ISSN 1063-455X, Journal of Water Chemistry and Technology, 2021, Vol. 43, No. 2, pp. 178–183. © Allerton Press, Inc., 2021.

NATURAL WATERS

Assessment of Hybrid Subsurface Flow Constructed Wetland Planted with *Arundo donax* for the Treatment of Domestic Wastewater at Different Hydraulic Retention Time

Neetu Rani[a], * and Karuna Narayan Pohekar[a]

[a] *University School of Environment Management, GGSIP University, Sector 16C, Dwarka, Delhi, 110078 India*

**e-mail: neetu_rani@ipu.ac.in*

Received July 30, 2019; revised April 20, 2020; accepted October 7, 2020

Abstract—Due to water scarcity, storage and reuse of water has become a great challenge all over the world. The conventional methods for the wastewater treatment require large capital investment, operating cost, and need trained personal for supervision and maintenance. Therefore non conventional wastewater treatment methods have gained the popularity worldwide. Use of constructed wetland (CW) technology for wastewater treatment is highly efficient since CW are easy to construct, cost effective and increase the aesthetic value. Wetlands behavior and efficiency concerning wastewater treatment mainly depends upon macrophytes, substrate, hydrology, temperature and hydraulic retention time in the system. Present study deals with the removal of pollutants in two stage hybrid subsurface flow CW at different hydraulic retention times (HRT). The domestic wastewater was supplied to CW and treated using the available perennial macrophyte, *Arundo donax*. The system was run in replicate along with one control. To assess the removal efficiency of the pollutants, parameters like pH, temperature, dissolved oxygen (DO), total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD) and total Kjeldahl nitrogen (TKN) were analyzed at different HRT i.e., 36, 30 and 24 h. The result of the study observed maximum percentage removal of TSS, BOD, COD, and TKN was up to 84.61, 98.37, 61.39 and 91.87% respectively at 30 h of retention time.

Keywords: CW, macrophyte, BOD, COD, TKN

DOI: 10.3103/S1063455X21020107

INTRODUCTION

Water being an essential component on the earth is of great demand and required for different purposes in rural, urban, industrial and irrigational areas. The wastewater generated from all these activities contains harmful pollutants into it which are the major cause of soil and water pollution. On the other hand utilization of water is more as compare to availability of freshwater [1]. So, to reduce the pressure on the freshwater demand reuse of treated wastewater is the only solution in present situation. Treatment of wastewater is also challenging task because the numbers of conventional sewage treatment plants in various countries including India are leaving behind more percentage of untreated wastewater apart from their cost. Discharge of this untreated wastewater deteriorates the water quality of receiving watercourse and makes it unhealthy for drinking, agriculture and aquatic life.

It is very much difficult for developing countries to treat wastewater using conventional methods [2]. With more than 70% of rural areas [3], countries like India struggle economically for installation and maintenance of conventional treatment plants. In recent years CW have been developed using locally available macrophytes for treatment of wastewater [4]. It is an emerging, low cost and active approach for improving the water quality to reuse it for different purposes.

Efficiency of CW depends on the important key factor of hydrological variation such as HRT. Some research studies also conclude that most effective removal of contaminants occurs at longer HRT which further depends on selection of macrophyte, design and area of the system [5]. Selection of macrophyte plays an important role since plants help in removal of organic matter and nutrients, supply oxygen to the root zone area for decomposition of biodegradable waste material and also plant roots help in maintaining hydraulic conductivity of the filter media [6, 7].

