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Short Communication

Application of Subsurface Flow Constructed Wetland System for Purification of Secondary Effluent from Municipal Wastewater Treatment Plant

Nan Zhang[1], Chenliang Shen[1], Huaide Wei[1], Haiyuan Liu[1], Zhenchuan Wang[1], Lijun Hou[1], Jingxi Tie[2, 1]*

[1]Zhong Zhou Water Holding Co., Ltd. Zhengzhou, 450000, PR China;
[2]School of Environmental and Municipal Engineering, North China University of Water Resources and Electric Power, Zheng Zhou, 450045, PR China

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Abstract

The main objective of this study was to investigate the efficacy of using the constructed wetland for purification of secondary effluent from a wastewater treatment plant (WWTP) in the eastern district of Anyang, Henan province, China. A Subsurface Flow Constructed Wetland (SSFCW) system was designed and constructed, consisting of 302 SSFCW units (L×W×H = 30×20×1.4 m for each unit) with a treatment capacity of 10^5 m^3/d. Each unit of the system was planted with equal number of *Phragmites australis*, *Typha orientalis Presl*, and *Zizania latifolia* at the density of 16 plants/m^2. The average values of the Chemical Oxygen Demand (COD_{Cr}), Biochemical Oxygen Demand (BOD_5), Ammonia Nitrogen (NH_3-N), and Total Phosphorus (TP) of the effluent sampled from 4 outlets of the system chosen at random for 17 months consistently met the Class III of Environmental quality standard for surface water in China, even during the cold season. According to the economic analysis, the system may generate an annual profit of around ¥ 1.4 million yuan. The SSFCW system is an cost-effective and profitable technique for the further polish of the secondary effluent from the wastewater treatment plant.

Keywords: Subsurface Flow Constructed Wetlands (SSFCW), Wastewater Treatment Plant (WWTP), secondary effluent, environmental quality standard for surface water

*e-mail: tjx@ncwu.edu.cn

Introduction

In recent decades, China has made tremendous social and economic growth, which has been accompanied by the increased water consumption, resulting in the generation of a massive volume of wastewater. The total wastewater discharge and municipal wastewater discharge rose from 41.5×10^9 m^3 to 73.5×10^9 m^3, and from 22.1×10^9 m^3 to 53.5×10^9 m^3, respectively, between 2000 and 2015 [1], causing serious water pollution, destroying hydrological systems, exacerbating existing water scarcity, creating huge economic losses, and impeding China's economic and social development [2-4]. Water contamination is a serious issue that is causing increasing social concern.

Wastewater Treatment Plant (WWTP) has been considered as the essential infrastructure to control water pollution and wastewater reclamation and reuse [5]. By the end of 2019, there were 4140 WWTPs in both cities and counties in China with treatment capacity of 6.2×10^{10} m^3 annually [6], accounting for 95.0% of the total annual discharged amount, meanwhile, the stringent discharge standard has been set to cut the pollutants discharged into receiving water bodies as much as possible, which improved the water environment quality greatly. However, some pollutants, such as refractory organic matters [7], emerging micro-pollutants, nitrogen and phosphorus [8] which fail to be eliminated in WWTPs, resulting in eutrophication and damage of aquatic environments. As a result, secondary effluents from WWTPs must be polished in order to reduce pollutant discharge and protect the environment and drinking water resources. Several procedures, including the cyclic activated sludge system process [9], membrane bioreactor [10] ozonation [11, 12], sequencing batch reactor [8, 13], activated carbon [14] have been implemented to further purify the secondary effluent from WWTPs. However, the above-mentioned strategies have the disadvantage of significant investment and operational cost [15, 16], limiting their wide application for the advanced purification of the secondary effluent from WWTPs.

In comparison to traditional tertiary treatment technologies, the use of constructed wetlands as a cost-effective, extensive, and efficient wastewater treatment technology has increased in recent decades due to their low cost, simple operation, convenient maintenance, effective pollutant removal, and aesthetic effect [17-19].

As a result, the purpose of this study is to evaluate the long-term performance of a SSFCW system that purifies secondary effluent from a WWTP in Anyang, northern China. The findings of this study would be useful in the design and application of SSFCW systems for the increased purification of WWTP effluent for the improvement of urban river water quality as an alternative and eco-friendly ecological treatment strategy.

