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Original Research Paper

Selection of Suitable Plant Species in Semi Arid Climatic Conditions for Quality Improvement of Secondary Treated Effluent by Using Vertical Constructed Wetland

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ABSTRACT

The wetland plant species play a critical role in determining the performance of the wetland systems. Thus selection of suitable plant species for vegetation in treatment wetland units is of great importance to enhance the efficiency of the system. The present research aims to identify the suitable plant species for constructed wetlands in the semi-arid climate of Rajasthan (India). The performance of the two widely used Indian wetland plants, *Phragmitis australis* and *Canna indica* were evaluated in vertical up-flow constructed wetland using secondary treated effluents. Performance efficiency of both the plant species was evaluated for physico-chemical and microbial contaminants removal. The proposed study highlights the comparative as well as significant suitability of *Canna indica* plantation over the *Phragmitis australis* under semi-arid climatic conditions. The unit planted with *Canna indica* showed 39.7 and 50.9% removal for total Kjeldahl nitrogen (TKN) and ammonia-nitrogen respectively. Nitrate nitrogen in the treated effluents has a significant increment of 3.8 times higher than influents. Importantly, the indicator organism coliform reduction was observed as 1.87 log (MPN/100mL) in the effluent of *Canna indica* planted unit as against 1.01 log (MPN/100mL) in the effluent of *Phragmitis australis* planted wetland.

INTRODUCTION

In recent decades, planned reuse of wastewater has gained importance, as the demand for water dramatically increased due to increased population growth, urbanization and technological advancements (Vigneswaran & Sundaravadivel 2004). As a part of urban planning and management, in India, government has developed the technically sound centralized wastewater treatment plants in every state of the country. Their effluent quality is regulated by imposing standards for their corresponding final disposal (discharge into water bodies and its reuse). But, it has been clearly stated in the report of Central Pollution Control Board, India that the effluent from treatment plants rarely meets the standard limits of final disposal (CPCB 2008). Therefore, a tertiary treatment step has been suggested and employed in many of the treatment sites.

The technologies like chemical dosing, biological treatment using constructed wetlands and disinfection by UV and others are being used at this step. Constructed wetland is the most popular environmentally sound option and its suitability has been proved for removal of the contaminants since 1950s. The treatment plants are conventionally based on physico-chemical contaminants as well as nutrient removal only. There is lack of strict national standards for microbial contaminants in effluent disposal; the research is an attempt to improve the quality of secondary treated effluent in Jaipur, Rajasthan using constructed wetlands. Constructed wetlands technology has been used to improve the effluent quality especially in terms of microbial contaminants removal. Large land availability is prime constraint in India for developing field scale constructed wetlands, therefore, vertical upflow constructed wetland (VUFCW) was selected within the aim of the study. The research is firmly based on literature which clearly indicated the significant use of constructed wetlands for microbial contaminants removal (Hench et al. 2003, Vacca et al. 2005, Sleytr et al. 2007, Kadam et al. 2008, Chang et al. 2010). The challenge was to select suitable, efficient and effective plant species that are available in semi arid climatic conditions prevailing in Rajasthan, India. However, the use of *Phragmitis* plant species for wetland establishment is a tradition and still in practice worldwide. *Canna indica* is a well studied plant species for wetland establishment in China and other countries (Calheiros et al. 2007, Naz et al. 2009).

The present research is aiming to investigate the best suitable plant species while comparing *Phragmitis australis* and *Canna indica* for secondary treated effluent for removal of coliforms and other contaminants.

MATERIALS AND METHODS

Pilot scale vertical up-flow constructed wetland units were established in April 2012 at Malaviya National Institute of Technology, Jaipur, India. The three constructed wetland units (UN-ph, UN-cn and UN-ct) were similar in terms of bed media configuration but different in terms of plantation (Table 1).

