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Effect of Operating Parameters of Surface Flow Constructed Wetland on Nitrogen and Phosphorus Removal and Sensory Quality of River Water

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In this study, four surface flow constructed wetlands (SFCWs) were used to treat river water, to explore the effect of operating parameters such as water depth (25 cm, 45 cm, 65 cm), hydraulic retention time (HRT) (1 d, 2 d, 3 d), and temperature (10 ± 2 °C, 20 ± 2 °C, 30 ± 2 °C) on the nitrogen and phosphorus removal performance and the improvement of sensory quality in the system. The results showed that when the water depth was 25 cm, the system had better removal effect of total nitrogen (TN), total phosphorus (TP), turbidity and chroma, with removal rates of 49.0 %, 61.7 %, 92.0 % and 94.8 %. When HRT was 2 d, the removal rates of TN, TP, turbidity and chroma in the system were 43.2 %, 54.3 %, 87.4 % and 93.3 %. As for temperature, in the high temperature period, the TN removal effect was better, with a removal rate of 58.7 %. In the low and high temperature periods, the TP removal effect was better, with removal rates of 55.0 % and 58.2 %. In the middle temperature period, the system had a good removal effect on turbidity and chroma, with removal rates of 90.6 % and 95.5 %. According to canonical correspondence analysis (CCA), water depth and HRT both had significant correlations with the removal of nitrogen and phosphorus and the improvement of sensory quality in the system, and the explanatory degrees were all above 50 %. Temperature had no significant effect on the removal of phosphorus and sensory quality.

1. Introduction

In recent years, the pollution of urban rivers has been attracted more and more attention, generally resulting from the discharge of industrial (Guo et al., 2018) and domestic wastewater. With the efforts to strengthen urban river management, the pollution of river waters in China has been eased. The water quality of rivers in some cities has been gradually improved to the grade V national surface water standards (GB3838-2002) (Zhang, 2018). In those river waters, though the content of organic matter, nitrogen, phosphorus and heavy metals is relatively low, the sensory quality of water is poor (Wang, 2018), and needs to be further improved. The poor sensory quality of water bodies is mainly due to the high turbidity, suspended matter, and chroma of river water, which causes the water body cloudy, colored, and low in transparency (Guo et al., 2016), and smell unpleasant (Wang et al., 2018).

As a new type of ecological purification technology, constructed wetlands (CWs) have been widely concerned and applied in the field of water treatment (Vitor et al., 2019). Currently, the application of CWs technology is mainly concentrated in the treatment of rainwater runoff, wastewater from sewage plants, domestic sewage, organic wastewater, ammonia nitrogen wastewater and heavy metal wastewater. CWs are mainly used to study the removal of inorganic salts, organic matter and nutrient salts in sewage (Qiu, 2019). There are relatively few studies on the improvement of the sensory quality of river water by CWs. Because SFCWs have the advantages of low investment, low operating cost, and no clogging problems, in this study the calamus-type SFCW was used to treat natural river water with low pollution and poor sensory quality. This study explored the effect of operating parameters such as water depth, HRT, and temperature on the nitrogen and phosphorus removal performance and the improvement of sensory quality in the system. Based on this, a comparative analysis was conducted to seek suitable operating parameters for two types of SFCWs systems,

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focusing on nitrogen and phosphorus removal or the improvement of sensory quality, to provide reference for river water management in some areas with similar conditions.

2. Materials and methods

2.1 Experimental equipment and process

This experiment was carried out in the Botanical Garden of Shanghai Jiao Tong University. The experimental devices were placed in the natural environment. The experimental equipment is shown in Figure 1. The wetland plant selected in this study is *Iris pseudacorus*, which has strong adaptability to the environment, and its root system can absorb nitrogen and phosphorus. The height of the reactor was 100 cm, and the plane size was 30 cm × 100 cm. The front end of the reactor was provided with a water inlet area, and its plane size was 30 cm × 10 cm. The back end of the reactor was provided with water outlets of different heights to set different water depth conditions (25 cm, 45 cm, 65 cm). The treatment object of this experiment was the river water in the botanical garden. The river water was pumped into the water storage tank with a water pump, and then the water was sent to the simulated wetland reactor through a peristaltic pump.