Methodology

Study Site Description

As shown in Fig. 1, the SSFCW system were built on both sides of the Chadian River with a total length of 7.2 km and a total area of 20.1 hectares, respectively, containing 302 SSFCW units. The river flows through the eastern district of Anyang, Henan province, northern China, and serves as the primary drainage channel of the district. The river channel became silted up as a consequence of mud and debris, resulting in significant degradation of the river's water quality and ruin of its natural system. The climate at the research location is moderate temperate continental monsoon, with annual average temperatures ranging from 12.7 to 13.7ºC and yearly average rainfall ranging from 581.1 to 693.1 mm.

Fig. 1. The location and distribution of the SSFCW system along the Chadian River.

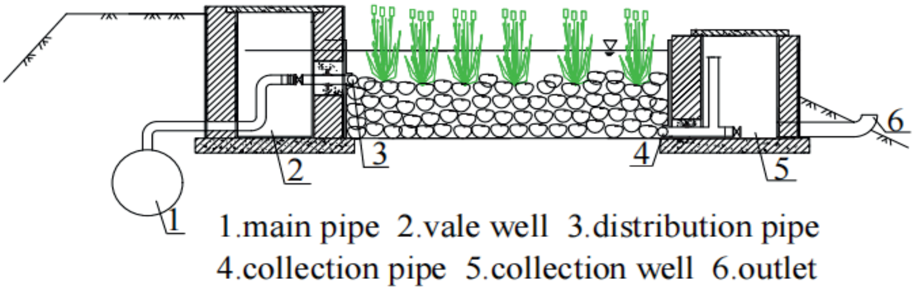

Fig. 2. The structure of the SSFCW unit.

Design and Operation of the SSFCW System

As shown in Fig. 2, each unit had a size of L×W×H = 30×20×1.4 m. The substrate section of each unit has a depth of 0.8m, and filled with cobblestone with diameter of 2-8 cm. Same amount of *Phragmites australis*, *Typha orientalis Presl*, and *Zizania latifolia* was planted in every unit with a density of 16 plants/m^2. The SSFCW system was divided into 4 sections to facilitate its construction due to the size of the project.

The SSFCW system was designed and built to polish the secondary effluent from the eastern district wastewater treatment plant with a treatment capacity of 10^5 m^3/d, and the tertiary effluent treated by the SSFCW was discharged into the river to improve its water quality. Meanwhile, the landscape design for the system created a stunning panorama of the surrounding area.

Field Sampling and Laboratory Analysis

Water samples were collected 3-4 times every month from 1 outlet of each construction section chosen at random due to the difficulty of collecting and analyzing water samples from all of the outlets of all of the SSFCW units, while the same design, construction and operation of every unit ensured the random sampling was representative. The collection period lasted from January 2020 to May 2021. All of the water samples were transported to a lab in a portable refrigerator to analyze BOD_5, COD_{Cr}, NH_3-N, and TP using the national standard methods of China, and the average values of the test results of each month was used to evaluate the polishing efficiency of the SSFCW system. The following equation was used to calculate the pollutants removal rates (1):

$$R = \frac{q_i - q_e}{q_i} \times 100\% \tag{1}$$

Where R was the removal rate of the pollutants, q_i and q_e were the concentrations of the pollutants in the influent and effluent, respectively.

Results and Discussion

To prevent water quality deterioration, the Chinese government has established stringent discharge standard for WWTP as well as environmental quality standard for surface water. Table 1 gives the upper limits of the four pollutants in the two standards discussed in this study, including COD_{Cr}, BOD_5, NH_3-N, and TP. The Anaerobic/Anoxic/Aerobic process is employed to treat the wastewater in Anyang eastern district WWTP in order to meet the discharge standard. As shown in Table 1, the concentrations of the four target pollutants in its effluent were below the upper limit of the national discharge standard throughout the monitoring period from January 2020 to May 2021, whereas the concentrations exceeded the upper limits of the four pollutants of the environmental quality standard for surface water. As a result, the SSFCW system was designed and constructed to further polish the WWTP effluent.

Table 1. Target pollutants concentrations in the effluent of the local WWTP (A), national discharge standard for WWTP effluent (B), and Environmental quality standard for surface water (C).

Pollutants	A (mg/L)	Upper limits of B (mg/L) (GB 18918-2002, Grade 1A)	Upper limits of C (mg/L) (GB 3838-2002, Class III)
COD_{Cr}	24.21±1.91	50	20
BOD_5	9.95±1.61	10	4
NH_3-N	0.34±0.11	5(8)	1.0
TP	0.28±0.03	0.5	0.2

Note: The figur in the blank in the table represents the discharge standard in case of the water temperature below 12ºC.

