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Phytoremediation of Secondary Treated Sewage through Constructed Wetland: Lab-Scale Study

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Abstract: Due to increasing urbanization and industrialization, India freshwater resources are deteriorating. Discharge of untreated wastewater into the aquatic ecosystems is the major source of pollution to these ecosystem. Conventional methods of treatment of the wastewater are quite costly, energy-intensive and require huge investment while natural systems such as Constructed Wetlands (CW) can be a better option for the treatment of wastewater. Under the present study laboratory scale Vertical Flow Constructed Wetland (VFCW) was utilized for the further treatment of secondary treated effluent collected from the MBBR (Moving bed biofilm reactor) based sewage treatment plants (STPs). The lab scale VFCWs were planted with *Typha latifolia* and *Canna indica* plants and filled with gravel and sand which act as growth and filter medium. Experiments have been performed to evaluate the performance of VFCW at different retention times (RT) in hours (h) i.e., 0 h, 24 h, 48 h, and 72 h. The secondary treated sewage was supplied to the VFCW and a change in the physicochemical properties of the sewage with increasing time was measured. There was continuous decrease in the major parameters of the secondary treated sewage in 72 h of incubation period thereafter a little or no change was observed. The removal efficiency for biological oxygen demands (BOD), chemical oxygen demands (COD), nitrate also phosphate was more after 72 h through VFCW planted with *Typha*than with *Canna*. The VFCW planted with *Typha*also showed greater performance than VFCW planted with *Canna*. The removal efficiency of VFCW for unplanted (control) system wase less than the planted system.

Keywords: Constructed wetlands, Domestic sewage, Freshwater, Removal efficiency, Retention time, Traditional methods, Vertical flow constructed wetland

Contamination of rivers, lakes, ponds, waterways, and groundwater has become a serious concern in developing nations like India. Agricultural run-off, industrial discharges, domestic sewage, and other sources of pollution have badly contaminated the bulk of aquatic habitats (Gupta et al 2020, Yadav et al 2021). In the Indian context, agriculture discharge, industrial effluents and sewage contribute as 65, 25, and 10% towards the quantitative pollution load of the aquatic environment (Kumar et al 2015). However, industrial effluents are now regulated and controlled by the laws and agricultural runoff being the diluted source domestic sewage being the most problematic fraction for the surface water resources (Kaur et al 2012). The majority of the water consumed in the houses and residential accommodations of the industries returned as sewerage (domestic sewage), and is discharged into nearby riverine ecosystems without proper treatment (CPCB 2013, Harshvardhan and Jha 2013) and thus become the greatest nuisance to the surface water resources. Existing sewage treatment plants are insufficient to treat the total sewage generated in India (CPCB 2016, Kamyotra and Sinha 2016). According to the survey conducted by Central Pollution Control Board (CPCB) of India in 2017 out of the total 1469 sewage treatment plants (STPs) 578 were operational thus treating 26869 Million Liters per Day (MLD) of sewage and the non-functional STPs at the same time discharged 123.16 MLD untreated sewage into the aquatic environment (CPCB 2018). Despite being the fact that there had been a sharp increase in the total installed capacity of STPs the gap between total sewage produced and untreated has widened (CPCB 2013). Most of STPs are quite costly, energy intensive and complex in natures which require huge capital and running cost. Such limitations put a demand for new, ecofriendly and cost effective technology for the sewage treatment. Constructed Wetland (CWs) is an effective, environment friendly, and economic feasible option for sustainable treatment of sewage (Mishra et al 2018, Singh et al 2021, Singh et al 2022). Constructed wetlands have been used for the treatment wide variety of pollutants including sewage. However, most of the studies dealing with CWs have been done in Europe and North America. Therefore, we performed this study with an objective to treat the secondary treated sewage by using lab scale Vertical Flow Constructed Wetland (VFCW).

MATERIAL AND METHODS

Study area: This study was conducted at the Institute of Environment and Sustainable Development (IESD), Banaras

Hindu University (BHU), Varanasi. The study involved further treatment of secondary treated domestic wastewater collected from Bhagwanpur Sewage treatment plant (STP) of Varanasi, Uttar Pradesh. This STP is located between 25°0' to 25°16' N latitude and 82°5' to 83°1' E longitude. This STP receives domestic sewage from BHU and the surrounding area with an installed capacity to handle 8 MLD sewage.

