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# Removal of Nutrients from Simulated Wastewater by *Canna*-based Wetland Mesocosms

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**Abstract**

The present study was undertaken to investigate the potential of *Canna*-based constructed wetlands in nutrient removal from wastewater. A Vertical Flow Constructed Wetland (VF CW) was used in this study and removal of Phosphorus (Available Phosphate and Total Phosphorus) and Nitrogen (Ammonia) by a vegetation layer of plant *Canna lily* was assessed. The findings showed that removal of ammonia varied with temperature from 72 to 52% as nitrification is reduced with temperature. Removal of total phosphorous varied between 66 to 40% in *Canna*-based vertical flow constructed wetland was found to be lower than removal of available phosphate 79 to 56%. Available phosphate is directly available for plant uptake and has fewer fluctuations in its removal. In the initial phase of growth of the plant removal was found high due to high uptake of plant and soil exchange capacity. The study concludes that biological oxidation play important role in the transformation of nutrients into the system, efficiency of which depends upon various physical and chemical parameters.

## 1. Introduction

Large volume of wastewater is being generated at an alarming rate, especially in developing countries. Urban sprawl and infrastructure development has resulted in increased surface runoffs with mixed pollutants like suspended solids, organic and inorganic compounds nutrients etc. and has become a major non-point source of water pollution (Haritash *et al.*, 2019). Treatment of huge volumes of wastewater is cost extensive which is a serious challenge globally. Traditional wastewater treatment strategies are successful in removing significant fractions of suspended impurities and organic carbon, however, the removal efficiency for nutrients (Nitrogen and Phosphorus) is limited (Haritash *et al.*, 2017). Advanced techniques like chemical precipitation, ion–exchange etc. that are generally adopted produce toxic sludge that cause secondary pollution (Haritash *et al.*, 2015). Thus, a more energy and cost-efficient alternative is required for wastewater treatment.

Nutrient load removal in wastewater treatment is an important step to prevent eutrophication of water bodies (Zhang *et al.*, 2007). Many studies have highlighted the role of wetlands as a Nature based Solution (NbS) for treating wastewater, particularly nutrient removal (Haddis *et al.*, 2020; Boano *et al.*, 2020). Wetlands are natural ecosystems that perform multitude of services such as flood control, nutrient cycling, regulation of water flow and quality etc. the inherent property of wetlands to remove pollutants from water can be employed as a cheap and energy efficient alternate to conventional techniques (Haddis *et al.*, 2020). Constructed Wetlands (CW) are engineered systems designed to mimic the natural wetlands for pollution control and wastewater treatment. CW are considered green infrastructure as it indirectly provide services like air and water quality, recreational and aesthetic value, and disaster attenuation (Vymazal, 2007).

The multi-functionality of CW and higher degree of control over operating conditions as compared to natural wetlands make it suitable for treatment of water (Vymazal 2010). Constructed wetlands have been classified into two broad groups based on the type of flow: Surface Flow CW and Sub-surface Flow CW. Surface flow CW are shallow and more efficient in degradation of organics. Sub-Surface CW is further classified as Horizontal (HF CW) and Vertical CW (VF CW), both of which consist of gravel bed and planted by vegetation. Wastewater is fed through an inlet and water flows towards the outlet in a horizontal path in HF CW. In VF CW, large batches of wastewater if fed which flows through the gravel beds vertically. This allows more diffusion of oxygen into the bed and creates aerobic conditions (Vymazal, 2005).

Nitrogen removal takes place through subsequent processes of nitrification and denitrification, followed by ammonia volatilization, with denitrification being the major removal mechanism. VF CW creates suitable aerobic conditions for nitrification process; however, denitrification does not place (Vymazal, 2007). Phosphorus uptake by plants is low compared to nitrogen as it is adsorbed or precipitates due to limited contact of water with soil particles. Ligand exchange reactions aid in phosphorus removal, where phosphate displaces hydroxyl ions from the surface of iron/aluminium hydrous oxides (Vymazal, 2007, Haritash *et al*., 2017).

