

French Type Constructed Wetlands for Sewage Treatment: Experiences from the SWINGS Prototype in India

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Abstract

This study aimed to investigate the performance of the French Type Constructed Wetlands (FTCW) at a pilot scale level in real field conditions for sewage treatment in India. The pilot plant consisted of hybrid wetlands in two stages, vertical and horizontal sub-surface flow types. The first stage comprised three compartments, vegetated with three different native plants (phragmites australis, canna indica, and sagittaria), operated in parallel, and sequentially loaded. Each VSSF bed of 12.25 m² was fed with raw sewage directly for 3.5 days followed by twice the time resting period. The second stage consisted of one bed of an area of 45m², planted with canna indica. The filter media used in stage 1 was a dual type (gravel and coarse sand) in three layers. The first stage was designed for the loadings of 33.75g BOD/m²d and 14.1 gNH₄-N/m²d with the flexibility to operate at a variable hydraulic loading rate (HLR). Two years of monitoring data after the steady-state condition show variable performances at different hydraulic loading rates of 0.4m/d to 0.97 m/d. Removal efficiencies of COD, BOD₅, TSS, TN, and TP of the hybrid system at HLR of 0.4m/day were 87.1%, 87.3%, 84.6%, 67.93%, and 69.32% respectively. Doubling the HLR, the efficiency of the system decreased marginally for the same parameters. Out of the three vegetation, the bed planted with phragmites has shown the highest removal efficiency. The study has demonstrated that FTCW can be a suitable proposition as one of the potential methods for sewage treatment in India and similar regions.



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Introduction

In Indian sub-tropical climatic conditions, nature-based solutions (NBS) like constructed wetlands technology for sewage treatment are also gaining popularity over the other methods.^{1,2,3} For small flows, constructed wetlands (CWs) have been a proven, cost-effective, and easy-to-implement method with low O&M costs compared to conventional high-rate treatment systems.^{4,5} One of the most promising configurations of the CWs is the French Type wetland system for wastewater treatment.⁶ In contrast to the conventional CWs, the FTCW can treat raw wastewater directly without any primary treatment and is easy to deal with sludge management.⁷ The FTCW can be either a single-stage or a two-stage hybrid system. In the latter case, the first stage involves a vertical sub-surface flow (VSSF) bed receiving raw wastewater directly without any primary treatment whereas the second stage is a horizontal sub-surface flow (HSSF) bed, both filled with media.⁸

In countries having sub-tropical climatic conditions as prevailing in the major part of northern India, and in similar regions of its sub-continent, wetlands have an advantage over the colder regions.⁸ The growth of macrophytes and enhanced microbial activities are the main factors due to which CWs offer higher removal efficiencies in these regions.^{7,14}

Literature suggests that FTCWs have been widely adopted for wastewater treatment.⁹ In the previous studies, and from the results of the

full-scale installations that are in operation, the HLR are ranging from 0.37 m/d to 0.45m/d.^{1,10} The organic loading rates are generally kept in between 150 and 300 g CODm⁻²•d⁻¹ and whereas TKN ranges in between 25 and 30 g.m⁻²•d⁻¹.^{11,13} Another important factor in the good design practices of the FTCW is the selection of the macrophytes.¹² In most of the cases, as has been reported in the literature, *phragmites australis* is the most common specie used in the FTCW.¹²

In this study, hybrid FTCW was designed at a pilot scale level in the two stages (vertical flow and horizontal flow) with three different plants (*phragmites australis*, *canna indica*, and *sagittaria*) with the objective to investigate its performance in the removal of the pollutants from the sewage in a real field under sub-tropical climatic conditions. The secondary objective was to investigate the impact of different species on the performances under varying hydraulic loading conditions.

Materials and Methods

The study was carried out at the Aligarh Muslim University (AMU), Aligarh in India. The city (27°88'N, 78°08'E) is situated in the northern part of India and about 130 km south west of the capital city, Delhi (Figure 1). The climate is sub-tropical with high temperatures (27°C to 46°C) in summer and humid and cold (10°C to 1°C) during the winter season. The rainy season also lies in between summers and winters with an average annual rainfall of about 590 mm.