Secondary treated wastewater was brought from STP (Sewage treatment plant) based on ASP (activated sludge process) in Jaipur. The treated wastewater was kept in a feeding tank and used to feed all the constructed wetland units. Each treatment unit was separately connected to the feeding tank via peristaltic pump and silicon piping, and effluent collection pots were properly placed for each of the unit. All the treatment units were established in the syntax tank of HDPE material which was structured as trapezoid. The bottom length of the each unit was smaller than the surface by 4cm. The empty volume of each treatment unit was 51123cm^3/51.123L and the measured void volume was 19-20L for each of the unit. The connection of feeding tank and treatment units was established through silicon pipes attached with separated outlet ports of feeding tank to inlet point of each treatment unit. The treatment units were installed with inlet port at the bottom and outlet port at the top. A steel sieve was kept at 12cm (h1) above, from the bottom, in each of the treatment unit to separate the inlet chamber from treatment bed and it also helps in uniform distribution of water throughout the treatment bed. The treated wastewater flows first into the inlet chamber via valve and then passes upwards to the treatment bed to allow continuous flow and finally collected from outlet ports in effluent pots. The system was operated at 6.8L/d hydraulic loading rate with continuous loading/flow which corresponds to approximately 3 day hydraulic retention time.

During the establishment of the system, two plant species *Phragmitis australis* and *Canna indica* were planted and seeded with gradually increasing ratio of secondary treated wastewater in lieu with tap water. The plantlets of *Phragmitis australis* were sourced from the already existing constructed wetland in north region of Jaipur while plantlets of *Canna indica* were sourced from nursery at MNIT campus. After 3 months of the establishment period, units were applied with secondary treated wastewater. Water samples of approximately 100mL were collected from influent and effluent to evaluate the performance analysis of all four different units. For microbiological analysis, three parameters: Total coliform, Faecal streptococci and *Salmonella typhi* were used and for physico-chemical analysis pH, DO, COD, NH_4-N, TKN and NO_3-N were measured following the methods described in APHA (1998). Samples were processed within 2hr of sampling for microbiological analysis and within 12hr for chemical analysis. The paper will deal with suitability of plant species in terms of removal of Total coliforms along with physico-chemical analysis for all the three constructed wetlands during the study period.

Table1: Insight of vegetation and media type present in three constructed wetland units.

UFCW	Vegetation	Medium
UN-ph	*Phragmitis australis*	Gravels
UN-cn	*Canna indica*	Gravels
UN-ct	None	Gravels

RESULTS AND DISCUSSION

In the present study, organic matter degradation was calculated as COD and reduction of nutrients calculated in terms of removal of TKN, ammonia-N and nitrate nitrogen. Such removal processes are mainly affected by ecological conditions within the constructed wetlands; pH reflects the buffering conditions whereas dissolved oxygen (DO) content will give an estimate of aerobic/anaerobic conditions prevailing in the system. Microbial contaminants are of major importance as they are related to health risk associated with effluent and observed in terms of number of Total coliforms.

Influent characteristics: The influent characteristics obtained from secondary treated wastewater for the present research (Table 2), highlight the need for tertiary treatment to reduce the microbial contaminant load. The variations occurred due to incoming raw sewage at the treatment site where the concentrations of different contaminants cannot be controlled. Mean concentration of organic matter and nutrients in treated effluent are within prescribed standard limits. Dissolved oxygen concentration needs to be increased and the concentration of total coliforms needs to be targeted in order to reduce the health risk.

Performance analysis: Functional sustainability of constructed wetland units was studied by analysing its buffering capacity using pH value, dissolved oxygen and organic matter contents, including nutrients throughout the monitoring period as described in Table 3. Comparison for the performance of the different wetland systems was made for effluent concentrations ($P>0.1$). The detailed description is as follows:

***pH and dissolved oxygen (DO)*:** Constructed wetland units fed with secondary treated wastewater revealed that there is no appreciable changes occurred for pH from inlet to outlets of the three wetland units. It could be related to the retention time that can be assumed to nullify the variation or equalize the flow in terms of pH variation. This also indicated

Table 2: Characteristics of secondary treated wastewater used to feed as influent for constructed wetland units (n=33).