Suspended solids are retained predominantly by filtration and sedimentation and the removal efficiency is usually very high. VF CWs are very effective in removing organics and suspended solids. Vertical flow constructed wetlands are efficient for 95% of BOD, 90% nitrification and 90% of phosphate after chemical precipitation (Brix and Arias, 2005). Removal of biological oxygen demand (BOD3) and chemical oxygen demand (COD) in a *Canna*-based constructed wetland (CW) cell is varied between 69.8-96.4% and 63.6-99.1%, respectively. C. lily could efficiently remove carbon from a difficult to degrade wastewater at COD: BOD ratio of 24.4 (Haritash *et al.* 2015). *Canna* is a perennial plant and allocates the majority of its biomass to shoots, it is possible to regularly harvest and remove biomass from the treatment system (Chen *et al.*, 2009).

Plant uptake is major nutrient removal pathway in the wetland microcosm (Zhang *et al.*, 2007). Microbial uptake is considered in all treatment systems only as temporary storage of phosphorus with very short turnover rate. Conclusively, this work aims to investigate the efficiency of constructed wetlands in wastewater treatment applications by removal of nutrients, particularly, Phosphorus and Nitrogen. This study also assesses the ability of Canna plants for effective nutrient removal using simulated wastewater under controlled conditions.

## 2. Material and Methods

### 2.1. Wetland Setup

This study was carried out in the campus of Delhi Technological University for five months during the period of June-October 2018. Experiments were conducted in a bench scale VF CW cell of dimensions 1.1 m length x 0.8 m width x 0.45 m depth. A cylindrical tank made of HDPE was used as the CW cell which was packed with a bed of sand and gravel substrate with thickness and volume of 35 cm and 0.325 $m^3$ respectively. 23 healthy plants of *Canna lily* with an average shoot length of 60 cm were used for the vegetation layer. A Hydraulic Loading Rate (HLR) of 400 L/day was maintained for flushing the cell for first 5 days, after which simulated wastewater was used with HLR of 30 L/day. The influent was fed from the top, and effluent was collected from an outlet placed opposite to inlet at the bottom of the tank (Fig.1).

### 2.2. Preparation and Analysis of Synthetic wastewater

Wastewater was prepared synthetically in lab by dissolving Ammonium sulphate [$(NH_4)_2SO_4$], Potassium dihydrogen orthophosphate ($KH_2PO_4$) and Potassium nitrate ($KNO_3$) in groundwater to stimulate natural characteristics of wastewater. The CW was fed with simulated wastewater on daily basis and outlet was collected. Physico-chemical characterization of both inflow and outflow was done as per the standard methods (APHA, 1998) to determine average values of pH, Oxidation-Reduction Potential (ORP), Dissolved Oxygen (DO), Temperature, Available Phosphate (AP), Total Phosphate (TP), and Ammonia (TKN).

The analysis of treated wastewater was done as per the standard methods and in triplicates using analytical grade chemicals and reagents. Dissolved Phosphate was analyzed as available phosphate using spectrophotometer (Labtronics make LT-290 model) at an absorbance of 690 nm. For total phosphate, the samples were acid digested with sulphuric acid and nitric acid in the ratio of 1:3 and heated prior to analysis on spectrophotometer. Ammonium-nitrogen was analyzed as Total Kjeldahl Nitrogen (TKN) using Kjeldahl's method. Based on the results obtained, statistical analysis was done on Ms-Excel to calculate percentage removal of nutrients from treated wastewater.

Fig. 1 Configuration of wetland cell used during the study

**3. Results and Discussion**

Nutrient is required for the growth of plants and various microphytes. Vegetation used in CW use this property to help remove the nutrients from the waste water. Based on the results obtained, the *Canna*-based vertical flow constructed wetland was found to be effective for the removal of nutrient from the waste water. The growth of *Canna lily* depends on the nutrient availability, and physico-chemical characteristic of water, and agro-climatic conditions (Haritash *et al.*, 2015). Variation of physico-chemical characteristics of water and average ambient temperature is given in table 1. Value of pH was found in the range of 8.0 to 8.6 and 7.4 to 7.6 in inflow and outflow respectively. Significant difference in the concentration of dissolved oxygen in the effluent was found. Similar difference in pH and dissolved oxygen was observed in a study by Zhang *et al.* (2007). ORP was observed to be positive i.e. oxidising condition into the system, varying from 114 mV to 173 mV and 121 mV to 178 mV in inflow and outflow respectively. ORP plays an important role in the removal of nutrients, as removal of both nitrogen as ammonia and phosphorous as available phosphate is high in oxidising condition (Haritash *et al.*, 2015; Vymazal, 2007). Temperature was also noted during the study to see the behaviour of *Canna* with change in the ambient temperature. Available phosphate, total phosphate and nitrogen (as TKN) removal are discussed in the following sections.

