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Removal Efficiency of Pollutants in Horizontal Reed Bed Constructed Wetland

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Abstract
The treatment of the wastewater is necessary to keep the natural water bodies in fresh condition. The treatment of wastewater by Constructed Wetland requires very less energy and easy to construct, operate and maintain, so, it could be the better option for the developing countries like Nepal. The main objective of the study is to know the variation pattern of nutrients such as Total Nitrogen(TN),Total phosphorous (TP), and Potassium (K^+) and Biochemical Oxygen Demand (BOD) removal with respect to different conditions (days from plantation and flow distance) and plant height w.r.t maturation of plant in the Horizontal Reed Bed Constructed Wetland. The study was carried out in the Wetland constructed in IOE premises and Reed (Narkat, *phragmites karka*) as macrophyte at an average 8.12 $m^3\ d^{-1}$flow rate. The concentration of TN, TP,K^+ and BOD in influent ranged from 48-92 mg-N/l, 7-18 mg-P/l, 36-54 mg/l and 46-110 mg/l respectively and in effluent ranged from 21-51 mg-N/l, 1-7 mg-P/l, 29-46 mg/l and 14-30 mg/l respectively with few exception giving the 1 year's average removal efficiency and decay rate for TN,TP,K^+ and BOD are 48.17,65.63, 15.63 and 74.20% and 0.018 m^{-1}, 0.023 m^{-1}, 0.005m^{-1} and 0.032 m^{-1} respectively. The average plant height is greater than 1 m in 180 days from plantation of the reed. The maximum nutrient decay coefficient was found to be 0.024 m^{-1} for TN, 0.038 m^{-1} for TP and 0.007 m^{-1} for K^+ and maximum removal efficiencies of TN, TP,K^+ and BOD during first 1 years maturation period of plant were found to be 63.01,82.04, 25 and 87.27% .

Keywords
Influent, Effluent, Macrophyte, TN, TP, BOD, Nutrient

1. Introduction

A constructed wetland (CW) is an artificial wetland to treat municipal or industrial wastewater, grey water or storm water runoff. Constructed wetlands have been used to treat both centralized and on-site wastewater. Primary treatment is recommended when there is a large amount of suspended solids or soluble organic matter.Kathmandu valley consists of five centralized wastewater treatment plants and over twenty decentralized wastewater treatment plants.Out of these, all centralized treatment plants are not in operation due to their design and capacity [1].

Water pollution causes several health hazards such as epidemic diseases, eutrophication of unwanted plants and consumption of DO (Dissolved Oxygen), causing no possibility of lives i.e., biologically dead sections. Moreover, the aesthetic values of the cities are also endangered. The treatment of wastewater or storm water by constructed wetlands can be a low-cost, low-energy process requiring minimal operational attention.

People have used wetlands for pollution control for centuries[2].The first experiments using wetland macrophytes for wastewater treatment were carried out in Germany in the early 1950s. Since then, the constructed wetlands have evolved into a reliable wastewater treatment technology for various types of wastewater [3].

Wetland plants consume macro-nutrients (Nitrogen (N) and Phosphorus (P)) and micro- nutrients (including metals) through their roots during active plant expansion. While municipal wastewater can supply sufficient quantities of these limiting nutrients, other type of contaminate water, including industrial wastewater, acid mine drainage and storm water, may not [4]. Plants play major roles in constructed wetlands (CWs).They maintain the temperature, decrease wind speed and avoid re-suspension of nutrient and sludge, supply Surface for periphyton and bacteria and help in providing the required conditions for various biological, physicochemical processes within a constructed wetland for effective treatment of wastewater [4].The impact of direct nutrient uptake by plants may only be significant when wastewater nutrient levels are low [5].The main parameters, which affect the removal efficiency of CWs, are the hydraulic residence time and temperature [6]; furthermore, oxygenation of the water and bed filtration also play very important role. Nitrogen removal is achieved not only by bacterial, but also by plant uptake, adsorption, where ionized ammonia reacts with the media in Horizontal Sub Surface Flow (HSSF) constructed wetlands [7].

Results of the investigations showed that the organic load, fecal coliform population and the N and P concentrations of the septic water decreased considerably by passing through the wetlands. Constructed wetland reduces BOD_5 of septic water by 80 to 90% [8].