Parameter	pH	COD*	TKN*	NH_4-N*	NO_3-N*	DO*	TC#
Average	8.37	156.07	75.08	28.20	5.99	1.56	5.49
Standard Deviation	0.19	41.02	23.59	12.84	5.54	0.43	0.58
Minimum	7.89	78.40	39.20	11.03	1.00	0.90	4.11
Maximum	8.65	235.20	140.00	53.78	18.82	2.80	6.20

* Value in mg/L; TKN = Total Kjeldahl nitrogen; TC = Total coliforms
# Value in log MPN/100mL

Table 3: Effluent concentration in mg/L of physico-chemical parameters from three constructed wetland units.

Parameters	UN-ph	UN-cn	UN-ct
pH	8.27	8.16	8.37
DO	4.72	5.28	2.25
COD	80.88	104.38	74.20
NH_4-N	18.19	13.24	18.41
TKN	48.46	47.72	54.33
Nitrate-N	10.61	46.16	3.14

that all the constructed wetland systems are well buffered.

The values of DO of secondary treated wastewater/inlet water did not meet the value required to sustain biota in lakes or other water streams as CPCB standard suggested 4mg/L or more for fisheries and wild life propagation. Because of sewage disposal in water streams, concentration of dissolved oxygen gets depleted since it has been used for organic matter degradation and it threatens the aquatic life in the receiving water streams. Therefore, dissolved oxygen value has been assumed as good indicator of aquatic life in water bodies. Therefore, in the proposed research, constructed wetland systems help to increase the dissolved oxygen level that can be sufficient to support the life in to water streams. Effluents of all wetland units, except UN-ct, showed significant increment in values of DO, which clearly signifies the presence of planted constructed wetland units in terms of DO concentrations for safe disposal into water bodies.

***TKN, NH_4-N and NO_3^-*:** The average percentage removal was 37.8, 39.7 and 34.9 for UN-ph, UN-cn and UN-ct respectively for TKN. The percentage removal efficiency for NH_4-N was 35.4, 50.9 and 34.4 for UN-ph, UN-cn and UN-ct respectively. Lowest percentage removal of TKN and NH_4-N from UN-ct, than planted units UN-ph and UN-cn, support the significance of plantation in constructed wetlands for removal of nutrients. The lower percentage removal of these contaminants from UN-ph are in accordance with Torrens et al. (2009) who did not find significance of presence of the plant *Phragmitis australis* for removal of NH_4-N. Concentrations for NO_3-N were found to be increased with 14.82 and 46.95mg/L in the outlet of UN-ph and UN-cn respectively. The decrease for NO_3-N, with 3.14 from 5.99mg/L in influent corresponding to 47.60% removal, was shown by UN-ct. The significant increase of nitrate concentration in UN-cn including UN-ph, clearly indicates the presence of aerobic conditions that are dominated especially within UN-cn with high percentage that enables the nitrification process. The increased concentration of NO_3-N with simultaneous removal of ammonia-N could be resulted by nitrification process.

***COD*:** The overall percentage removal of COD for UN-ph, UN-cn and UN-ct was 47.5, 34.2 and 54.6 respectively. Higher percentage of removal of COD in unplanted unit reflects similar observations as in the study given by Stefanakis & Tsihrintzis (2012).

DISCUSSION

UN-cn was found to be superior for removal of nutrients that supports significant presence of *Canna indica* for constructed wetland treating secondary treated wastewater. Higher mean percentage removal of nutrients in terms of TKN and ammonia-N especially from *Canna indica* planted wetlands was likely in the support of study conducted by Chang et al. (2010). Lowest removal of ammonia-N and nitrate-N removal from control unit might be due to the presence of sequential presence of aerobic as well as anoxic zones resulted from up-flow regime. Where upper zone i.e., below the surface layer, aerobic conditions prevails and at the bottom zone of the system anoxic condition might be presented. Such conditions enable organic matter to be utilized additionally by carbon utilization in both the processes and results in the highest removal of COD from UN-ct in the proposed study.