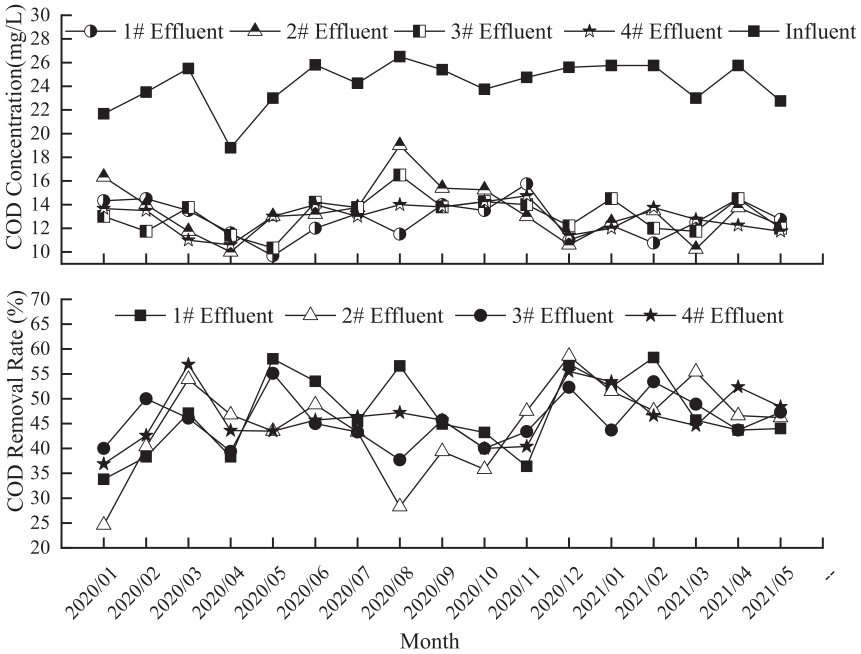

Fig. 3. COD_{Cr} in the influent and effluents of the SSFCW system and the corresponding removal rates.

COD_{Cr} Removal

COD_{Cr} can be partially consumed by aquatic microbes, causing oxygen deficiency in the water. As a result, further removal of COD_{Cr} is necessary for water environment protection. As shown in Fig. 3, the influent COD_{Cr} concentration was (24.21±1.91) mg/L, and the COD_{Cr} concentrations in the effluents of the SSFCW system from the four sampling points were (12.79±1.55), (13.38±2.2), (13.16±1.49), and (12.91±1.19) mg/L, respectively, and the average removal rates were (46.84±7.64), (44.6±8.69), (45.58±4.91), and (46.45±5.33)%, respectively.

BOD_5 Removal

BOD_5 is an important component of COD_{Cr}, representing organics that are easily used by microbes and has the same negative effects as COD_{Cr}. As shown in Fig. 4, the influent BOD_5 concentration was (9.95±1.61) mg/L, and the effluent BOD_5 concentrations were (3.40±0.66), (3.48±0.62), (3.40±0.44), and

