Water Purification Capacity of the Constructed Wetland to Micro-Pollution Water Source—a Case Study in Jiaxing

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Abstract. Constructed wetlands are commonly applied to improve and maintain water quality of micro-polluted water sources as a feasible and cost-effective technique. However, the purification capacity of the constructed wetland for micro-polluted water was lacking of understanding. This study collected the turbidity, ammonia nitrogen (NH3-N), nitrite nitrogen (NO2-N), total nitrogen (TN), Fe, Mn, total phosphorus (TP), permanganate index (CODMn), dissolved oxygen (DO), and chemical oxygen demand (COD) at the water inlet and outlet of Guanjinggang Wetland in Jiaxing City from 2019 to 2021. The comparisons among the pollution indicators showed that the wetland reduced the pollutants and slowed down the fluctuations of pollution indicators, except for Do, TN and COD. The removal rates are different due to the causes of pollution indicators. The partial regression analysis to different influencing factors showed the water temperature were the main influencing factor to the turbidity, NH3-N, Fe with the partial correlation of 0.447, -0.631, 0.510, respectively. Precipitation showed the highest influence on Mn with the partial correlation of 0.323. Flow showed highest influence on COD with the partial correlation of -0.339. Both flow and water temperature were the highest influence factors on No2-N, CODMn, Do and TN. However, water purification agent was not the main influence factor on any pollution indicators. The research results are conducive to improving the understanding of water security in the Yangtze River Delta region.

1 Introduction

The freshwater resources are threatened by pollution or other water environmental issues with the development of social and economic growth. Consequently, it is difficult to secure water supplies and maintain water purity [1]. Constructed wetlands are used often as a practical and economical way to maintain and improve the water quality of sources of micro-pollution. Nevertheless, the constructed wetland's removal performance for micro-polluted water was constrained due to the low carbon to nitrogen ratio (C/N) and restricted biodegradability of the micro-polluted source water. In order to address the requirement for managing contaminants in micro-polluted water sources and the increasingly strict water quality standards at discharge, combined constructed wetlands—which incorporate diverse types of constructed wetlands at several stages—have steadily arisen in recent years. However, because the current methods for selecting and combining integrated built wetlands primarily rely on experience, the treatment efficiency varies substantially.[2]. The implementation of engineered wetlands technology has created a difficulty for how to ensure the coupled processes scientifically and optimally. Prior studies largely examined the overall and immediate performance of mixed constructed wetlands, but they rarely examined the contributions of each component and the couplings between different processes.[3]. Combined constructed wetlands have varied influencing factors that are difficult to predict and manage in the long run, such as the construction, management, influent, and wetland plants [4]. Wang et al. [5] presented that the treatment performance, as measured by the primary water quality indexes, improves with increasing temperature and influent concentrations of pollutants after analysing daily treatment data of a jointly created wetland obtained in 28 months. White[6] studied two surface flow constructed wetlands for four years and discovered that the richness of plant species and influent concentration have an impact on the removal of pollutants. In order to ensure the sustainable deployment of mixed created wetlands, it is crucial to thoroughly analyse the long-term monitoring data of installed constructed wetlands. However, the majority of the currently conducted research on artificial wetlands is based on medium- and small-scale trials that primarily concentrate on parameter optimization and purification methods of pollutants [7-9]. Determining the fundamental and complete driving mechanisms for the evolution and decline of purification functions, as well as ensuring the stable long-term operation of such wetlands, requires the long-term in-
2 Materials and methods

2.1 Study Area

Jiaxing's Guanjinggang ecological wetland, which is located at N 30°41′–30°42′, E 120°45′–120°46′, has a surface area of 147 hm² and a long-term treatment capacity of 450,000 m³/day. Three sub-blocks can be made up of the wetland (Fig. 1). They are (A) the pretreatment area, (B) the ecological wetland root channel purification region, and (C) the deep purification area. The water generally flows like this: Pump station lifting → pipe jacking project (through Haiyantang Stream underneath) → pretreatment area (multiple levels) → wetland root channel ecological purification area (multiple levels) → connecting river section → deep purification area → water intake of waterworks.