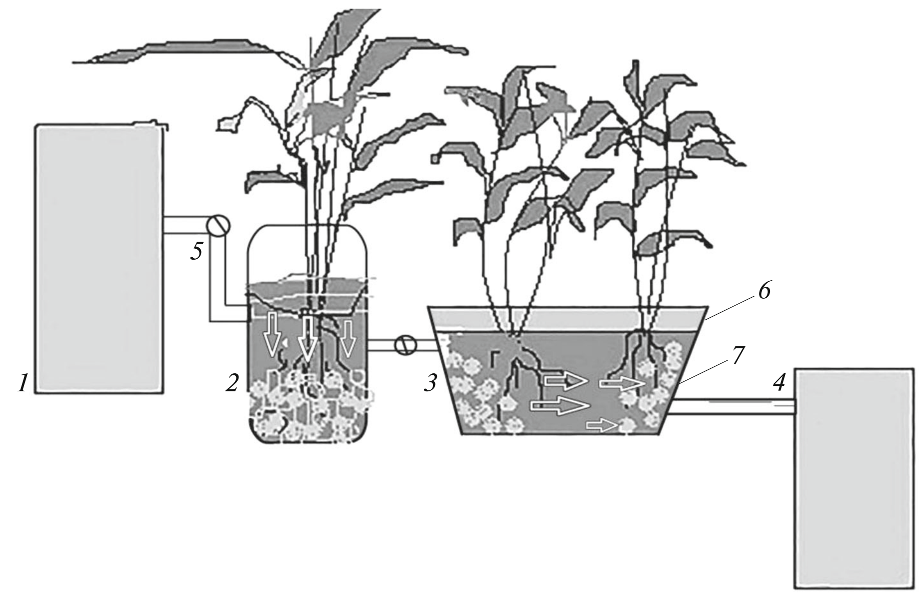

Fig. 1. Schematic diagram of HSFCW system planted with *Arundo donax*: (*1*) sedimentation tank; (*2*) vertical subsurface flow tank; (*3*) horizontal subsurface flow tank; (*4*) collection tank; (*5*) flow control; (*6*) soil layer; (*7*) gravel bed.

In present study, a hybrid subsurface flow constructed wetland (HSFCW) system comprising of both vertical and horizontal subsurface flow bed was designed to study the impact of different HRT on removal of pollutants. The structure was designed based on some studies which reveal that horizontal subsurface flow constructed wetland (HSSFCW) system do not transfer oxygen adequately so to balance the aerobic condition vertical subsurface flow constructed wetland (VSSFCW) may be designed before the horizontal subsurface flow system [8]. The study was focused to explore uncommon but available plant species. Most of the Indian constructed wetlands are using *Canna indica* or Typha spp. The chosen plant species *Arundo donax* is also available in study area but not commonly used in CW. Hybrid system needs shorter HRT which will need a smaller land footprint and will enhance the applicability of the system. Plant species *Arundo donax* used in this study is also not tested in Indian climatic situation. Thus, this study also provides a new plant species for use in constructed wetlands in Indian situation. The proposed system of hybrid wetlands is design for higher nitrogen removal.

EXPERIMENTAL

Two stage HSFCW was constructed near sewage treatment plant, GGSIP University, Dwarka, New Delhi. Located at 28°35′31.7040″ N and 77°2′45.7836″ E. Delhi lies in the sub-tropical belt of earth's North Temperate geographical region, a few latitudes north of the Tropic of cancer, with high variation between summer and winter temperatures and precipitation.

HSFCW was established consisting of sedimentation tank, VSSFCW, HSSFCW and collection tank. Vertical tank was kept before horizontal tank to enhance the aerobic condition, having working volume of 75 L and a height of 70 cm. The diameter of tank was measured to be 35 cm. The vertical tank was packed with large sized gravels up to the height of 20 cm from the bottom, 20 cm of small sized gravels, 15 cm of sand and 15 cm of soil at the top. Size of horizontal bed was kept 50 cm × 25 cm × 35 cm (length × width × height) packed with gravels at the inlet and outlet to avoid the blockage and tank was then filled with small size gravels at the bottom followed by sand and soil in the upper layer (Fig. 1). Domestic wastewater was supplied to the system through perforated pipe provided with flow control valve at the entrance of inlet. Perforated pipe was used for the equal distribution of wastewater into the filtering bed of the system. System was planted with *Arundo donax* because of availability in the study area, its rapid growth and resistance to different stress. A control (unplanted) hybrid wetland system with the same configuration was run along with.

Performance of the system was assessed during the month of April, May and June 2018 to optimize hydraulic retention time. The system was supplied with domestic wastewater at different HRT of 24, 30, and 36 h over a given period of time. At each HRT wastewater was run for at least 15 days for proper accli-

Table 1. Average values of pH, temperature and DO in influent and effluent at different HRT

Parameter	Influent concentration	Effluent concentration					
		36 h HRT		30 h HRT		24 h HRT	
		HSFCW outlet (planted)	control outlet (unplanted)	HSFCW outlet (planted)	control outlet (unplanted)	HSFCW outlet (planted)	control outlet (unplanted)
pH	7.6 ± 0.16	7.8 ± 0.13	7.9 ± 0.42	7.5 ± 0.10	7.4 ± 0.24	8.24 ± 0.10	7.85 ± 0.08
Temperature, °C	31 ± 4	30 ± 5	31 ± 5	28 ± 1	29 ± 1	32 ± 1	32 ± 1
DO (mg/L)	0	5 ± 0.5	2.5 ± 0.5	3 ± 1	2 ± 1	3 ± 0.5	1.3 ± 1

* Average ± standard deviation.

matization of macrophytes and further influent and effluent samples were collected in the polyethylene bottles from system. The analysis of samples was carried out regularly to observe the performance of constructed wetland. Temperature, pH and dissolve oxygen of collected samples were analyzed onsite by the multiparameter probe. Further samples were taken to laboratory for the analysis of TSS, BOD, COD and TKN. Wastewater quality parameters were determined using standard America Public Health Association (APHA) methods [9].