This experiment was carried out from June 2018 to October 2019 and was divided into three temperature periods (10 ± 2 °C, 20 ± 2 °C, 30 ± 2 °C). In addition, HRT was set as 3 d, 2 d, and 1 d successively during the experiment to explore its effect on nitrogen and phosphorus removal and sensory quality.

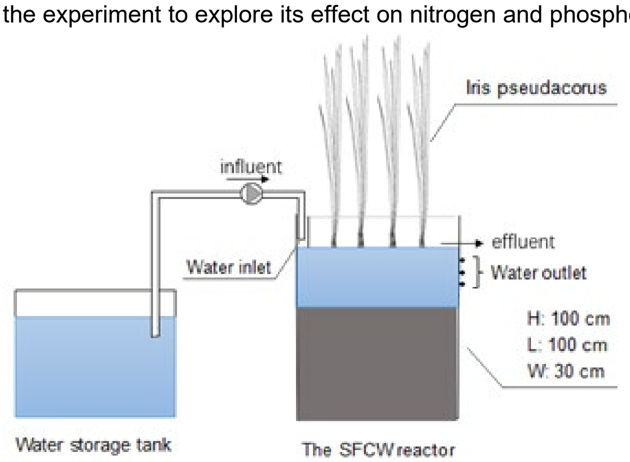

Figure 1: Experimental equipment

2.2 Analytical instruments

TN and TOC were monitored by Analytik Jena multi N/C TOC/TN analyzer. TP and various forms of nitrogen were measured according to the national standard methods (State Environmental Protection Administration of China, Monitoring and Analysis Methods of Water and Wastewater, fourth ed., China), and the measuring instrument was a Shimadzu UV-1800 UV spectrophotometer. The turbidity and chroma measuring instruments were HACH-2100Q and Luheng Biological Desktop Colorimeter LH-SD500. The temperature and DO were monitored by HACH-HQ 40d. The CCA analysis was conducted by Canoco V5 software.

3. Results and discussion

3.1 Effects of water depth on TN, TP, turbidity and chroma

Water depth is critical to the ecological environment of SFCWs systems. Water depth can affect physical and chemical environment, microorganisms of the wetland system (Headley et al., 2005) and photosynthesis and growth status of plants in the wetland (Zhang et al., 2012).

Figure 2a showed the removal rates and loads of TN and TP in SFCWs system under different water depths. When water depth was 25 cm, 45 cm and 65 cm, the TN removal rates of the system were 49.0 %, 48.0 % and 43.0 %. It could be seen that the TN removal rate of the system decreased with water depth increasing, which was also demonstrated by the previous study (Hu, 2017). The reason might be that as the water depth deepened, the dissolved oxygen (DO) in the water gradually decreased, especially in the mud-water junction. When DO was less than 2 mg/L, the activity of aerobic microorganisms (*Nitrospira, Nitrosococcus,* and *Nitrosolobus*) was inhibited (Xiao et al., 2006), which could slow down the nitrification process. As shown in Figure 2a, when the water depth was increased from 45 cm to 65 cm, the TN removal rate of the system decreased greatly. This was because when the water depth rose to a certain level (65 cm), the growth of *Iris* *pseudacorus* was limited. It was found that some roots and stems of *Iris pseudacorus* in the system began to rot and black, so 65 cm was an excessive water depth. As Figure 2a showed, the removal rate of TP in the system decreased with water depth increasing, which was the highest at the water depth of 25 cm. The reason might be that the DO content in shallow water was higher, aerobic microorganisms such as *Acinetobacter* became more active, and then the absorption of phosphorus in the system was enhanced.