**3.1. Removal of Available phosphate (AP)**

Plants uptake available phosphate (unbound phosphate) through its roots as it is the direct source of P for plants for their growth. Removal of AP was observed in the range of 79%, 72%, 71%, 67%, and 56% during June, July, August, September, and October respectively. Figure 2a show the seasonal variation of the removal of available phosphate in the system. The nutrient removal from the waste water depends upon the plant type, growth rate, nutrition composition, water uptake of the plant (Zhang *et al.,* 2007). *Canna lily* has a higher water demand in order of 1.4 Litres/plant/day (Chen *et al.* 2009). During summer as plant uptake increases removal of nutrient also increases. Figure 2b show the trend of AP removal has fewer fluctuations. Higher removal rates of available phosphate may also be attributed to higher uptake by *Canna* plants during the initial growth phase before maximum growth is attained (Haritash *et al.* 2015). The phosphate removal rate of plants may decrease after attaining maturity and with increasing biomass (DeBusk *et al.,* 1995). Higher percentage removal of available phosphate during initial growth phase of the system may also occur due to the adsorption of P on soil surface, which continuously get reduces with time until there is equilibrium between soil and soil pore water (Vymazal, 2007). Microbial uptake is taken as negligible because P remains in the system after decay of the microorganism (Zhang *et al.*, 2007, Vymazal, 2007).

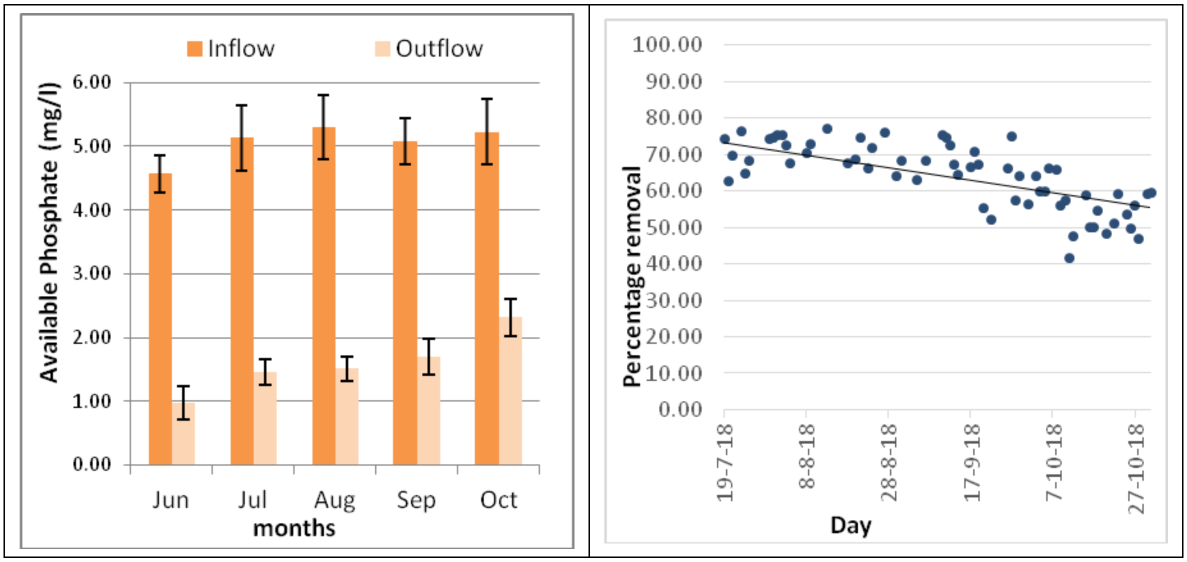


Fig. 2. (a) Removal of AP in *Canna*-based CW during the study; (b) Trend of removal of AP during the study.