Jiaxing has the East Asian monsoon, which lies on the southernmost boundary of the northern subtropical zone. With four distinct seasons, a mild climate, copious amounts of rain, and plenty of sunshine. It exhibits the traits of a humid spring, a scorching summer, a dry autumn, and a chilly winter. Due to its mid-latitude location, the summer's hot, muggy, and rainy weather is significantly shorter than the winter's dry and chilly weather. The extreme maximum temperature is 40.5°C, while the extreme minimum is -12.4°C. The yearly average temperature is 15.9°C. The relative humidity is 82%, and there are 2109 hours of sunshine on average each year. The average wind speed is 2.6-3.4m/s with little difference among different months and the wind direction is mainly east and Northwest throughout the year. The annual average rainfall is 1230.7mm with the maximum of 1768mm (1999) and the minimum of 723.1mm (1978). The maximum daily rainfall is 229.5mm (June 12, 1963), and the maximum three-day rainstorm is 313.8mm (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 [1].

According to China's environmental quality regulations for surface water (GB 3838-2002), the water quality in the Jiaxing area is normally between grades IV and V. It is a typical river system with considerable organic matter and NH3-N pollution[5]. The following list summarizes the key issues with river network water sources: (1) Water sources have a high pollution load and numerous (micro) sources of pollution. Since most localities lack other water sources, the raw water for the drinking water plant has always been collected directly from the river channels in this region. (2) The river network area's hydrodynamic characteristics are fluctuating. The region is low-lying, with numerous gates and dams, as well as water networks that cross it. The flow direction and discharge of many rivers exhibit complicated fluctuations due to the influence of tide, sluice management, and rainfall, and cross contamination is a severe problem. (3) The river network area receives the upstream visitor water, and the sink area has a greater accumulation of pollutants and a weaker capacity for water purification. Natural wetlands have almost entirely disappeared or been destroyed as a result of anthropogenic disturbances and human impact. The river bank has also become significantly harder, which reduces the water body's ability to purify itself and makes the accumulation of contaminants in the receiving water more problematic.

2.2 Study methods

2.2.1 Data collection

Water samples were collected monthly at the inlet and outlet of Guanjinggang Wetland from January 2019 to December 2021. The measure indicators contain water turbidity (NTU), NH3-N (mg/L), DO (mg/L), NO2-N (mg/L), TN (mg/L), Fe (mg/L), Mn (mg/L), TP (mg/L), CODmn (mg/L), COD (mg/L). The turbidity reflects the...
status of suspended matter in the water body, mainly inorganic matter. COD, COD\textsubscript{Mn} mainly reflect the reducing capacity and organic matter condition in the water body. NH\textsubscript{3}-N, TN and NO\textsubscript{2}-N are the nutrient in the water body, which is also the main oxygen-consuming pollutant in the water body. DO is the indicator of oxidation status in water indicating the ecological health of the water body. TP represents the phosphorus content.

2.2.2 Statistical analysis

1) Difference method
Using difference method to analyze pollutant removal rate.

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

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

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

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

\[ r_{x,y|x_1,z_2} = \frac{r_{x,y,z_1} - r_{x,z_2,z_1}r_{y,z_2,z_1}}{\sqrt{1-r_{z_2,z_1}^{2}} \sqrt{1-r_{y,z_2,z_1}^{2}}} \]  

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 \( Z_1 \); \( r_{x,z_2,z_1} \) is the correlation coefficient between the variables \( x \) and \( Z_2 \) with the control variable being \( Z_1 \); \( r_{y,z_2,z_1} \) 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 Water pollution indicators at inlet and outlet of the Guanjinggang wetlands

The values of the water pollution indicators in Guanjinggang Wetland from 2019 to 2021 shows the difference and fluctuations of water quality at the inlet and outlet (Fig. 2). The turbidity of the wetland influent is between 20-60 with the turbidity of wetland effluent fluctuating within the national standard III for surface water. The NH\textsubscript{3}-N of wetland effluent is between 0.1-0.6, which were stable within the national standard III for surface water. The TN fluctuated seasonally with the peak value in March and minimum value in June, the values were similar between the influent and effluent. No\textsubscript{2}-N showed the similar law of fluctuation. TP value increased after June and fluctuated at high value until October. DO of wetland influent ranged from 4 to 10, with low value from July to August and high value from December to January. COD is basically better than the value 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 influent and wetland effluent. COD\textsubscript{Mn} were within the national standard III showing a downtrend during the monitor period.
3.2. Analysis of pollutant removal rate of the wetland