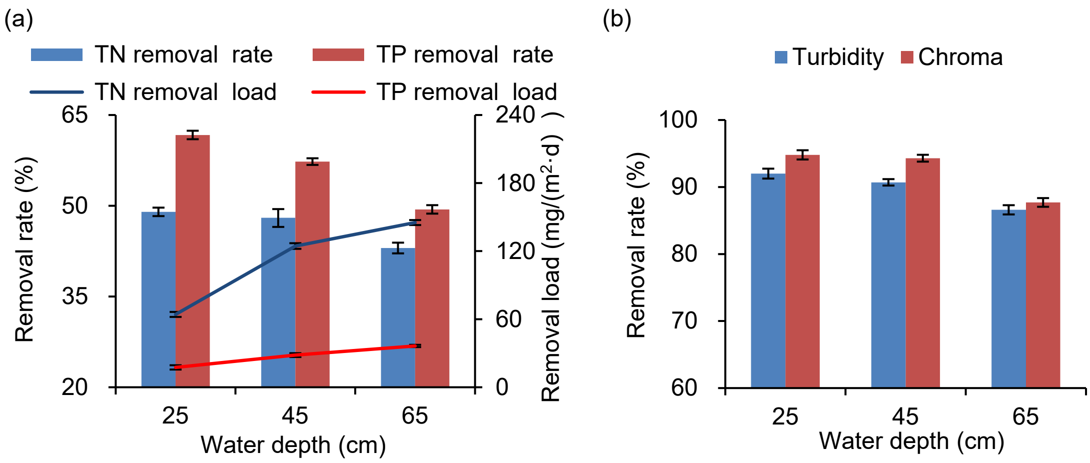

Figure 2: Influence of water depth on (a) TN and TP, and (b) turbidity and chroma

Turbidity and chroma play a crucial role in sensory quality of the whole system. Figure 2b revealed that the system had a strong ability to remove turbidity and chroma. The removal rates of turbidity and chroma were both above 85 %, decreasing with the increase of water depth. When the river water flowed through the reactor, part of the particulate matter could be adsorbed by the roots and stems of *Iris pseudacorus* and then settled. The total amount of particles and the particle size of the effluent were reduced, and then the turbidity of the effluent decreased. As water depth increased, although the volume of treated water increased, the volume of plant stems immersed in water also increased, resulting that the particulate matter adsorbed by plants increased as well. The turbidity removal rate only decreased a little with water depth increasing. In summary, for the SFCWs systems mainly based on nitrogen and phosphorus removal, 25cm could be set as the optimal water depth. The optimal water depth was 25 cm or 45 cm for the SFCWs systems mainly based on the improvement of sensory quality.

3.2 Effects of HRT on TN, TP, turbidity and chroma

HRT is the time from the water enters into the system until the water completely flows out (Yu et al., 2011), which is closely related to the degradation and removal efficiency of pollutants in CWs. Some studies had shown that when HRT was 1-2 d, a better nitrogen and phosphorus removal effect could be achieved (Chen et al., 2012).

Effect of HRT on TN, TP, turbidity and chroma was shown in the Figure 3. It could be observed that by properly prolonging HRT, the removal rate of TN increased and the removal load decreased. The reason might be that when HRT was long enough, the sewage could fully contact the plants and microorganisms in the reactor. The nitrogen in the water could be more transformed by the microorganisms and absorbed by the plants (Yu et al., 2012). It was noteworthy that when HRT increased from 1 d to 2 d and then to 3 d, the removal rate and load of TN had changed greatly in the previous stage, the reason might be that the amount of treated water in the system in the previous stage changed greatly. For the TP removal effect, the result was similar to the situation of TN removal. In general, when HRT was 2 d, the removal effect of TN and TP was better.