The new and mature constructed wetlands successfully removed traditional pollutants such as BOD from domestic wastewater. However, the biochemical oxygen demand, chemical oxygen demand, suspended solids, and ammonia- nitrogen concentrations were reduced within the mature constructed wetland system even after approximately 5 years of operation [9]. The removal efficiency of NH_4^+-N, phosphorous (P), Potassium (K) is higher in the lower influent rate among the three flow rate 8 m^3/d than in 11 m^3/d and 15m^3/d [10].

2. Methods and Materials

2.1 Experimental Set Up

The wetland is horizontal bed subsurface flow newly construct constructed wetland inside the premises of IOE planted with common reed plant (Narkat, *phragmites karka*)as macrophyte at 600mm c/c at 17^{th} April 2019 and pebbles as substrate, which treats wastewater from neighboring houses.

Wastewater enters through inlet chamber to the settling tank where solid particle settles down and after that goes into the wetland in controlled manner by flow controlled valve is situated just adjacent to settling tank. Finally the purified wastewater goes to the outlet zone.

For the inspection, 110mm vertical pipes are also placed along the center at an average interval of 1.25m. Slope of the bed is kept to be 1% and Porosity of media is assumed to be 40% as per standard of USEPA.

Table 1: Different components of constructed wetland and their size

Components	Dimension(m)	Remarks
Settling Tank	4.20 X 2.55	Brick masonry
Horizontal Bed	42 X 7 X 0.45	Single bed
Effluent tank	4.90 X 2.20	Brick masonry
Inlet,outlet	100mm dia perforated pipe	
Media:	crushed stone	150mm compacted clay and pvc geomembrane sheet is used for lining
Inlet	40-80mm	
outlet zone	40mm-80mm	
Filter media	20mm-30mm	

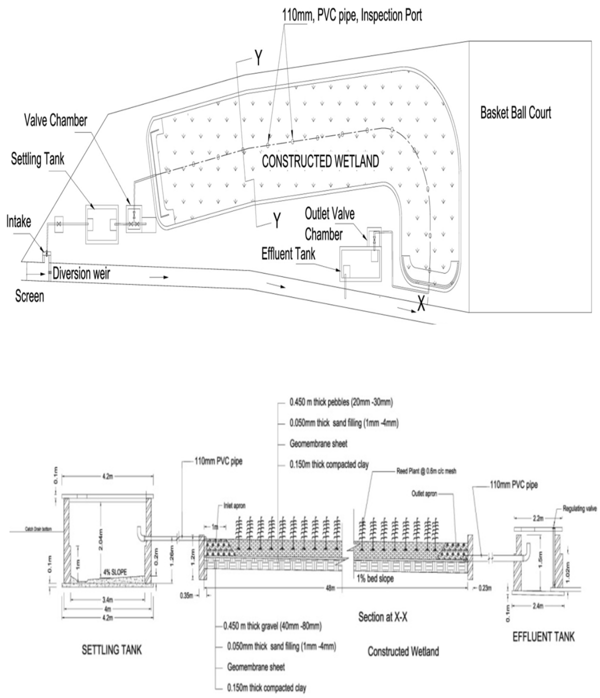

Figure 1: Plan and sectional view of the constructed wetland in IOE

2.2 Flow Regulation

One of the major challenge is to regulate the flow constant through out the year. With the help of gate valve connected to inlet pipe, flow was regulated and fixed to be 8.12m^3/day by considering the average flow in the dry season. Detention time in the constructed wetland for the flow is given by equation 1.

$$t = nLWd/Q \qquad (1)$$

Where
L is the Bed length = 42m
W is width of bed=7m
d is depth of the flow=0.225(Average depth of flow assumed to be half of full depth)
n is the porosity=40%
Q is the discharge= 8.12m^3/day
we get the detention time to be 3.26 days.

2.3 Sample Collection

After plantation of the Narkat and maintenance of the flow valves, the inflow was maintained to be 8.12m^3/day.
Sample was extracted in the clean and dried sample bottles (rinsed with sample water too) from the different inspections ports along with the length (installed at an average interval of 1.25m) with the help of a mineral water bottle, with a hole at mid and a large stick inserted in the mouth of the mineral water bottle.
The sampling stick and bottle was cleaned each time after dipping in the inspection ports and rinsed with distilled water. Samples were taken from the inlet, and different port numbers and the measurement of the length of wetland from the Influent pipe.