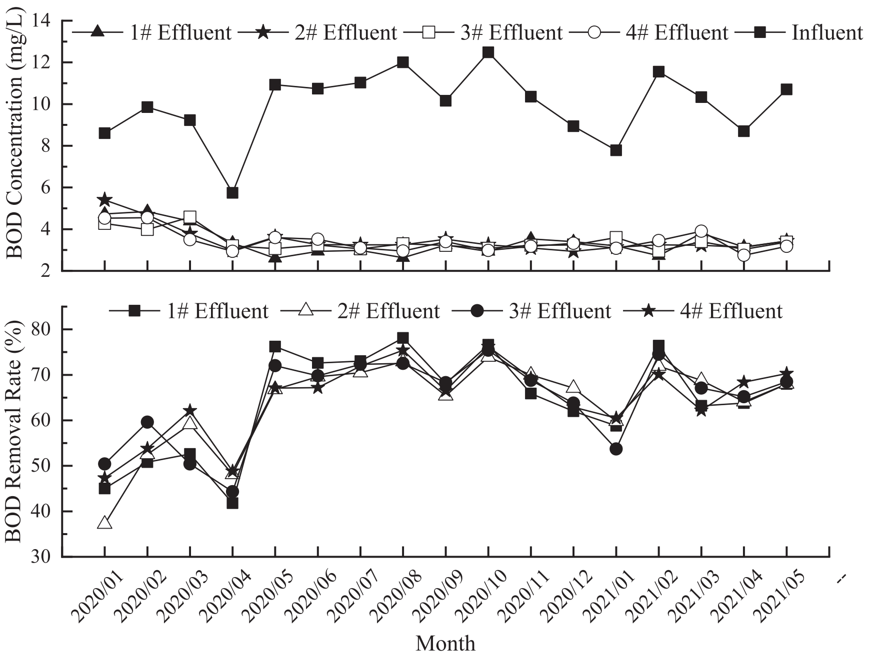

Fig. 4. BOD_5 in the influent and effluents of the SSFCW system and the corresponding removal rates.

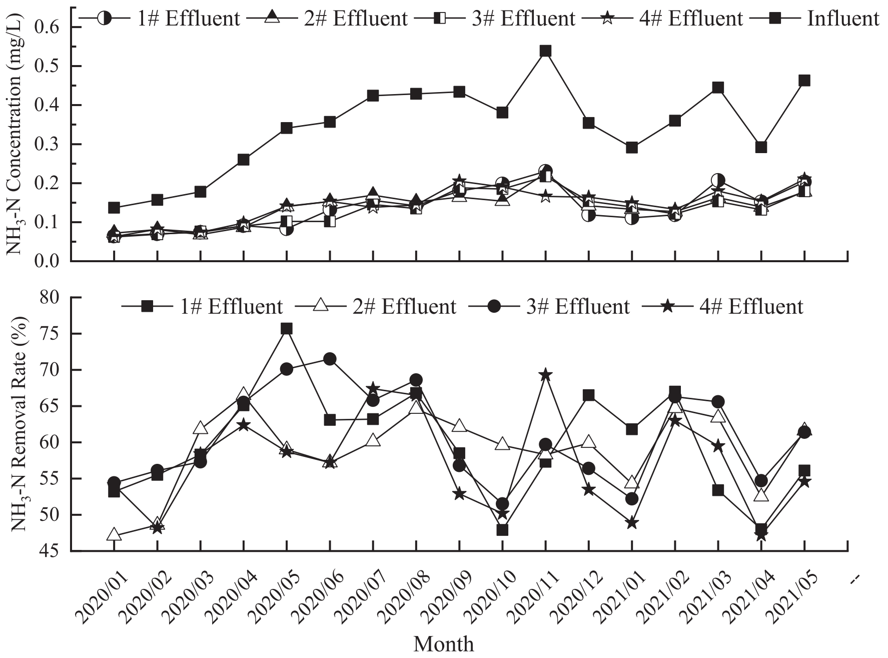

Fig. 5. NH_3-N in the influent and effluents of the SSFCW system and the corresponding removal rates.

(3.41±0.5) mg/L, respectively, and the corresponding average removal rates were (64.29±10.96), (63.87±9.56), (64.50±9.17), and (64.70±8.11) %, respectively.

NH_3-N Removal

NH_3-N must be removed from wastewater because it encourages eutrophication and depletes dissolved oxygen. As shown in Fig. 5, the NH_3-N concentration in the influent was (0.34±0.11) mg/L, and the NH_3-N concentrations in the effluents were (0.14±0.05), (0.14±0.04), (0.13±0.043) and (0.14±0.042) mg/L, respectively, and the corresponding average removal rates were (59.84±7.11), (58.90±5.32), (60.83±6.28), and (57.18±6.65) %, respectively.

TP Removal

TP is the essential nutrient that results in eutrophication when its concentration in fresh water exceeds 0.02 mg/L. To stop the eutrophication, the effluent from the WWWP has to be further treated.

