Study on Water Purification Efficiency and Influencing Factors of a Constructed Wetland in Jiaxing

Shengsheng Han¹², Lijun Wu¹², Junjie Li²⁻³*, Jianfeng Li¹², Qiang Zhou²³, Fenfei Chen²³, Tianfei Li¹², Jianhang Li²³

¹Huadong Eco-Environmental Engineering Research Institute of Zhejiang Province, 311122Hangzhou, Zhejiang, China
²Power China Huadong Engineering Corporation Limited, 311122Hangzhou, Zhejiang, China
³Yangtze River Delta (Jiaxing) Ecological Development Co., Ltd., 314000Jiaxing, Zhejiang, China

Abstract. Constructed wetland plays an important role in the removal of micro-polluted water pollutants in urban water sources. However, the water purification capacity and influencing factors of the constructed wetlands still need to be explored. This study monitored the turbidity, ammonia nitrogen (NH₃-N), dissolved oxygen (DO), and chemical oxygen demand (COD) at the water inlet and outlet of Shijiuyang Wetland in Jiaxing City from 2019 to 2021. The results showed that the turbidity and the wetland turbidity removal rate stayed high. The DO couldn’t meet national standard III for surface water during the high temperature time in summer, and NH₃-N and COD are stable within national standard III. The partial regression analysis shows that the addition of chemicals is the most important factor affecting the turbidity. Temperature had the most important affect to NH₃-N and DO, the higher the temperature, the lower the NH₃-N value and the DO. The flow rate is the most important factor affecting the COD, the higher the flow rate, the lower the COD. Moreover, this paper proposes operation and maintenance improvement measures for the problem of excessive turbidity and DO in Shijiuyang Wetland. The research results are conducive to improving the understanding of water security in the Yangtze River Delta region.

1 Introduction

Constructed wetlands are based on the principle of material migration and transformation in natural wetland ecosystems, which have the advantages of high efficiency, low consumption, and strong resistance to hydraulic shock in sewage treatment and ecological restoration technologies. "World Water Resources Development Report 2018" of the United Nations emphasized that the nature-based solutions (NBS) should be used as an important means to improve water quality. As a typical NBS, the number of constructed wetlands in operation on a global scale continues to increase rapidly, and has become an important water purification technology and an important type of wetland ecosystem[1].

The plain water network areas are widely distributed in the middle and lower reaches of the Yangtze River and the Pearl River. There are a large number of bacteria and viruses in the river, which raised the purification cost of the water plant. By configuring artificial wetlands at the front of the water plant, the purification pressure of the water plant can be effectively relieved. It has received more and more attention in practice[2, 3]. The types of constructed wetlands used for water source water treatment mainly include surface flow, horizontal subsurface flow, vertical subsurface flow and composite types. Surface flow, horizontal subsurface flow and composite constructed wetlands are widely used in China. Zhuo[4] reported the treatment effect of surface flow artificial wetland on the source water of Python River in Longgang Town, Yancheng City. Plants, where has the annual average temperature of 14°C. The results show that the wetland has the average removal rates of 40.6%, 19.3%, 23.1%, 3.6% and 50.8% for total phosphorus (TP), total nitrogen (TN), nitrate nitrogen (NH₃-H), COD (COD) and turbidity Effect. Wang[5] built four groups of composite constructed wetlands to treat the Fuzhou River in Dalian where has the annual average temperature was 8.6-10.5°C. The filters of the wetlands were gravel and coarse sand, reeds with calamus planted. And COD have good removal effect, the removal rate of TN in the four groups of wetlands is 13.4%-17.0%, the results show the removal rate of TP is 16.4%-29.3%, and the removal rate of COD is 32.8%-45.7%. Although there are many studies on the treatment of slightly polluted source water in constructed wetlands, a unified standard has not yet been formed, which brings difficulties to the popularization and application of this technology. Therefore, it is urgent to evaluate the water quality maintenance and purification improvement to drinking water sources of constructed wetland[6].