2.4 Analysis of Sample

For the nutrient analysis, standard method will be followed. Methods and instruments that will be used in the analysis are listed in below

Table 2: Method of analysis and instrument used

S.N	Parameters	Methods/Equipments
1	Nitrogen	UV Spectrophotometric Screening
2	Phosphorous	Persulfate Digestion Method
3	Potassium	Instrument: LAQUAtwin K^+ HORIBA Scientific
4	BOD	Titrimetric Method
5	pH	Standard pH meter

3. Result and Discussion

3.1 Total Nitrogen(TN)

Nitrogen is a nutrient to the plants, microorganism and animals to growth.

Nitrogen data will be required to evaluate the treatability of wastewater by biological processes because it is an essential building block in the synthesis of protein [11].

Mechanisms responsible for total nitrogen reduction are volatilization, plant,bacteria uptakes, adsorption and denitrification [7].

The concentration of Total Nitrogen (TN) in influent varies in different month but the range of that in between 48 to 92 mg-N/L except in rainy season and the effluent concentration varies between 21 to 51 mg-N/L except in rainy season.

The decay rates of TN was found to be in ranged from 0.009 to 0.024m^{-1} during first 1 year's maturation period.

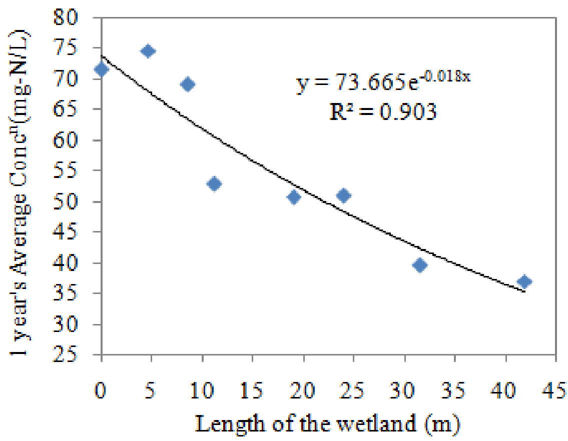

Figure 2: 1 year's average concentration according to the maturity of plant for TN

Figure 3 shows the removal efficiency of TN ranged from 31 to 63.01 % during the first 1 year's maturation period whereas the average removal efficiency of TN during first 1 year's maturation period of the plant is 48.17% and the average decay rates for TN was found to be 0.018m^{-1} given in Figure 2.

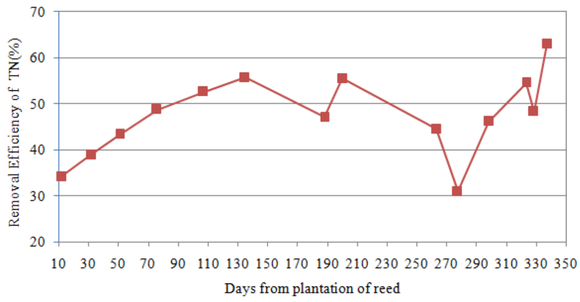

Figure 3: Removal efficiency of Wetland for TN during first 1 year's maturation period of the plant

3.2 Total Phosphorous(TP)

For the growth of the algae and other biological organism, phosphorous is also an essential nutrient. Because of noxious algal blooms that occur in surface waters, there is presently much interest in controlling the amount of phosphorous compounds that enter surface waters in domestic and industrial waste discharges and natural runoff [11].

The concentration Total Phosphorus (TP) in influent varies in different month but the range of that in between 7 to 18 mg-P/L except in rainy season and the effluent concentration varies between 1 to 7 mg-P/L except in rainy season. The decay rates of TP was found to be in ranged from 0.029 to 0.038m^{-1} during first 1 year's maturation period.The removal may have occurred by the chemical precipitation and plant uptake and by adsorption.

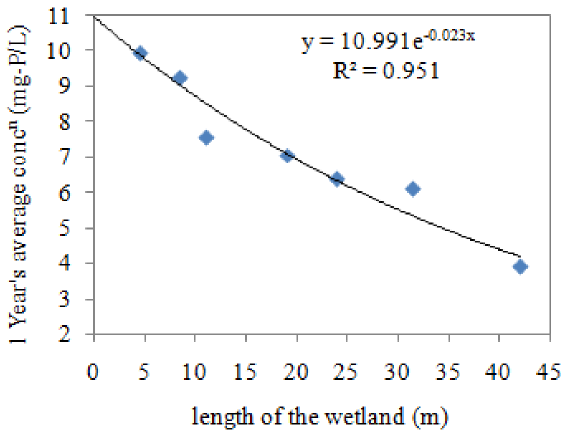

Figure 4: 1 year's average concentration according to the maturity of plant for TP

Figure 5 show the removal efficiency of TP ranged from 50 to 83% during the first 1 year's maturation period whereas the average removal efficiency of TP during first 1 year's maturation period of the plant is 63.63% and Figure 4 shows the average decay rates for TP is 0.023m^{-1}.