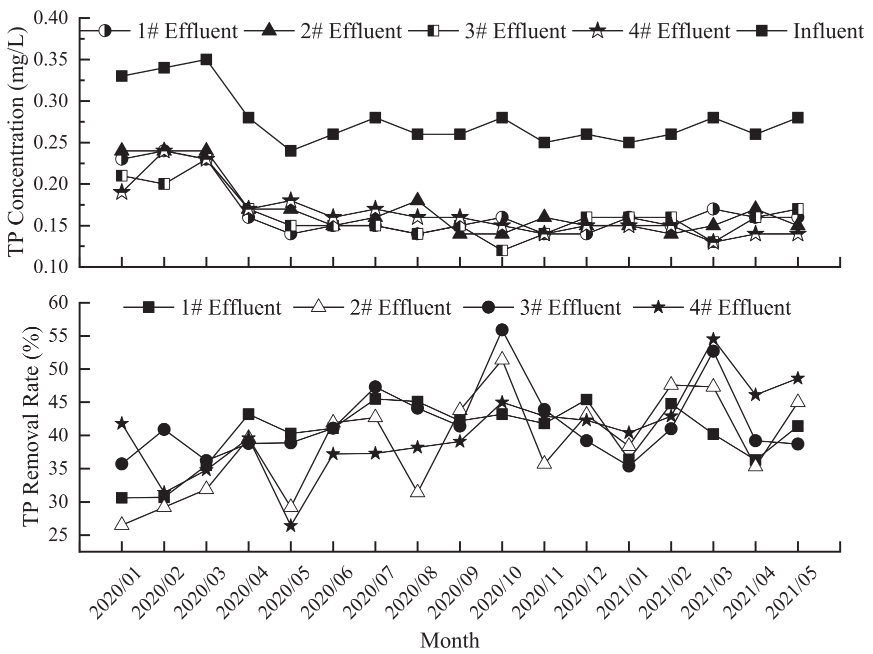

Fig. 6. TP in the influent and effluents of the SSFCW system and the corresponding removal rates

Table 2. Comparison of the removal rate of the four target pollutant in the two time spans.

Pollutants	First time span (%)	Second time span (%)
COD_{Cr}	46.94±7.46	44.66±5.94
BOD_5	58.55±9.45	70.85±3.42
NH_3-N	57.54±6.24	61.05±6.32
TP	39.29±6.15	41.49±5.73

As shown in Fig. 6, TP concentrations in the influent was (0.28±0.03) mg/L, which was lower than 0.5 mg/L. and its concentrations in the effluents were (0.17±0.03), (0.17±0.03), (0.16±0.03), and (0.16±0.03) mg/L, respectively, and the corresponding average removal rates were (40.20±4.61), (38.82±7.18), (41.78±5.47), and (40.49±6.3) %, respectively.

In comparison to the upper limits provided in Table 1, the SSFCW effluent quality reached Class III of the environmental quality standard for surface water .

The corresponding average values of the four pollutants for two separate time periods, including the first (January-April, 2020 and November, 2020-April, 2021), and the second (May-October, 2020 and May, 2021) was calculated to further investigate the impact of temperature on SSFCW purification efficiency. Low water temperature caused by cold climate made plants withered and microorganisms inactive, which resulted in poor pollutant removal in the first time span, whereas higher temperature in the second time span could result in active physical and chemical reactions for better pollutant removal. As shown in Table 2, with the exception of BOD_5, there were no noticeable variations in removal rates between the two periods, demonstrating that the SSFCW was still effective even in the cold temperature.

Economic Analysis

The total investment of the project was ¥ 126 million yuan, with ¥ 25 million yuan coming from the Central Environmental Protection Fund and ¥ 101 million yuan coming from a self-raised fund, with a required payback of ¥ 31.1 million yuan over a 10-year repayment cycle. The funds were used to construct a pump station and and SSFCW units, as well as lay the pipelines and dredge the river channel. The operation cost of ¥ 0.31 yuan/t includes power consumption, maintenance, management fees, labor expenses, material costs, and depreciation. The local government pays ¥ 0.39 yuan/t for sewage treatment services. After deducting loan payments and operational expenses such as electricity fees, maintenance and material costs, depreciation charges, and management expenses, the annual profit is roughly ¥ 1.4 million yuan. The construction and operation of the project not only improved the local water environment, it also created profits to the operator of the project, proving the SSFCW is a desirable approach for secondary effluent purification.

Conclusions

A SSFCW system was built to further polish the secondary effluent from the Anyang eastern district WWTP, Henan province, in order to improve the water quantity of the Chadian river. The effluent from four SSFCW system outlets was collected, and four pollutants including COD_{Cr}, BOD_5, NH_3-N and TP were continuously tested for 17 months. The average values of COD_{Cr}, BOD_5, NH_3-N and TP of the sampled effluents met the Class III of environmental quality standard for surface water in China, and the system worked well even in winter, generating a yearly profit of ¥ 1.4 million yuan as well, indicating that the SSFCW systems is an ideal ecological measure for the advanced purification of the secondary effluent.

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Conflict of Interest

The authors declare no conflict of interest.

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