As Figure 3b showed, the results revealed that the system had a good removal effect on turbidity and chroma, and the average removal rates were both above 82 %. And the removal rate of turbidity and chroma first increased and then decreased with the increase of HRT. The reason was that prolonging HRT allowed more suspended and particulate matter to be adsorbed and settle, so the turbidity and chroma of the effluent were reduced. But at the same time, prolonging HRT could reduce the system's treated water volume, making the treatment efficiency reduced. If the effluent quality of the system reaches the requirements, there is no need to further increase HRT. In summary, when HRT was set to 2 d, the removal effect of nitrogen and phosphorus and the improvement of sensory quality could reach the best.

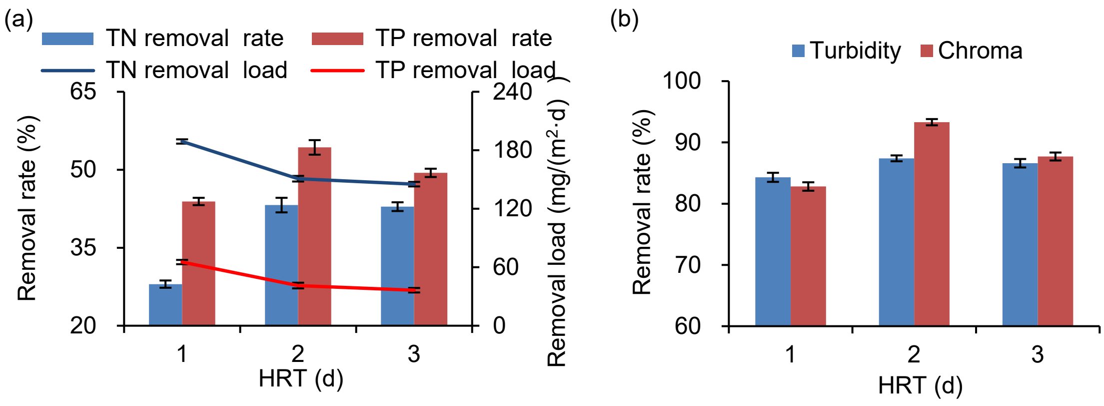

Figure 3: Influence of HRT on (a) TN and TP, and (b) turbidity and chroma

3.3 Effects of temperature on TN, TP, turbidity and chroma

Water temperature can affect the growth of plants and microorganisms, and then affect the ability of the system to remove nitrogen and phosphorus and enhance sensory quality. The removal effect of TN, TP, turbidity and chroma in SFCWs under different temperature periods was evaluated, and the results were shown in Figure 4.

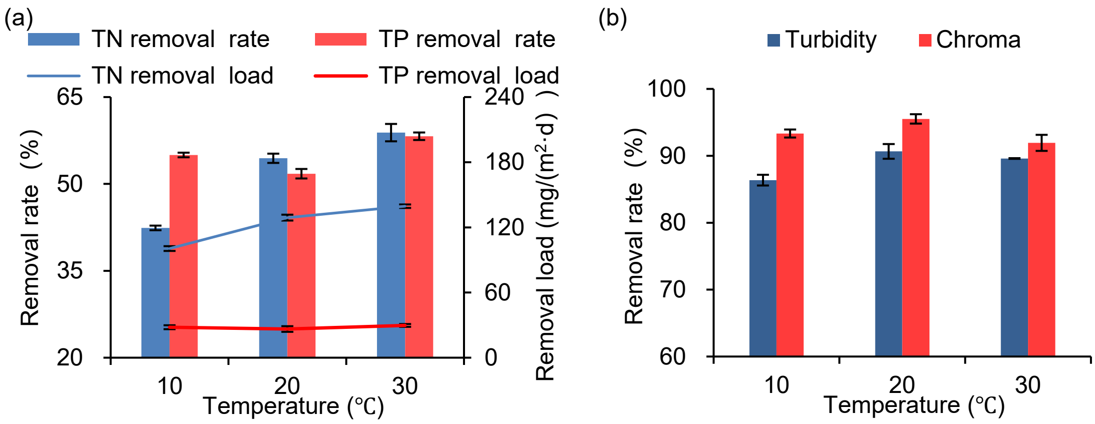

Figure 4: Influence of temperature on (a) TN and TP, and (b) turbidity and chroma