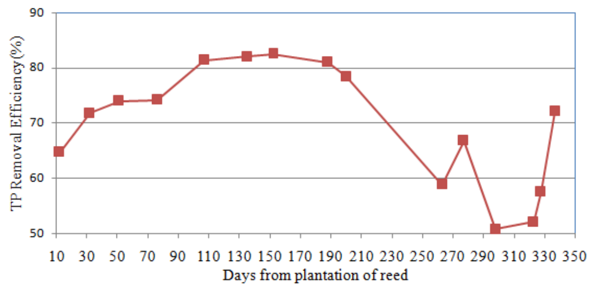

Figure 5: Removal efficiency of Wetland for TP during first 1 year's maturation period of the plant

3.3 Potassium(K^+)

The concentration of Potassium [K^+] in influent varies in different month but the range of that in between 36 to 54 mg/L except in rainy season and the effluent concentration varies between 29 to 46 mg/L except in rainy season. The decay rates of [K^+] was found to be in ranged from 0.002 to 0.007m^{-1}during first 1 year's maturation period.

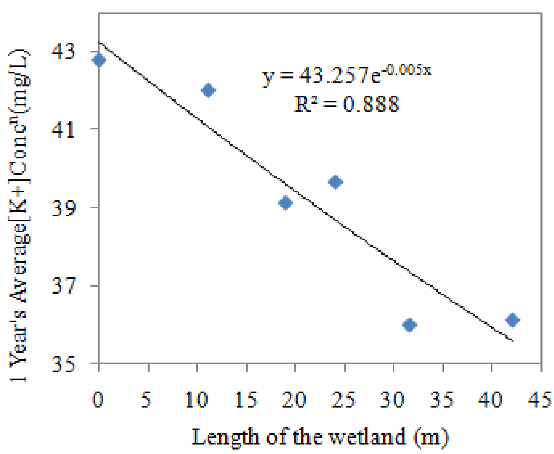

Figure 6: 1 year's average concentration according to the maturity of plant for [K^+]

Figure 7 show the removal efficiency of [K^+] ranged from 5.56 to 25% during the first 1 year's maturation period whereas the average removal efficiency of [K^+] during first 1 year's maturation period of the plant is 15.63% and the average decay rates for [K^+] was found to be 0.005m^{-1} given in Figure 6.

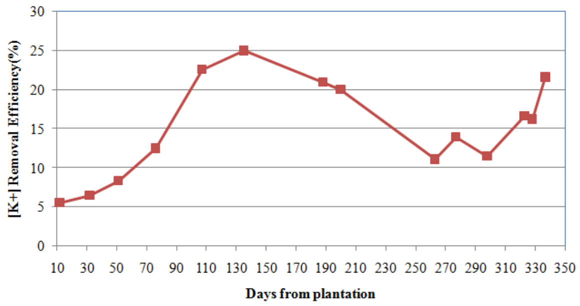

Figure 7: Removal efficiency of Wetland for $[K^+]$ during first 1 year's maturation period of the plant

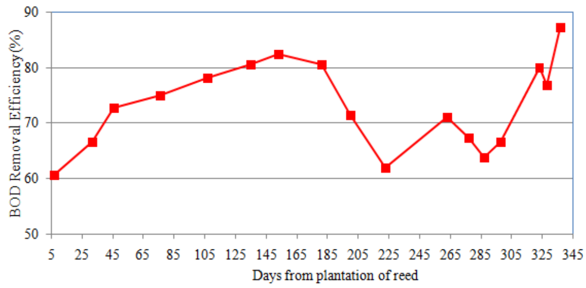

Figure 9: Removal efficiency of Wetland for BOD during first 1 year's maturation period of the plant

3.4 Biochemicall Oxygen Demand (BOD)

BOD test results are used (i) to determine the approximate quantity of oxygen that will be required to biologically stabilize the organic matter present, (ii) to determine the size of wastewater treatment facilities, (iii) to measure the efficiency of treatment processes [11]. The concentration of BOD in influent varies in different month but the range of that in between 46 to 110 mg/l and the effluent concentration varies between 10 to 28 mg/L except in rainy season.