Table 1.Variation of physico-chemical characteristics (pH, ORP, DO) of water and ambient temperature during the study.

| | pH | | ORP (mV) | | DO (mg/l) | | Temperature $^0$C | |
|---|---|---|---|---|---|---|---|---|
| | Inflow | Outflow | Inflow | Outflow | Inflow | Outflow | Min | Max |
| JUNE | 8.3 ±0.1 | 7.4 ±0.1 | 151 ±10.3 | 160 ±15 | 3.9 ±0.3 | 0.9 ±0.3 | 29 ±3 | 41 ±5 |
| JUL | 8.0 ±1.7 | 7.5 ±0.1 | 156 ±37 | 178 ±31 | 4.8 ±1.2 | 1.7 ±0.9 | 28 ±2 | 37 ±2 |
| AUG | 8.2 ±0.3 | 7.5 ±0.2 | 173 ±12 | 187 ±11 | 5.1 ±0.8 | 2.1 ±1.0 | 26 ±1 | 35 ±1 |
| SEP | 8.5 ±0.1 | 7.6 ±0.1 | 114 ±22 | 123 ±27 | 5.7 ±0.6 | 2.0 ±0.2 | 25 ±2 | 33 ±2 |
| OCT | 8.6 ±0.1 | 7.6 ±0.2 | 127 ±14 | 121 ±8 | 5.1 ±0.3 | 2.0 ±0.2 | 20 ±2 | 34 ±2 |

### 3.2. Removal of Total phosphate (TP)

Removal of TP was observed in the range of 66%, 50%, 48%, 47%, and 40% during June, July, August, September, and October respectively. Figure 3a show the seasonal variation of the removal of total phosphate in the system. Removal of TP was higher in the initial growth phase of *Canna*, and it reduces with time similarly to AP, but with high fluctuations and low percentage removal. Chemical transformation of bound phosphate to orthophosphate (AP) is majorly due to the microorganisms and enzymes secreted by plant roots (Haritash *et al.*, 2017). Microbial activities are dependent upon many factors and measurement of amount of P solubilized by organism is complicate. Although bacteria are generally considered decomposers that simply mineralize organic P, they have also been shown to regulate the P flux across the sediment–water interface and contribute to terminal P burial through production of refractory organic compounds (Vymazal, 2007). The release of bound phosphorous to free soluble form is regulated by pH and redox condition (Kim *et al.*, 2003, Zhang *et al.*, 2012). The availability of phosphorus decreased with increase in pH of aquaponics nutrient solutions. It is recommended that pH in aquaponics systems is maintained from 5.5 to 7.2. Other important factors responsible for nutrient removal are sediments and microorganisms. Gravel-based sediments and plant roots offer suitable substrate for microbial growth (Haritash *et al.* 2015).

### 3.3. Removal of Nitrogen (as TKN)

Nitrogen transformation in wetlands is influenced by temperature, pH, and alkalinity of the water, inorganic C source, moisture, microbial population, dissolved oxygen and concentration of ammonium-N (Vymazal 2007). Fig. 4 shows the removal of ammonical nitrogen which was observed in the range of 72%, 69%, 64%, 52%, and 54% during June, July, August, September, and October respectively. Nitrogen removal was found maximum in the initial phase of growth of the plant and reduces as it approaches to maturity. Similar observation was found by Zhang et al. (2007). Plant uptake is the major source of nitrogen removal upto 62-87% (Zhang *et al.*, 2007), 51% (Breen 1990) from the wetlands but plant did not take ammonia directly. Biological oxidation of ammonia is also affected by temperature, optimum temperature for nitrification in soil is 30-40 $^{0}$C (Cooper *et al.*, 1996). An approximate amount of 4.3 mg $O_2$ per mg of ammonical nitrogen oxidised to nitrate nitrogen is required (Vymazal, 2007), this indicate that nitrification is the major process of ammonia removal in the present study. It was observed that nitrification is dominant in vertical flow constructed wetlands (Vymazal, 2007). Favourable condition (pH>7.0) for ammonia volatization was also observed.