The results revealed that the removal rate and load of TN increased to a certain extent as temperature increased. When temperature was 20 ± 2 °C, the TP removal rate and load were the lowest. The reason might be that the DO content at 20 ± 2 °C was lower than 10 ± 2 °C, while plant biomass at 20 ± 2 °C was lower than 30 ± 2 °C. The microorganisms in the system release phosphorus under anaerobic conditions, which leads to a decrease in the removal effect of TP (Hua et al., 2017). At 10 ± 2 °C, the DO content in the system was relatively sufficient, so the TP removal rate was higher. Studies had shown that the TN and TP removal rates were highest in summer and spring (Sheng et al., 2019), lowest in winter and in the middle in autumn (Zhong, 2018).

As Figure 4b showed, the turbidity and chroma removal rate showed a trend of first increase and then decrease with water temperature increasing. In summer (30 ± 2 °C), the influent turbidity was relatively higher, the external environment and abundant biomass in the water had a large impact on the turbidity in the system, so the turbidity removal rate was lower. At 10 ± 2 °C, due to the withering of *Iris pseudacorus*, the adsorption and interception of particulate matter in water was weakened. The decay and decomposition of withered plants could also have a negative impact on the turbidity removal effect of the system. The turbidity removal rate of the system was lower at low temperature. For chroma, when temperature was high, the algae content in the water was high, which led to an increase in the chroma of the effluent. A large number of litters released humic acid and other substances into the water at low temperature, making the chroma of the system increase. The chroma removal rates of the system were lower at the low and high temperature periods. In summary, for two SFCWs systems concentrated on nitrogen and phosphorus removal and the improvement of sensory quality, the optimal temperature was 30 ± 2 °C and 20 ± 2 °C.

3.4 CCA analysis

In order to study the impact of operating parameters on the removal of nitrogen and phosphorus and sensory quality in SFCWs, the CCA analysis was conducted. The results were shown in Figure 5. The CCA analysis showed that water depth explained the removal of nitrogen and phosphorus and the improvement of sensory quality by 95.2 % and 84.3 %, indicating that the effects of water depth on the removal of nitrogen and phosphorus and the improvement of sensory quality were both significant. As shown in the Figure 5a, the angle between the water depth line and the TN line was obtuse angle, indicating that there was a negative correlation between water depth and the removal of nitrogen. Similarly, the removal effects of TP, turbidity and chroma in the system were negatively correlated with water depth. The result was consistent with the conclusion in period 3.1 that the removal rates of TN, TP, turbidity and chroma in the system could decrease with the increase of water depth.