RESULTS AND DISCUSSION

pH, Temperature and DO

The average experimental values of pH, temperature and DO for both influent and effluent are shown in Table 1. Minimum and maximum temperature was found to be 25 to 36°C during the functional period. In addition to temperature, pH plays an important role in CW especially during nitrification and denitrification process. Results showed that pH value varied from 7.2 to 8.3 in HSFCW, which is slightly alkaline and many research studies also indicate that pH value greater than 6.5 promotes denitirifcation [10]. On the other hand the slight variation in pH values may be due to microbial activities and plants exudation [11]. The effluent pH also meets the disposable standards prescribed by Central Pollution Control Board (CPCB) [12] and overall both temperature and pH were found to be in suitable range for the growth of microorganisms.

Influent sample showed absence of DO while DO was found to be improved in effluent collected from outlet of both planted and control wetland system. The mean values of the DO were observed to be 5 ± 1 mg/L, 3 ± 0.5 mg/L and 3 ± 0.5 mg/L in case of planted system while in control the mean values of the DO were 2.5 ± 0.5 mg/L, 2 ± 1 mg/L and 1.3 ± 1mg/L at 36, 30 and 24 h of HRT respectively. Increase in effluent DO may be due to photosynthetic activity as well as the atmospheric diffusion to the hollow air filled channels in the wetland plants that transport oxygen to the roots [13]. The leaves of the *Arundo donax* grows so well that might help in promoting photosynthetic activity, also the roots help in prevailing aerobic conditions within the system.

TSS

The average TSS concentrations obtained at 36, 30 and 24 h HRT are presented in Fig. 2a. The mean influent concentration of TSS was found to be 276 mg/L which cannot be disposed of either into inland water or in irrigation land directly as per the CPCB guidelines [12]. During the study, percentage removal of TSS was found to be 86.2, 84.61, 75.73% in case of planted wetland system and 76.44, 80.78, 74.11% in case of control wetland system at 36, 30, and 24 h of HRT respectively. Removal of TSS was successfully achieved by the slow movement of wastewater through the substrate as well as the root network formed by the macrophytes.

BOD

The results for average influent and effluent BOD concentrations are shown in Fig. 2b. Percentage removal of BOD was 89.75, 94.9, and 90.3% in case of control system while 94.22, 98.37, and 96.22% in case of planted system at 36, 30, and 24 h of HRT. Results obtained indicate that maximum BOD removal was achieved at 30 h of HRT. The decomposition of organic matter in HSFCW may be due to aerobic con-