Sampling and analysis of secondary treated and CW treated sewage: Sewage samples were collected from the discharge point of the Bhagwanpur STP and brought to the laboratory for analysis. The study was performed for six months during which the treatment of secondary and tertiary sewage was performed through lab-scale VFCW. The effluent was analyzed before it was batched into the laboratory-scale constructed wetlands. To each wetland set up 3.5 liters of secondary treated effluent was supplied and the effluents were analyzed at various retention times i.e., 0 h, 24 h, 48 h, and 72 h for different physicochemical properties. Samples were collected and analyzed for various physicochemical properties viz TDS, alkalinity, total hardness, BOD, COD, nitrates, phosphates, and microbial activity (total coliform, fecal coliform, and *E. coli*). The samples were analyzed following the methods of APHA (2017). Microsoft Excel (version 2013) was used for the statistical analysis. Following formula was used to calculate the removal efficiency for different parameters.

$$\text{Removal percentage (\%)} = \frac{\text{Initial concentration} - \text{Final concentration}}{\text{Initial concentration}} \times 100$$

Experimental design: A lab scale vertical flow constructed wetlands (VFCW) was built at the IESD, BHU, Varanasi. The wetland was constructed using a plastic bucket of dimensions 30 cm x 36 cm x 30 cm. The bucket was filled with sand (<0.5 mm) of 13cm length followed by gravel (20 mm – 22mm) of 10 cm of length at the bottom of the bucket. The perforated polyvinyl chloride (PVC) pipes were used for the aeration in the constructed wetland. Three different setups of VFCW in triplicates were established in the laboratory. Setup 1 was planted with *Typha*, set up 2 with *Canna,* and set up 3 with no plant (control), to evaluate the concentration of sewage with increasing time. Each Set of VFCW was irrigated with tap water for one month initially before the experiment to acclimatize the wetland plants to their new environment. The detailed study and design of experimental VFCW is presented in Table 1 and Figure 1 respectively.

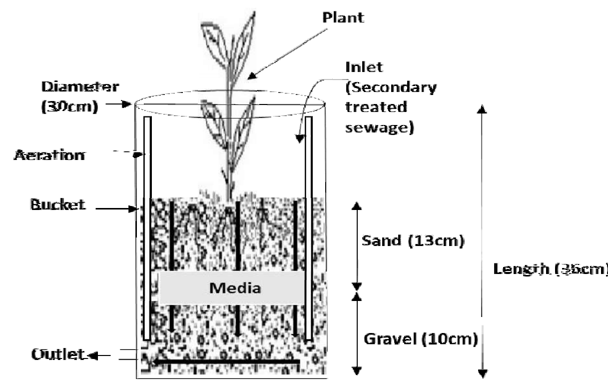

Fig. 1. Diagrammatic representation of constructed wetland set up in the laboratory

RESULTS AND DISCUSSION

General physicochemical properties of treated sewage: The secondary treated sewage collected from Bhagwanpur STP was analyzed immediately after the collection and analyzed before treatment i.e., at zero hours (Table 2).

Performance of vertical flow constructed wetland (VFCW) for sewage treatment: The sewage from Bhagwanpur STP was subjected to treatment with two different setups of VFCW, v.i.z., setup 1; wetland planted with *Typha* and set up 2 wetland planted with *Canna*.The analyses of the treated sewage samples were performed at different time intervals i.e. 0, 24, 48, and 72 h. The experiment was performed further but there were no significant changes therefore further experiments were conducted up to 72 hours of retention time (RT) (Figs. 2, 3).

Table 1. Details of experimental VFCW

Set up no.	Set up type	Container size	Media used	Media length	Plant used
1.	Set up 1	D-30 cm L-36 cm V-25 lit.	Sand & Gravel	13 cm 10 cm	*Typha* (Triplicates- plant A, B & C)
2.	Set up 2	D-30 cm L-36 cm V-25 lit.		13 cm 10 cm	*Canna* (Triplicates- plant A, B & C)
3.	Set up 3	D-30 cm L-36 cm V-25 lit.		13 cm 10 cm	Unplanted (Control)

