000 kg, and the edible watercress vegetables can reach 10000 kg. According to the annual average

wholesale price of watercress of 3 yuan/kg, and after deducting the planting, maintenance, and labor costs of watercress, the annual pure economic benefits of watercress vegetables can be about 10000 yuan. Through the reuse of the tailwater resources by the constructed wetland, the direct economic benefit can be about 93000 yuan per year.

The current operation of the project will make use of the tailwater resources nearby to avoid secondary pollution of the environment. Control of pollutant discharges from the source greatly reduced the pressure of local river and lake governance and minimizes the cost of water ecosystem restoration. Recycling of water resources is conducive to protecting the total amount of water resources in China. The utilization rate of water resources was improved, effectively reducing the water consumption per 10000 yuan of GDP, saving energy and reducing consumption. Utilizing water to grow an agricultural product saves land resources needed for planting vegetables of the same economic value but also reduces the fertilizer application amount of the same vegetable output and reduces the agricultural nonpoint source pollution. The functional plant used in the constructed wetland, water celery, is a four-season biological species, which brings a good landscape effect while volatilizing and controlling pollution, and meets the requirements of national ecological civilization construction. It can be used as an ecofriendly material for the ecological restoration of black-odorous watercourses in China. This mode meets the needs of resource-saving and environment-friendly social development, greatly improves the technology mode of ecological treatment and resource-based utilization of wastewater from a chicken breeding transfer station in China, and explores a

new way for the treatment and resource-based utilization of aquaculture wastewater in China.

4. Conclusions

Based on the technical route of pretreatment+constructed wetland depth treatment of wastewater, the ecological treatment and resource utilization mode and optimization research of wastewater in the Hesheng chicken transfer station in Xianning were carried out. Through the analysis of the removal effect of main structures of the two wastewater treatment projects on wastewater pollutants, the following conclusions were obtained:

(i) The project of the physicochemical+A/O+water celery constructed wetland has achieved the organic collection of wastewater treatment and resource utilization, which can realize the zero discharge of pollutants in the chicken transfer station and the recycling of tailwater resources

(ii) The physicochemical+A/O pretreatment is better than the A^3/O pretreatment. The physicochemical +A/O pretreatment process is ideal for the average removal rate of COD, NH_3-N, and TP, which is suitable for the wastewater treatment of a chicken transfer station

(iii) Four-season water celery has a wide range of adaptability to water pollutants, strong environmental adaptability, and can survive the winter. The purification effect of pollutants is significant, and it can produce significant economic, environmental, and landscape benefits. It is an ideal functional plant species for wastewater treatment of a chicken transfer station

(iv) The wastewater treatment mode of a physicochemical+A/O+water celery constructed wetland is an optimized treatment mode according to the characteristics of the wastewater in the chicken transfer station. The operation results show that its comprehensive benefits are significant, and it has a high promotion and application value in the wastewater treatment of the chicken transfer station

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgments

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