There are many factors that affect water purification by constructed wetlands, mainly including water temperature, wetland oxygen environment, and wetland hydraulic performance[7]. This study analyse the law of water quality change based on the meteorological observation data, the water quality monitoring data of
turbidity, NH3-N, DO, and COD at the water inlet and outlet of Shijiuyang Wetland from 2019 to 2021. Then, this study used partial regression method to analyse the main influencing factors of the purification of Shijiuyang Wetland based on the data of precipitation, temperature flow data and water purification agent. Further, this study proposed improvement measures for the problems of high DO and turbidity. This paper provides a reference for the wetland operation and maintenance management.

2 Materials and methods

2.1 Study Area

The studied wetland (total area of 2.59 km²) was constructed for the pretreatment of river water. And the purified water is used as a source of drinking water treatment plants in Jiaxing city located in the Yangtze River Delta. It is a typical constructed wetland plant-bed/ditch purification system. The system is mainly composed of four different treatment processes: the pretreatment area, pumpstation lifting, root-channel ecological purification area, and deep purification area (Fig. 1). The pretreatment area (A) is a grit chamber into which the sediment in the raw water settled. Water is pumped to approximately three meters high in the pump station lifting (B), and then the DO in the water is increased by falling aeration. The rootchannel ecological purification area (C) is a plant-bed/ditch system, and the pollutants in the river water are physically intercepted and adsorbed, and chemically and microbiologically degraded under the action of the water-soil-plant-root microorganism coupling system. The total area is approximately 0.16 km², and the main aquatic plant species are reed (57.7%), Zizania latifolia (13.0%) and Scirpus tabernaemontani (5.3%). The deep purification area (D) is an artificial lake in which the flow velocity is slow and the raw water is subject to particle deposition and quality purification. The hydraulic retention times (HRTs) are 9.7, 28.6 and 56.4 h in the area A, C and D, respectively. Samples were collected from the inlet and outlet of each treatment area three times in one day and mixed for the following experiments[8].

Fig. 1. Map of the constructed wetland. A: pretreatment area, B: pump station lifting, C: root-channels purifying area, and D: deep purifying area.

The study area has a subtropical monsoon with abundant sunshine and rainfall in different seasons. The annual average temperature is 15.9°C with the extreme maximum temperature of 40.5°C, and the extreme minimum temperature of -12.4°C. The annual average sunshine is 2109 hours and the relative humidity is 82%. The average wind speed is 2.6-3.4 m/s with little difference among different months and the wind direction is mainly east and Northwest throughout the year.

The annual average rainfall is 1230.7 mm with the maximum of 1768 mm (1999) and the minimum of 723.1 mm (1978). The maximum daily rainfall is 229.5 mm (June 12, 1963), and the maximum three-day rainstorm is 313.8 mm (September 4, 1962). Most of the precipitation is concentrated from April to September, and the distribution of the annual precipitation presents the double-peak characteristics of the plum rain type and the typhoon type. Among them, the plum rain type occurs from May to June and the typhoon type mainly occurs from July to September, which often cause serious urban waterlogging [9].

2.2 Study methods

2.2.1 Data collection

Water samples were collected at the inlet and outlet of Shijiuyang Wetland at the beginning of each month from January 2019 to December 2021. The water temperature (°C) was measured on site, and the water turbidity (NTU), NH3-N (mg/L), DO (mg/L) and COD (mg/L) were measured in the laboratory. Turbidity reflects the status of suspended matter in the water body, mainly inorganic matter, COD mainly reflects the organic matter in the water body. NH3-N is the nutrient in the water body, which is also the main oxygen-consuming pollutant in the water body. DO is an indicator of oxidation status in water indicating the ecological health of the water body.
2.2.2 Statistical analysis

1) Difference method

Using difference method to analyze pollutant removal rate.

\[ s = \frac{d_{m} - d_{out}}{d_{in}} \]  

Where \( s \) is the removal rate of pollutants, \( d_{out} \) is the water quality of wetland effluent, and \( d_{in} \) is the water quality of wetland inlet.