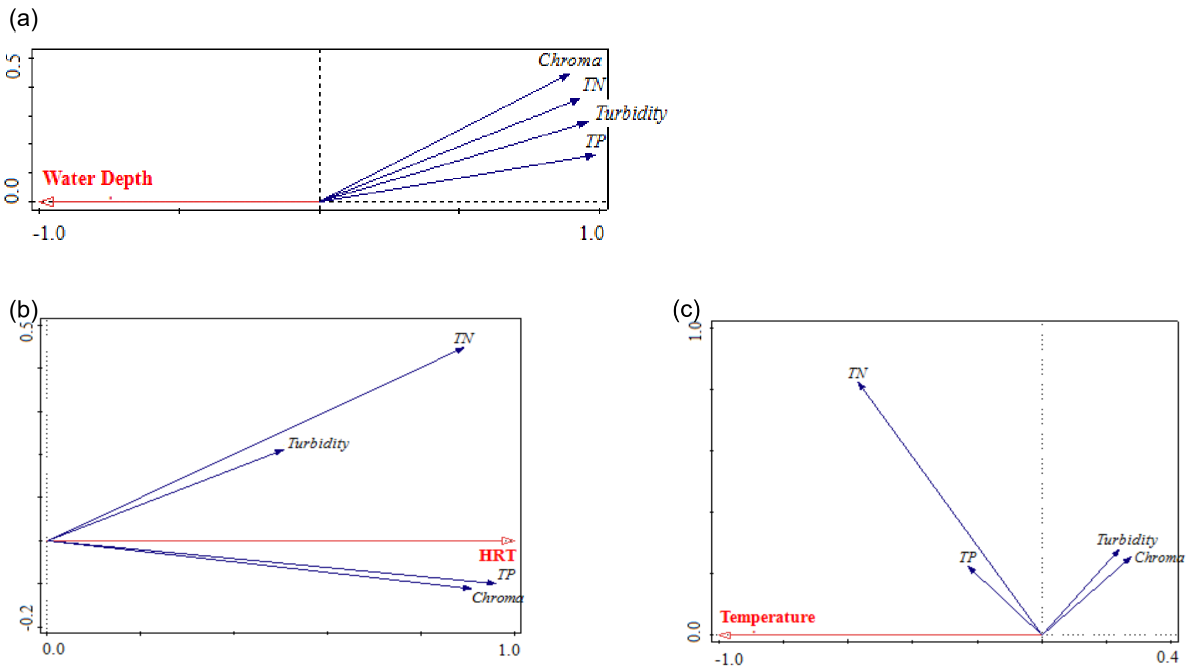

Figure 5: The CCA analysis of (a) water depth, and (b) HRT, and (c) temperature affecting nutrients removal (TN, TP) and sensory quality (turbidity, chroma)

According to the CCA analysis results, the effect of HRT on the removal of nitrogen and phosphorus was greater than that on the improvement of sensory quality, with explanations of 80.8 % and 50.8 %. As Figure 5b showed, the length of the chroma line segment was significantly longer than that of the turbidity line segment, indicating that HRT had a more significant effect on chroma than turbidity. In period 3.2, when HRT was extended from 1 d to 2 d and from 2 d to 3 d, the turbidity removal rates in the system changed by 3.1 % and 0.8 %, while the chroma removal rates changed by 10.5 % and 5.6 %. It could be seen that the effect of HRT on the chroma removal was greater than that on the turbidity removal.

The CCA analysis revealed that temperature had a certain effect on the removal of nitrogen and phosphorus and the improvement of sensory quality in the system, and the explanatory degrees were 30.3 % and 7.0 %. As shown in the Figure 5c, there was a positive correlation between temperature and nitrogen removal effect. It was noteworthy that the length of the TP line segment was shorter, indicating that the correlation between temperature and the TP removal effect of the system was not significant.

4. Conclusion

According to the CCA analysis results, the effects of water depth, HRT, and temperature on the removal of nitrogen and phosphorus in the system were significant, and the explanatory degrees were 95.2 %, 80.8 %, and 30.3 %. And the effects of water depth and HRT on the improvement of sensory quality in the system were also significant, with explanations of 84.3 % and 50.8 %. At the same time, the temperature had no significant effect on sensory quality in the system. For two SFCWs systems that mainly focus on nitrogen and phosphorus removal or improving sensory quality, the optimal water depth, HRT, and temperature were 25 cm, 2 d, 30 ± 2 °C, and 25 cm or 45 cm, 2 d, 20 ± 2 °C.

This research only studied the effect of operating parameters of SFCWs on nitrogen and phosphorus removal and sensory quality, without establishing an evaluation system. Besides, it is necessary to conduct in-depth analysis of the reasons why operating parameters have different effects on nitrogen and phosphorus removal and sensory quality.

Acknowledgments

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