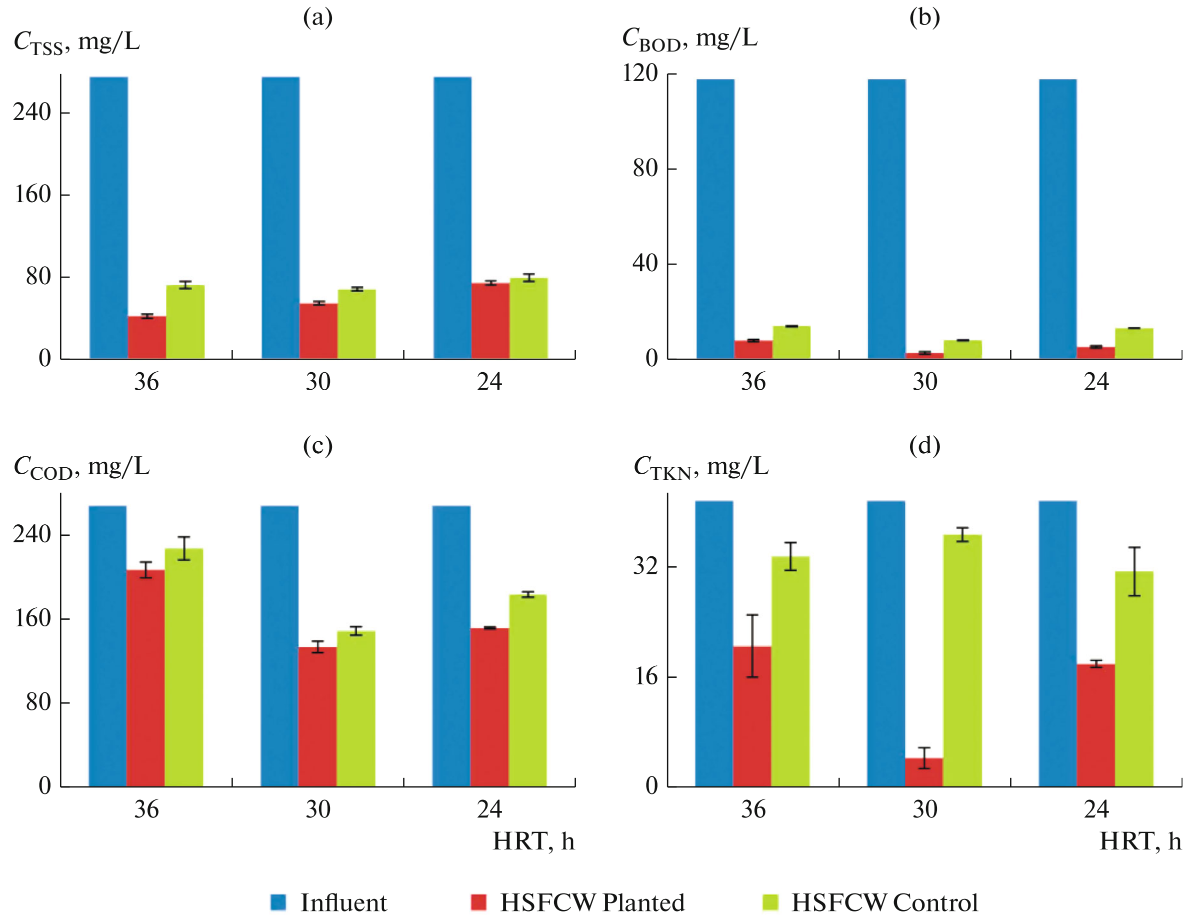

Fig. 2. Average concentration of (a) TSS, (b) BOD, (c) COD), (d) TKN in influent and effluent (planted and control) at 36, 30, and 24 h HRT.

dition in the root zone area of VSSFCW, anaerobic biological process in HSSFCW, filtration and sedimentation [14–16]. Results do not show any significant difference between planted and control (unplanted) systems in case of BOD removal and similar results are reported during different studies [17].

Concentration of BOD in effluent lies within the range of disposal on irrigation land and inland surface water prescribed by CPCB [12].

COD

The average COD concentrations obtained at 36, 30 and 24 h HRT are presented in Fig. 2c. COD removal was observed to be 38.16% at retention time of 24 h and 42.35% at 36 h of HRT. For 30 h of HRT removal of COD was found to be 61.39% in planted system. Similarly the removal of COD in control system was observed to be 16.25, 56.98, and 36.62% at 24, 30, and 36 h of HRT. A significant increase in COD removal was observed at 30 h of HRT which concludes that 30 h of HRT is sufficient for removal of organic matter. Difference in removal efficiency at different retention times is accomplished by good cooperation between the physical and microbial contact time [16]. Some of the studies also observed similar results for organic matter removal indicating that longer HRT as well as plants improve removal efficiency but on the other hand it has also been evident from their studies that it does not depend on the plants richness completely [18].

TKN

Mean values for TKN removal at different HRT are presented in Fig. 2d. Nitrogen is an important polluting constituent of domestic wastewater because of its role in algal growth and eutrophication in water bodies. Total nitrogen concentration in influent was observed to be 41.3 ± 1 mg/L during the operation period.

The percent removal of TKN during the study was found 55.87, 91.87, and 61.27% respectively in planted system and 28.11, 32.11, and 32.63% in control at 36, 30, and 24 h HRT. Significant removal of TKN was observed in planted HSFCW as compare to control system at 30 h of retention time. Removal mechanism of nitrogen in CW happens significantly due to ammonification, aerobic nitrification and anaerobic denitrification [19]. Therefore the hybrid wetland system was designed having VSSF and HSSF wetland bed where both aerobic nitrification and anaerobic denitrification could take place to achieve the sufficient nitrogen removal.

CONCLUSIONS

HSFCW system planted with *Arundo donax* has potential to treat domestic wastewater in terms of organic pollutants including BOD and COD. The removal observed was 98.37 and 61.39% respectively. The efficiency of TSS and TKN removal was 84.61 and 91.87% at 30 h of HRT. The purification process including vertical and horizontal subsurface flow system had a vital role in removal of organic pollutants, TSS and TKN. The average concentrations of all the pollutants were measured lower than the prescribed limits set by CPCB. Hybrid constructed wetland system planted with *Arundo donax* and other CW system studied in the literature proves that CW are economic and environment friendly treatment systems.