Fig. 1: Maps showing the location of the state of Uttar Pradesh and the Aligarh district. (Source: Uttar Pradesh district factbook)

The basic structure of the pilot set-up was constructed in reinforced concrete. The construction and study on this pilot were one of the objectives of the Indo-European SWINGS Research Project within the FP7 Framework program. The pilot set-up consisted of a screen chamber, grit channel, holding tank, and hybrid wetlands in two stages: a vertical sub-surface flow with 3 beds in parallel followed by a horizontal sub-surface flow wetland (Figure 2).

The two stages of the French CW system have a net area of around 82 m² (36.75 m² for the first stage and 45 m² for the second stage) designed to be operated at a variable hydraulic loading rate (0.4m/d to 0.97 m/d). The raw sewage was made available from the adjoining and existing sewage treatment plant (STP) of the university campus where this pilot study was conducted.

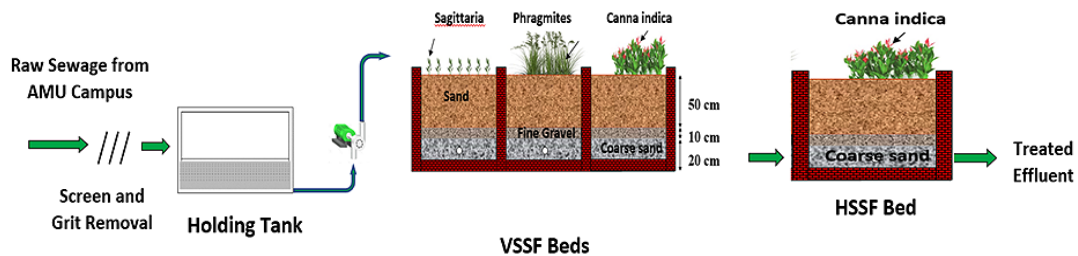


Fig. 2: Flow Scheme of the French Type CW Pilot Plant at AMU Aligarh, India

The raw sewage was tapped from the inlet chamber of the STP to the holding tank of the pilot set-up. Table 1 shows the dimensions and type of filter

media used in the construction of VF and HFCW units and the design parameter details are given in Table 2.

Table 1: Key Features of the Construction

VSSF CW	HSSF CW
Number of beds: 03	Number of beds: 01
Length: 3500mm or 3.5 m	Length: 10000mm or 10 m.
Width: 3500mm or 3.5 m	Width: 4500mm or 4.5 m.
Depth: 800mm or 0.8 m	Depth: 500mm or 0.5 m.
Media:	Media:
From the top to the bottom:	6-16 mm Ø gravel
50 cm of 2-4 mm Ø sand	
10 cm of 6-16 mm Ø gravel	
20 cm of 20-40 mm Ø gravel	

Table 2: Details of design parameters of different pilot units of FTCW

Different units	Effective area (m ²)	Water depth (m)	HRT (hours)	Loading rate (m ³ /day)	Effective volume(m ³)	Plantation
Bed 1	12.25	0.97	17	5,10,12	11.88	<i>Canna indica</i>
Bed 2	12.25	0.97	17	5,10,12	11.88	<i>P. australis</i>
Bed 3	12.25	0.97	17	5,10,12	11.88	<i>Sagittaria</i>

Operations, Sampling, and Monitoring

The first stage (VSSF) was operated in a sequential mode: each bed was fed with raw sewage directly for 3.5 days followed by twice the time resting period

of 7 days. Figure 3 shows the view of the pilot VSSF CW and HSSF CW units in Aligarh during the initial stages and after achieving steady-state conditions respectively.