Analysis of different parameters of effluent treated by both the experimental VFCW set up revealed a significant change in all the parameters during 72 h period. The VFCW planted with *Typha* has removed 68.65, 63.26, 67.14 and 65%, of biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate, and phosphate respectively during 72 hours of retention time. The removal efficiencies after 72 h of incubation period through VFCW planted with *Canna* for BOD, COD, nitrate, and phosphate were 26.40, 55.90, 28.57 and 61.66%, respectively. When compared the change in the BOD, COD by both the setups it was observed that set up 1, i.e. VFCW planted with the *Typha latifolia* showed the higher removal of BOD & COD in comparison to the set up 2, i.e. VFCW planted with *Canna*. Therefore, *Typha latifolia* as better performer than *Canna indica* for the removal of BOD & COD (Fig. 4). This indicates that *Typha* has developed a dense network of roots in short span of time in comparison to *Canna*. The elimination of BOD and COD may be accelerated by the presence of dense plant roots and the filter media such as sand and gravel (Stefanakis et al 2014, Barya et al 2020, Shukla et al 2021). The BOD and COD elimination was also dependent on the retention time, increasing retention time results in higher removal efficiencies (Bakhshoodeh et al 2020). Sehar et al (2015) elucidated that the BOD and COD elimination is supported by the mutual interactions among the microbial and physical mechanism of the removal of the pollutants by involving the dissolved oxygen.

The major nutrients present in sewage i.e. nitrate and phosphate were also removed by VFCW. The highest removal of these parameters was observed at the retention time of 72 hours in both the set ups of VFCW (set up 1 & 2) (Fig. 4). The VFCW planted with *Typha* (set up 1), showed the 28.3% and 61% removal of nitrate and phosphate while for the same parameters VFCW planted with *Canna* (set up 2) showed 56.4 and 57.6% removal, respectively. The removal of nitrate and phosphate might be due to physico-chemical pathways with sorption and precipitation (Reddy et

Table 2. General physicochemical composition of sewage (Mean ±SD)

Parameters	Concentration (0 h)
TDS (mg/l)	362.06±0.11
Alkalinity (mg/l)	586.03±0.06
Total hardness (mg/l)	230.006±0.01
BOD (mg/l)	47.56±0.05
COD (mg/l)	231.33±0.57
Nitrate (mg/l)	27.10±0.001
Phosphate (mg/l)	0.60±0.001

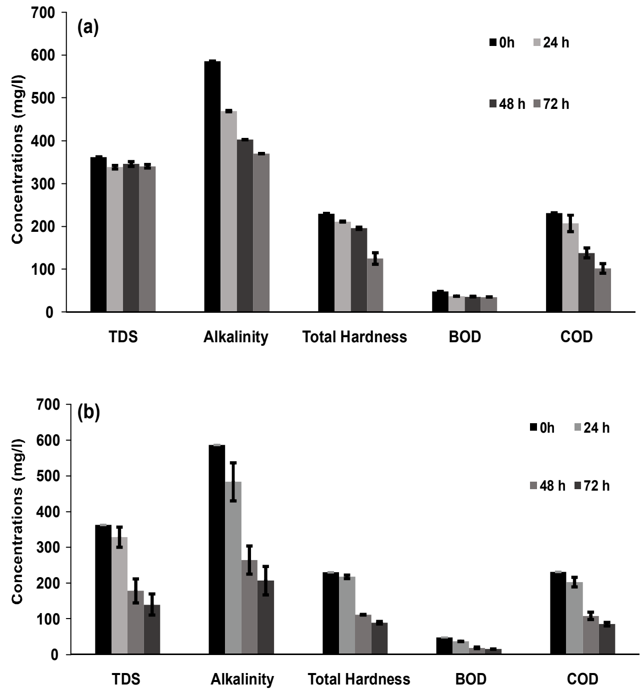

Fig. 2. Performance of (a) *Typha* sp. and (b) *Canna* sp. in reducing different physicochemical parameters at different retention times (RT) in VFCW

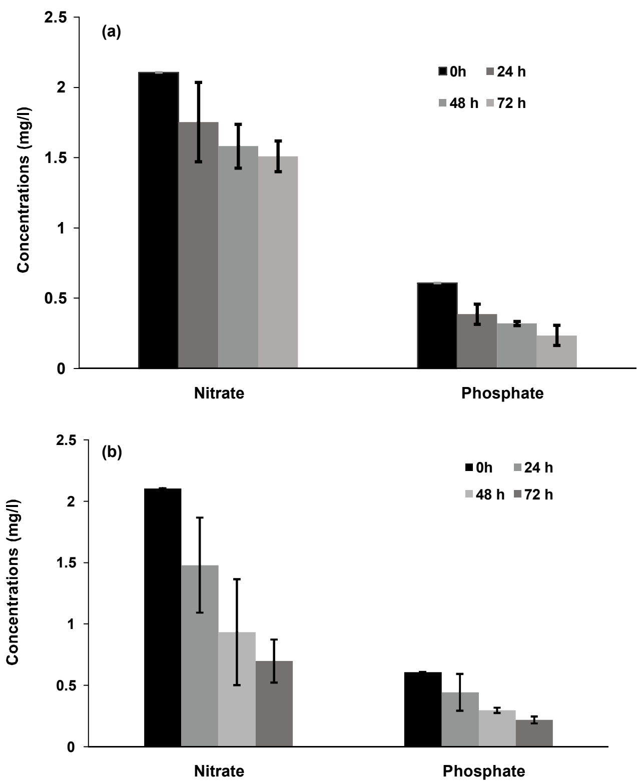

Fig. 3. Performance of (a) *Typha* (b) *Canna* in reducing nitrate and phosphate at different retention time (RT) in VFCW