FUNDING

Authors are extremely grateful to Guru Gobind Singh Indraprastha University, Dwarka, Delhi, India for providing financial support in successful completion of the research work.

REFERENCES

1. Alcamo, J.M., Vörösmarty, C.J., Naiman, R.J., Lettenmaier, D.P., and Pahl-Wostl, C., A grand challenge for freshwater research: Understanding the global water system, *Environ. Res. Lett.*, 2008, vol. 3, no. 1, 010202.
2. Varis, O. and Somlyódy, L., Global urbanization and urban water: Can sustainability be afforded? *Water Sci. Technol.*, 1997, vol. 35, no. 9, pp. 21–32.
3. Chand, R., Srivastava, S.K., and Singh, J., *Changing Structure of Rural Economy of India Implications for Employment and Growth*, Aayog: Natl. Inst. Transforming India, 2017. https://niti.gov.in/writereaddata/files/document_publication/Rural_Economy_DP_final.pdf.
4. Ávila, C., Salas, J.J., Martín, I., Aragón, C., and García, J., Integrated treatment of combined sewer wastewater and storm water in a hybrid constructed wetland system in southern Spain and its further reuse, *Ecol. Eng.*, 2013, vol. 50, pp. 13–20.
5. Toet, S., van Logtestijn, R.S., Kampf, R., Schreijer, M., and Verhoeven, J.T., The effect of hydraulic retention time on the removal of pollutants from sewage treatment plant effluent in a surface-flow wetland system, *Wetlands*, 2005, vol. 25, no. 2, pp. 375–391.
6. Brix, H., Functions of macrophytes in constructed wetlands, *Water Sci. Technol.*, 1994, vol. 29, no. 4, pp. 71–78.
7. Brix, H., Do macrophytes play a role in constructed treatment wetlands? *Water Sci. Technol.*, 1997, vol. 35, no. 5, pp. 11–17.
8. Cooper, P., Griffin, P., Humphries, S., and Pound, A., Design of a hybrid reed bed system to achieve complete nitrification and denitrification of domestic sewage, *Water Sci. Technol.*, 1999, vol. 40, no. 3, pp. 283–289.
9. *Standard Methods for the Examination of Water and Wastewater*, Washington, DC: Am. Publ. Health Assoc., 2005, pp. 258–259.
10. Verhoeven, J.T. and Meuleman, A.F., Wetlands for wastewater treatment: Opportunities and limitations, *Ecol. Eng.*, 1999, vol. 2, nos. 1–2, pp. 5–12.
11. Kyambadde, J., Kansiime, F., and Dalhammar, G., Nitrogen and phosphorus removal in substrate-free pilot constructed wetlands with horizontal surface flow in Uganda, *Water, Air, Soil Pollut.*, 2005, vol. 165, nos. 1–4, pp. 37–59.
12. CPCB, General standards for discharge of environmental pollutants, Part A: Effluents, 2019. http://www.cpcb.nic.in. Accessed June 11, 2020.
13. Vymazal, J., Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment, *Ecol. Eng.*, 2005, vol. 25, pp. 478–490.
14. Akratos, C.S. and Tsihrintzis, V.A., Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands, *Ecol. Eng.*, 2007, vol. 29, no. 2, pp. 173–191.

15. Knight, R.L., Cooper, P., Brix, H., Vymazal, J., Haberl, R., and Kadlec, R.H., *Constructed Wetlands for Pollution Control*, London: Int. Water Assoc., 2000.
16. Kadlec, R.H. and Wallace, S.D., *Introduction to Treatment Wetlands*, Boca Raton, FL: CRC, 2009, 2nd ed., pp. 3–30.
17. Idris, S.M., Jones, P.L., Salzman, S.A., Croatto, G., and Allinson, G., Evaluation of the giant reed (*Arundo donax*) in horizontal subsurface flow wetlands for the treatment of dairy processing factory wastewater, *Environ. Sci. Pollut. Res.*, 2012, vol. 19, no. 8, pp. 3525–3537.
18. Zhang, C.B., Liu, W.L., Wang, J., Ge, Y., Gu, B.H., and Chang, J., Effects of plant diversity and hydraulic retention time on pollutant removals in vertical flow constructed wetland mesocosms, *Ecol. Eng.*, 2012, vol. 49, pp. 244–248.
19. Kadlec, R.H. and Knight, R.L., *Treatment Wetlands*, Boca Raton, FL: CRC, 1996.