a. Start-up Phase of the beds of VSSF CW



b. Steady-State Condition of VSSF CW



(c) Start-up Phase of the bed of HSSF CW



(d) Steady-State Condition of the bed of HSSF CW

Fig. 3: View of the Pilot Plant at AMU Aligarh, India

The pilot plant was operated and monitored for a period of 2 years for three variable HLRs of 0.4, 0.81, and 0.97m/day at a pulse loading of a single bed. Locally available native plants were used in the study. Each compartment of stage 1 was planted with different species. These were *Canna indica*, *Phragmites australis*, and *Sagittaria*. The wastewater was distributed uniformly over the top of the bed surface through perforated pipes perpendicular to the water flow 10 cm below the surface. Drainage pipes were installed at the bottom of the beds perpendicular to the flow at the other side of the filter. The purpose of HSSF CW was to polish the treated wastewater from VF beds on a continuous basis.¹⁵ This single bed of stage two in this study (HSSF CW) was vegetated with *Canna indica*.

After the steady-state condition, the monitoring of the plant was carried out over a period of two years. The study was started in the year 2017 and completed in 2019. The system took about 4-5 months to reach the steady-state condition after the vegetation was planted in the beds. After attaining good growth of macrophytes with proper development of shoots and root zones in all the beds, regular sampling and

monitoring were started. The sampling was carried out for Physico-chemical pollutants. The wastewater parameters such as temperature, pH, electrical conductivity, and dissolved oxygen (DO) were recorded with a multimeter on an in-situ basis where BOD₅, COD, TSS, TN, and TP were analyzed in the Environmental Engineering Laboratory, Department of Civil Engineering, AMU, Aligarh. Grab samples were collected in properly prepared clean and acid-washed bottles and the samples were transported in a refrigerated box while maintaining a temperature of 4°C to the laboratory. For analysis purposes, the procedures given in the Standard Methods for Water and Wastewater Examination (APHA, AWWA, WEF, 2005) were used.

Results and Discussions

The mean concentrations of the wastewater contaminants are presented in Table 3. For the domestic wastewater available, the mean of the fluctuations of the inlet concentrations in all three beds over its cyclic loading was observed in terms of COD (125.51 ± 31.9 mg/l), BOD₅ (68.58 ± 17.1 mg/l), and TSS (43.48 ± 9 mg/l).

Table 3. The mean concentration of raw, untreated wastewater observed over 2 years period

Influent and Effluent Concentrations in (mg/l)										
Vertical Flow Constructed Wetlands (FTCW)										
Parameter		BED 1		BED 2		BED 3		After HFCW		
		In	Out	In	Out	In	Out	BED 1	BED 2	BED 3
BOD	Mean±	66.67	22±9.1	69.48±	20.25±	69.61±	25.93±	8.74±	9.03±	9.29±
	SD	±17		17.5	10.8	16.8	10.7	4.7	4.8	4.9
COD	Mean±	120±	36.73±	128.4±	33.73±	128.13±	44.66±	15.73±	14.66±	19.33±
	SD	24.7	14.4	39.7	16.4	31.5	17.6	7.9	6.7	10.4
TSS	Mean±	42.37±	8.4±	42.95±	8.02±3	45.13±	8.57±3	6.98±	6.42±3	6.76±
	SD	9.6	2.2	9.9		7.7		2.4		3.1

The first stage efficiency after the influent passed through the three vertical flow beds planted with the three macrophytes species was observed as *Canna indica*: 70.3%, 67.93% and 79.99% for COD, BOD₅ and TSS respectively; *Phragmites australis*: 74.47%, 71.91% and 81.32% for COD, BOD₅ and TSS, respectively and

Sagittaria: 66.11%, 63.76% and 81.09% for COD, BOD₅ and TSS, respectively.

The second stage of treatment involved a horizontal flow CW planted with *Canna indica* species which further enhanced the quality of treated effluent from the vertical flow beds by removing the

contaminants. Stage 2 efficiency was observed as *Canna indica*: 58.07%, 62.07% and 18.27% for COD, BOD₅ and TSS, respectively, *Phragmites australis*: 55.02%, 55.07% and 22.02% for COD, BOD₅ and TSS, respectively; and *Sagittaria*: 58.38%, 65.58% and 23.01% for COD, BOD₅ and TSS, respectively.