al. 1999). The particulate phosphorous is removed through filtration (Kadlec and Wallace 2009) by the filter media used in the constructed wetland system. Gagnon et al (2010) have observed that the contents of the organic compound into the specific organic carbons are the factors that determine the elimination of the nitrates from the wastewater into the artificially created swampland systems. Zhang et al (2018) and Zhu et al (2014) have verified that by the escalation of the COD/NO_3 ratio into the treated wastewater, the efficiencies of the nitrate elimination may increase. Macrophytes with the CW system plays an essential role in the treatment of various parameters by the releasing oxygen through their rhizomes to the bottom treatment wetlands, as well as provides the medium underneath the water surface for the attachments of the micro-organisms to achieve the biological treatments (Batool and Seleh 2020). Zhang et al (2007) have demonstrated that the perennial plant ensures the continuous treatment. The *Typha latifolia* and *Canna indica* are resistant, fast growing and robust plant which can perform for the treatment of diverse set of pollutants.

Treatment of coliforms from secondary treated sewage through VFCW planted with *Typha:* The macrophytes such as *Typha* rooted in the filter media of sand and gravel possesses a great potential to reduce the number of coliforms. As revealed by the lab analysis the secondary treated sewage still contains significant number of total coliforms and is the source of pathogens which is the most important indicator of fecal contamination of water bodies.

Under the present investigation VFCW also performed well for the reduction of total and fecal coliforms as well as *E. coli.* from the secondary treated sewage. The initial value (MPN) of total coliformwas 1.6×10^4 before the treatment. During 72 h of experimental period there was a significant reduction in this number and after treatment it was reduced to 9.2×10^2 at 72, whereas the control shows a reduction in MPN up to 1.6×10^3. The initial value of fecal coliform was 1.7×10^2 at 0 hours which after 72 hours of treatment was reduced to 1.7×10. The control experimental set up (without plant) showed a reduction in MPN to 7.8×10 after 72 hours. The MPN value of *E. coli* at 0 hours was 5.1×10 and it was reduced to 2.2×10 after treatment in 72 h. It implies that the plants are responsible for reducing the coliform in the samples. The VFW without plant also showed the some pathogen removal in the same period.

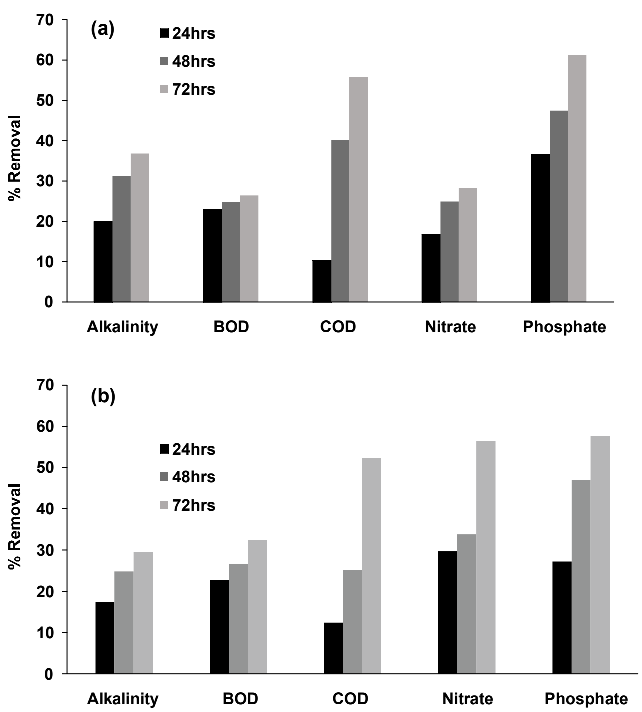

Fig. 4. Removal efficiency of VFCW planted with (a) *Typha* and (b) *Canna* for the treatment of various parameters