2) Partial correlation analysis

Adopting partial correlation analysis to analyze the influence factors of water quality. The calculation formula of the partial correlation coefficient between the variables \( x \) and \( y \), with control variable being \( z \), is as follows:

\[ r_{x,y,z} = \frac{r_{x,y} - r_{x,z}r_{y,z}}{\sqrt{1 - r_{x,z}^2} \sqrt{1 - r_{y,z}^2}} \]  

Where \( r_{x,y,z} \) is the partial correlation coefficient between the variables \( x \) and \( y \) with the \( z \) being control; \( r_{x,y} \) is the correlation coefficient between the variables \( x \) and \( y \); \( r_{x,z} \) is the correlation coefficient between the variables \( x \) and \( z \); \( r_{y,z} \) is the correlation coefficient between the variables \( y \) and \( z \).

The calculation formula of the partial correlation coefficient between the variables \( x \) and \( y \), with control variables being \( Z_1 \) and \( Z_2 \), is as follows:

\[ r_{x,y,z_1,z_2} = \frac{r_{x,y,z_2} - r_{x,z_2,z_1}r_{y,z_1,z_2}}{\sqrt{1 - r_{x,z_2,z_1}^2} \sqrt{1 - r_{y,z_1,z_2}^2}} \]  

Where \( r_{x,y,z_1,z_2} \) is the partial correlation coefficient between the variables \( x \) and \( y \) with the control variable being \( Z_1 \) and \( Z_2 \); \( r_{x,y,z_1} \) is the correlation coefficient between the variables \( x \) and \( y \) with the control variable being \( Z_1 \); \( r_{x,z_1,z_2} \) is the correlation coefficient between the variables \( x \) and \( Z_2 \) with the control variable being \( Z_1 \); \( r_{y,z_1,z_2} \) is the correlation coefficient between the variables \( y \) and \( Z_2 \) with the control variable being \( Z_1 \).

When there are 3 or more control variables, calculate the partial correlation coefficient between variables \( x \) and \( y \) by analogy with the above formula.

3 Research results

3.1 Spatial-temporal variation law of water quality in wetlands

The water quality monitoring results of Shijiu Yang Wetland from 2019 to 2021 are fluctuated with the season changes (Fig. 2). The turbidity of the wetland inlet is between 40-120 with the turbidity of wetland effluent between 10-60. The turbidity fluctuates greatly in different time. NH3-N is between 0.2-0.8 at the wetland inlet, and fluctuates with double peaks as seasonal changes, which are in June and December every year. The NH3-N of wetland effluent is between 0.1-0.6, which were stable within the national standard III for surface water. DO of wetland inlet ranged from 3 to 11, with low value from July to August and high value from November to December. DO fluctuates seasonally, the values was lower than the national standard III for the high temperature in summer. The COD is basically better than that of national standard III, and the fluctuation has no obvious rules. At the same time, the COD has no obvious removal law between the wetland inlet and wetland effluent.

Fig. 2. a) turbidity, b) NH3-N, c) DO, d) COD of wetland inlet and wetland effluent from 2019 to 2021

The wetland shows the apparently improve due to the pollutant removal of Shijiu Yang Wetland from 2019 to 2021 (Fig. 3). The turbidity removal rate is between 0.4-0.8, the NH3-N removal rate is between 0.4-0.7, the DO improvement rate is between 0.1-0.8, and the removal rate of COD is unstable. The wetland has a certain effect on the improvement of all 4 water quality indicators, but the increase in COD is not obvious, indicating that the Shijiu Yang Wetland's ability to remove organic matter in water is limited in the case of Class III water.