The overall efficiency of the French-type CWs system was observed as 87.1%, 87.3%, and 84.6% for COD, BOD₅, and TSS, respectively. Stage 1, Stage 2, and overall efficiency are shown in Figures 4(a), (b), and 3(c) respectively.

The use of variable filter media such as gravel and sand for the vertical flow CWs also affected

the treatment process by enhancing the growth of microorganisms and the development of the sludge layer on top of the beds.¹⁶ The removal efficiencies of nutrients like TN and TP were also assessed. The treatment efficiency measured for TN and TP is 67.93% and 69.32% respectively (Fig.3 (d)). These efficiencies were observed to be comparable to those reported for domestic wastewater,¹³ which can be most likely due to the favourable growth conditions for macrophytes and microorganisms in a climatic condition, as was prevailing in the study region.¹²

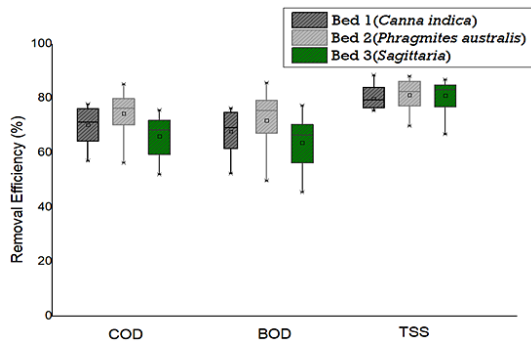


Fig. 3: (a) First Stage Efficiency

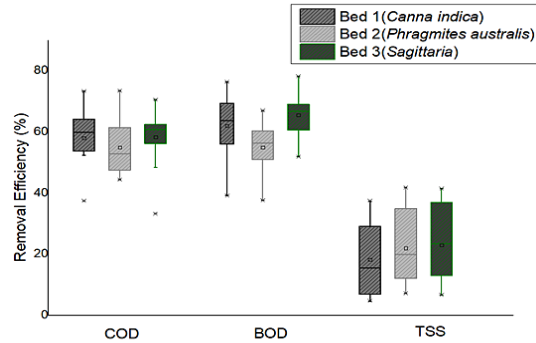


Fig. 3: (b) Second Stage Efficiency

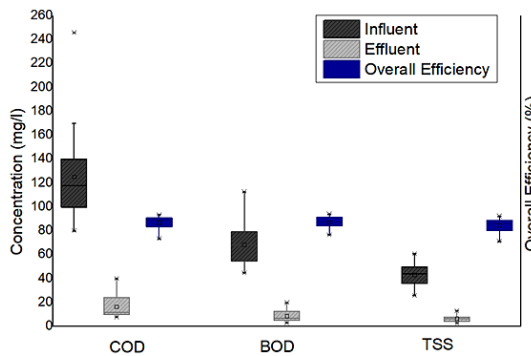


Fig. 3: (c) Overall Efficiency

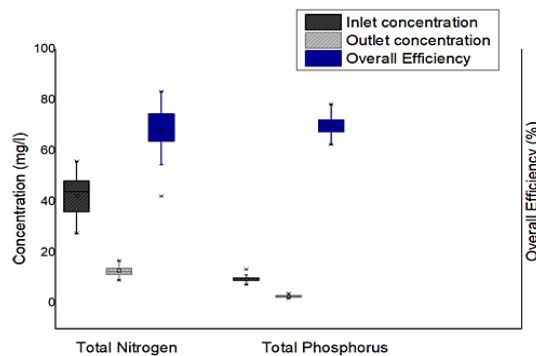


Fig. 3: (d) TN and TP removal efficiencies

Influence of Variable influent flow rates on the Performances

The influent flow rate was varied for the performance evaluation of the French system of CWs during the assessment and monitoring period. The HLR was gradually changed from 0.4m/d, 0.81m/d, and finally