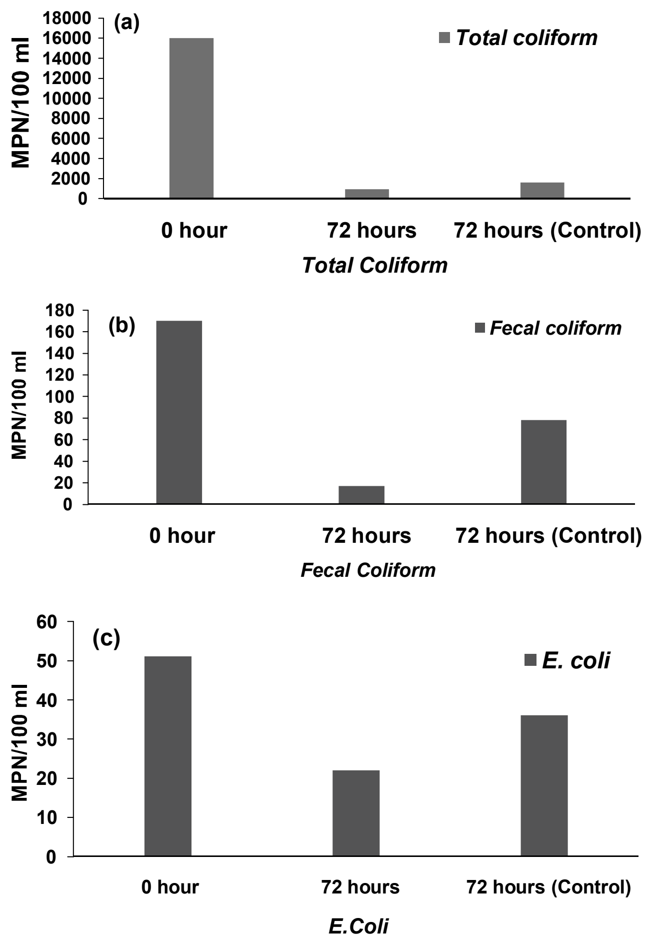

Fig. 5. Performance of (a) *Total coliforms*, (b) *Fecal coliform* & (c) *E. coli* at different retention time (RT) in VFCW

Overall, the results revealed the significant removal of various important parameters like BOD, COD, nutrients, and coliforms of the secondary treated sewage through VFCW planted with *Typha latifolia* and *Canna indica*. The performances of the planted VFCW were better for the removal of almost all the parameters of the secondary treated sewage. This may be attributed to the role of the plant's root which aerated the root zone and performed the uptake of nutrients from the root zone. This was also recognized that the elimination of almost all the parameters increased with increasing detention time till 72 hours. Figure 3 shows the behavior of nutrients and organic matters. The reduction of microbes (Coliforms and *E. coli*) with planted VFCW system showed was higher than the unplanted (control) systems. Lesser removal in unplanted (Control) constructed wetland system was due to the pore size available in the substrate (sand and gravel) (Ramprasad et al 2017) and unavailability of vegetation. Substrates like gravel and sand provide a large surface areas for the microbial growths, also high oxygen accessibility which functioned proficiently to the elimination of the pollutants (Ge et al 2015). Substrates (sand and gravel) play essential roles in percolation, adsorptions, as well as ion exchange. Hydraulic permeability and the adsorption capacities were the chief characteristic of the substrate which promoted the performance of the experimental CWs. The gravel generally increases the percolation of the swamp lands as well as minimizes clogging also increases the nitrification process (Rai et al 2015). Sand media provides support to plants' development and also provides a platform for microbial development as well as ion exchange (Arroyo et al 2013).

CONCLUSION

Constructed wetlands are gaining the attention of scientists as valid alternative for the sewage treatment in India. It is an effective as well as efficient system for removing nutrients loads from municipal sewage wastewater. VFCW have proven efficient in treating the sewage for almost all the major parameters. The activity of the substrate (sand & gravel), plants, and microbes inside the systems supports the decent environmental conditions which enhance the water quality. *Typha latifolia* as the vegetation was a better performer for the treatment of sewage VFCW. *Canna indica* remained assessed as proficient in the reduction of some parameters like nitrates. There were important differences in reducing the physicochemical parameters between the control (unplanted) and planted system. VFCW have abundant potentials to be applied for the treatment of domestic sewage. Decades of researches have shown the domestic wastewater treatment through VFCW is a promising alternative to conventional treatments. This can be applied as a means of educations to identify the individuals about the low-cost also about low maintenance wastewater treatment technology specially in Indian context.

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