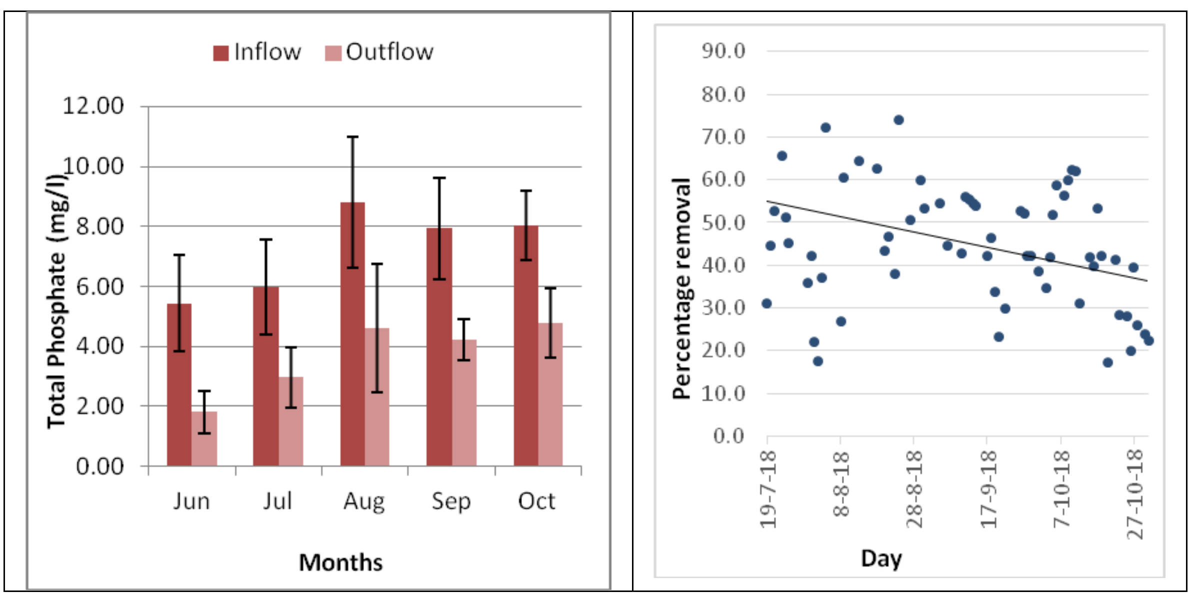


Fig. 3. (a) Removal of TP in *Canna*-based CW during the study, (b) Trend of removal of TP during the study.

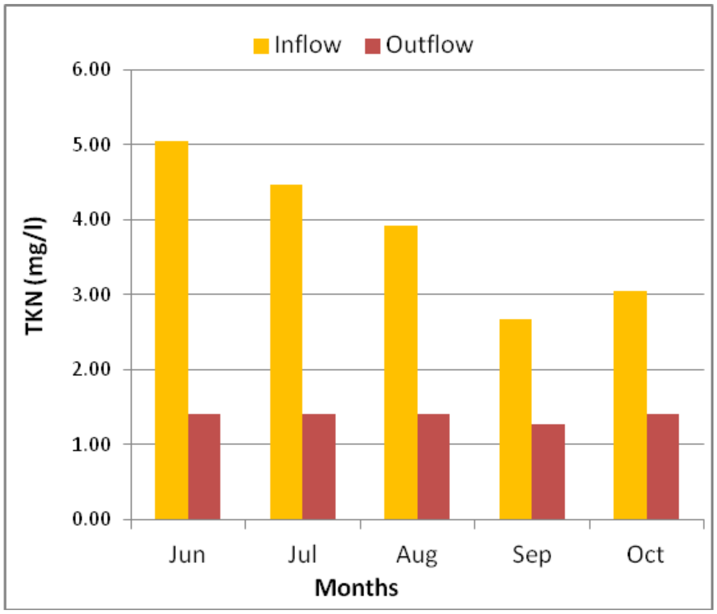


Fig. 4 Removal of $NH_4^+$-N in *Canna*-based CW during the study

## 4. Conclusion

Biological oxidation play important role in the transformation of Nutrients into the system, efficiency of which depends upon various physical and chemical parameters. Removal of ammonia varied with temperature from 72 to 52% as nitrification is reduces with temperature. Removal of total phosphorous varied between 66 to 40% in *Canna*-based vertical flow constructed wetland was found lower than removal of available phosphate 79 to 56%. Available phosphate is directly available for plant uptake and has fewer fluctuations in its removal. In the initial phase of growth of the plant removal was found high due to high uptake of plant and soil exchange capacity. From the results obtained, it was found that *Canna lilly* can effectively reduce the nutrient load from wastewater through biological processes when conditions like temperature and pH are favourable. This study concludes that Wetland Mesocosms are sustainable and efficient treatment alternatives that can be opted for organic rich wastewater.

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