to 0.97m/d over a monitoring period. Varying HLR resulted in a change in stage 1, and stage 2, and the overall efficiencies of the system.¹⁰ However, a significant change was not observed in the removal efficiencies when the HLR varied from 0.81m/day to 0.97m/day. It was observed that there was

a decrease in the removal efficiencies of the pollutants with the increase in influent flow rates^{10,20,21} (Fig.3). The removal rates observed for the overall system for COD, BOD₅, and TSS at different HLRs are as at

0.4m/day: 87.15%,87.37%, and 84.66%; At 0.81m/day: 84.68%,85.40%, and 83.60%and at0.97m/day: 84.24%,84.43%, and 83.49% respectively.

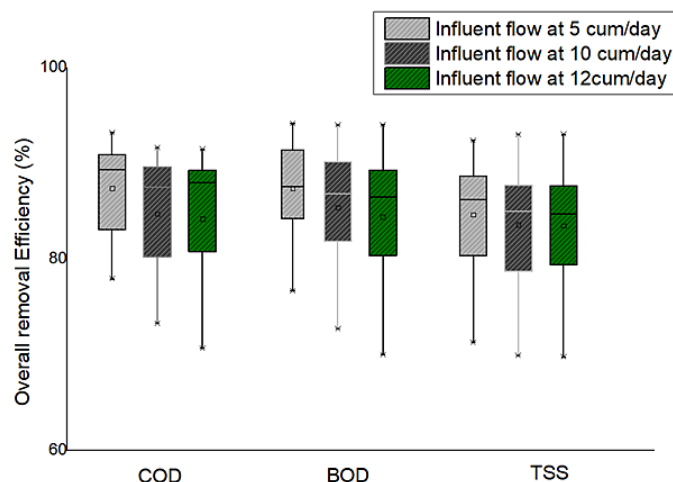


Fig. 3: Overall performance of the FTCW at loadings (equivalent to 0.4m/d, 0.81m/d and 0.97m/day)

During the commissioning phase, low efficiencies were observed. This can be attributed to less deposition of the sludge layer on top of the filter beds thereby reducing the interaction between the macrophytes and micro-organisms.^{11,16,17} However, once the steady condition was reached during the course of this study, it was observed that the performance of the FTCW improved with time and this can be attributed to the deposition of the sludge layer on top of the vertical flow beds and its role in the removal process.^{11,14,17} The study is also in concurrence with the previous studies that mineralization of the sludge layer increases the capacity of the treatment system and the effect of low influent flow increases the contact time between wastewater and microorganisms.^{11,17} The decrease in second stage efficiency was observed due to the better removal efficiency by the first stage VF beds.^{18,20}

Conclusions

Two years of monitoring data of the pilot plant based on the hybrid French-type constructed wetlands configuration in real field conditions under the Indian sub-tropical climatic conditions has shown average removal efficiencies (overall) for the parameters

COD, BOD₅, TSS, TN, and TP of 87.1%, 87.3%, 84.6%, 67.93%, and 69.32% respectively. Out of the three VSSF beds with a different plantation, the bed with sp. *Phragmites australis* has shown the highest removal efficiency at an HLR of 0.4m/d followed by sp. *Canna indica* and sp. *sagittaria*. The efficiencies gradually reduced when the HLR was increased from 0.4m/d to 0.81m/day and further to 0.97m/day. This shows that by lowering the hydraulic retention time, the efficiency of the stage 1 system decreases, and ultimately it has an impact on the overall water quality. Once the steady state condition is reached, the quality of the treated effluent after the second stage of treatment was found within the permissible Indian limits for disposal in the surface water. The findings showed that the French Type CW in a hybrid configuration can be a very promising way to deal with sewage in India or in regions having similar climatic conditions.

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Conflict of Interest

The authors do not have any conflict of interest.

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