Removal of total coliforms: Significant presence of *Canna indica* has been proved for removal of nutrients from wastewater which is in agreement with reported literature (Zhang et al. 2007, Konnerup et al. 2009). Most importantly, its suitability must be clear in terms of microbial contaminant removal as limited knowledge has been shared in recent years (Zurita et al. 2006, Chang et al. 2010). In the light of these investigations, the proposed study was aimed to reduce the coliform count in the treated effluent.

In the research experiments, the observed mean log removal of total coliform was 1.01, 1.87 and 1.24 log units from UN-ph, UN-cn and UN-ct, respectively, that corresponds to total log removal of 1.37 log units. This total mean log removal is in accordance with reported studies (Arias et al. 2003 and Garcia et al. 2003). The results revealed that the removal of total coliform is higher in UN-cn than UN-ph, when comparison was made for suitable plant species. Interestingly, the planted unit UN-ph showed the lower performance then unplanted UN-ct in terms of total coliform removal which is in agreement with previously reported studies done by Hench et al. (2003) and Vacca et al. (2005). Results could be justified by observations found by Torrens et al. (2009), who documented that the presence of *Phragmitis australis* could be of less significance in vertical flow as compared to the horizontal flow. The given probable reasons for increased removal from unvegetated wetland than planted with *Phragmitis australis,* was the presence of enteric bacteria and other competing bacteria around exudates of plant species being a part of the rhizosphere communities and plant vigour with time (Axelrood et al. 1996, Pierson & Pierson 1996).

Moreover, increased bacterial die-off can be related to increased dissolved oxygen (Pearson et al. 1987, Fernandez et al. 1992). Likewise, higher DO values obtained from UN-cn than UN-ph and UN-ct due to high aeration capacity of fibrous roots of *Canna indica* that helps to create unfavourable environment within the bed, as the improved aeration of root zone of planted filters provide additional explanation for removal efficiency (Decamp et al. 1999). Higher oxygenation may also help to affect the total bacterial load through reducing the oxygen sensitive bacteria and causes destruction of microbial community through oxidising the surface of bacteria. This effect was dominantly observed for the microbial species in this study throughout the monitoring period. UN-ct has the lowest DO value throughout the system which proves the significance of vegetation for oxygenated environment. It also supports the design characteristics of up-flow CWs which are especially meant to have aerobicity followed by anaerobic environment at the bottom (Ong et al. 2009, Ghosh & Gopal 2010).

CONCLUSION

The observed results suggested that high removal rate was observed for nutrients by UN-cn than UN-ph. UN-cn showed the best performance for removal of coliforms as well and suggests the vegetation with *Canna indica.* The high concentration of nitrate-N also suggests the high aeration conditions prevailing in the system which was supported by higher dissolved oxygen concentration in the same unit. Presence of *Phragmitis australis* is of less significance. The additional utilization of carbon content was resulted from aerobic followed by anoxic conditions in UN-ct, that shows the basic characteristics of the up-flow constructed wetland.

So far, our findings indicate that plantation with *Canna indica* is suitable choice for vegetation over *Phragmitis australis* to improve the quality of secondary treated effluent for reducing health risk. The plantation with *Canna indica* species is favourable in semi arid conditions prevailing in Rajasthan State of India. The better performance with *Canna* planted wetland could be due to its high phytoremediation with high tolerance capacity for pollutants, high root zone aeration, large root surface area and high root numbers. The larger leaf area of *Canna indica* might have helped to increase the assimilation and absorption of the nutrients. Moreover, it can be suggested that fibrous rooting system acted as a supportive system that enabled well aeration conditions across the treatment bed and created favourable environment to reduce the bacterial load effluent. The major removal of microbes occurred due to the release of antimicrobial extract, especially from the rhizomatic part of the plant *Canna indica* (Abdullah et al. 2012, Gaur et al. 2014). Additionally, increased surface area facilitated by increased and fibrous roots might have helped to result into higher filtration and adsorption mechanism of microbial removal.

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