Analysis of pollutant removal rate of the Guanjinggang wetland shows the purification capacity and temporal difference of the wetland from 2019 to 2021 (Fig. 3). The turbidity removal rate is between 0-0.9; the NH3-N removal rate is between 0.25-0.7; the TN removal rate is between -0.15-0.25; the NO2-N removal rate is between 0-0.8; the TP removal rate is between 0-0.5; the Fe, Mn removal rate is between 0-0.7; the DO improvement rate is between -0.5-0.5; and the removal rate of COD Mn was between 0-0.25, with COD fluctuating within -0.5-0.5. The results showed the wetland had limited effects to TN, COD and DO, in contrast, that had better influences on other pollution indicators. The removal rate had no consistent laws in different seasons to all the pollution.
3.3 Analysis of Influencing Factors of Water Quality Purification of Wetland

The partial correlation analysis is used to analyse the influencing factors of water quality purification of the Guanjinggang wetland. The higher the partial regression coefficient, the greater the impact of this factor on water quality. The results (Table 1) showed the water temperature were the most important factor affecting the turbidity, NH3-N, Fe with the partial correlation of 0.447, -0.631, 0.510, respectively. Precipitation showed the most influence on Mn with the partial correlation of 0.323. Flow showed highest influence on COD with the partial correlation of -0.339. Further, flow and water temperature were the highest influence factors of NO2-N, CODMn, Do and TN. Moreover, water purification agent was not the highest influence factor on any other pollution indicators.

<table>
<thead>
<tr>
<th>Influencing Factors</th>
<th>Turbidity</th>
<th>NH3-N</th>
<th>Fe</th>
<th>Mn</th>
<th>NO2-N</th>
<th>CODMn</th>
<th>Do</th>
<th>TP</th>
<th>TN</th>
<th>COD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water purification agent</td>
<td>-0.118</td>
<td>0.149</td>
<td>-0.120</td>
<td>0.306</td>
<td>0.221</td>
<td>-0.273</td>
<td>-0.122</td>
<td>0.146</td>
<td>-0.140</td>
<td>-0.139</td>
</tr>
<tr>
<td>Flow</td>
<td>0.098</td>
<td>0.069</td>
<td>0.076</td>
<td>0.128</td>
<td>0.453*</td>
<td>0.488**</td>
<td>-0.380*</td>
<td>-0.275</td>
<td>0.500**</td>
<td>-0.339*</td>
</tr>
<tr>
<td>Water temperature</td>
<td>0.447*</td>
<td>0.631***</td>
<td>0.510**</td>
<td>0.092</td>
<td>0.394*</td>
<td>0.364*</td>
<td>0.831***</td>
<td>-0.077</td>
<td>0.714***</td>
<td>0.263</td>
</tr>
<tr>
<td>Precipitation</td>
<td>-0.178</td>
<td>0.155</td>
<td>-0.185</td>
<td>0.323*</td>
<td>0.174</td>
<td>-0.009</td>
<td>-0.057</td>
<td>-0.026</td>
<td>0.017</td>
<td>0.057</td>
</tr>
</tbody>
</table>

Note: * Correlation is significant at P < 0.1, pearson; ** Correlation is significant at P < 0.01, pearson; *** Correlation is significant at P < 0.001, pearson.

4 Conclusions

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 collected the turbidity, NH3-N, DO, NO2-N, TN, Fe, Mn, TP, CODMn, COD at the inlet and outlet of Guanjinggang wetland in Jiaxing City from 2019 to 2021. The results showed that the wetland reduced the influent water pollution indicators and slowed down the fluctuation of pollution indicators. The water quality purification was apparent to NH3-N, NO2-N, Fe, TP, on the contrary, the purification of the wetland on DO, TN and COD was relatively small. The removal rates were not consistent among different indicators and fluctuated with seasons. The partial regression analysis showed the water temperature were the most important factor affecting the turbidity, NH3-N, Fe with the partial correlations of 0.447, -0.631, 0.510, respectively. Precipitation showed the most influence on Mn with the partial correlation of 0.323. Flow showed highest influence on COD with the partial correlation of -0.339. Further, flow and water temperature were the highest influence factors of NO2-N, CODMn, Do and TN. Moreover, water purification agent was not the highest influence factor on any other pollution indicators. The research results are conducive to improving the understanding of water security in the Yangtze River Delta region.

References

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