Fig. 3. Pollution removal rate of wetlands for a) turbidity, b) NH3-N, c) DO, and d) COD from 2019 to 2021
3.2 Analysis of Influencing Factors of Water Quality Purification of Wetland

The partial correlation analysis was used to analyze the influencing factors of wetlands. The higher the partial regression coefficient, the greater the impact of this factor on water quality. The results (Table 1) showed the water purification agent had a partial correlation of -0.524 for the turbidity, which showed a significant negative correlation, indicating the water purification agent was the most important factor affecting turbidity. The correlation coefficients of flow, precipitation with turbidity is -0.075, -0.050, showing flow and precipitation also having certain influences to turbidity; Temperature is the most important factor affecting NH3-N and DO, with the partial correlation coefficients of -0.3992, -0.833 respectively. The flow rate is the most important factor affecting the COD with the partial correlation coefficients of -0.416, the higher the flow rate, the lower the COD.

Table 1 Partial correlation coefficient of influencing factors to wetland water quality

<table>
<thead>
<tr>
<th>Influencing Factors</th>
<th>partial correlation coefficient</th>
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<tbody>
<tr>
<td></td>
<td>turbidity</td>
</tr>
<tr>
<td>water purification agent</td>
<td>-0.524</td>
</tr>
<tr>
<td>Flow</td>
<td>-0.075</td>
</tr>
<tr>
<td>Water temperature</td>
<td>-0.250</td>
</tr>
<tr>
<td>Precipitation</td>
<td>0.050</td>
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</tbody>
</table>

Note: Pearson, * p<0.1, ** p<0.01, *** p<0.001

3.3 Operation and Maintenance Management

DO is the main indicator of Shijiuyang wetland exceeding the standard. The insufficient of DO in the wetland limits the transformation and removal of NH3-N and organic pollutants. The main influencing factor of DO is water temperature. Aiming at the improvement of DO, the current common wetland oxygenation methods mainly include: 1) Increase the oxygen of the wetland by naturally changing the wetland operation mode, such as tidal flow operation, falling water reoxygenation and effluent reflux mode, etc. This method is energy saving and easy to use; 2) Artificial mechanical oxygenation. Oxygenation is increased by laying porous ventilation pipes, blowing aeration, water pre-aeration and spraying water, etc. The oxygenation method consumes a lot of energy. However, the oxygenation effect is more significant. The commonly strategy to use oxygenation is intermittent or continuous oxygenation. 3) Use biological measures such as algae, plants and earthworms to increase oxygen in wetlands.

The turbidity of wetland water is relatively high. Adding alum and other chemicals is the most effective way to reduce the turbidity of water in wetlands. At the same time, both flow and rainfall will have a certain impact on turbidity. The improvement strategy is to strengthen precision dosing. Furthermore, the environmental protection dredging of sediment and methods such as restoration and reconstruction of submerged plants should be carried out in suitable areas to reduce the resuspension of surface sediment, which also reduce nitrogen and phosphorus in the water body.

4 Conclusions

Constructed wetland is a NBS ecological restoration solution, which plays an important role in the removal of micro-polluted water pollutants in urban water sources. However, the water purification capacity and influencing factors of the constructed wetlands still need to be explored. This study monitored the turbidity, NH3-N, DO, and COD at the water inlet and outlet of Shijiuang Wetland in Jiaxing City from 2019 to 2021. The results showed that the turbidity and the wetland turbidity removal rate stayed high. The DO couldn’t meet national standard III for surface water during the high temperature time in summer, and the other indicators are stable within national standard III. The partial regression analysis shows that the addition of chemicals is the most important factor affecting the turbidity. Flow and rainfall will also have small impact on the turbidity. Temperature is the most important factor affecting NH3-N and DO. The higher the temperature, the lower the NH3-N value and the DO. The flow rate is the most important factor affecting the COD, the higher the flow rate, the lower the COD. Moreover, this paper proposes operation and maintenance improvement measures for the problem of excessive turbidity and DO in Shijiuang Wetland. The research results are conducive to improving the understanding of water security in the Yangtze River Delta region.

References

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