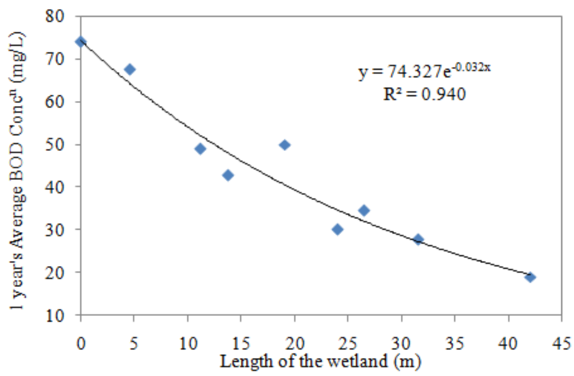

Figure 8: 1 year's average concentration according to the maturity of plant for BOD

The concentration of the BOD with respect to the length of the wetland was decreasing in all season due to consumption of organic matter present in wastewater by microorganism and plant present in the system.

The removal efficiency BOD ranged from 60 to 88% during the first 1 year's maturation period whereas the average removal efficiency of BOD during first 1 year's maturation period of the plant is 74.20% and Figure 8 shows the average decay rates for BOD was found to be $0.032m^{-1}$.

3.5 pH

The pH of the wastewater flowing in the constructed wetland was found to be almost constant but very slightly increasing at some distance then slightly decreasing after wards. The pH of flowing water in the CW has been presented in Figure 10.

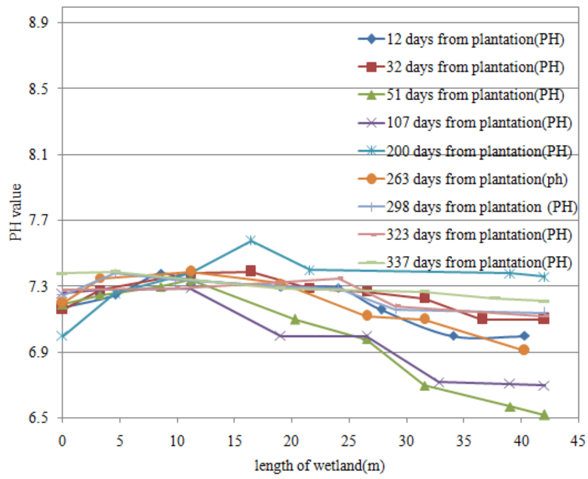

Figure 10: pH value w.r.t length of the wetland according to the days from plantation

3.6 Plant Height

The increment of the plant is slower in first and second month from the plantation date. During first 2 months the average plant height of the wetland with the given discharge $8.12m^3$/s is about 30 cm and after 2 months the plant growing in faster rate and at the end of 5 months from plantation average height of the plant is about 1m. The faster increment of the plant height as well as thickness is due to plants gets more enough nutrients from the wastewater and enough sunlight.

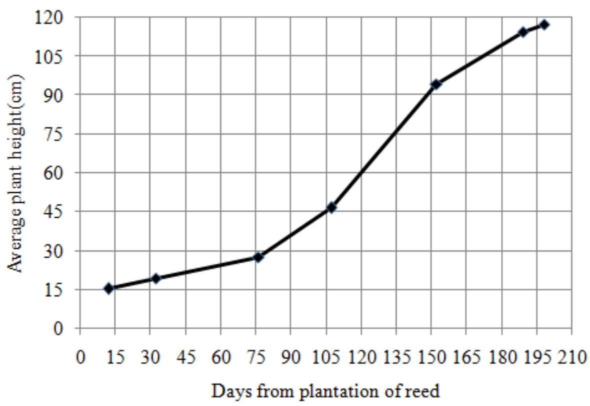

Figure 11: Average plant height(cm) in wetland w.r.t maturation period with given discharge of 8.12m^3/sec

The concentration of Total Nitrogen(TN), Total Phosphorus(TP), Potassium(K^+) and BOD was found to be gradually decreasing with the length of the wetland with all maturation of plant. The removal efficiency of these pollutants is found to be lower in the initial period and afterward removal efficiency is increased but in colder season removal efficiency as well as decay rate drops in lower value this is due to the less microbial activity as well as less oxygen transfer by reed plants to the wastewater through its roots, for necessary aeration or nitrification.But afterwards, the plants slowly get maturity and the wastewater might have got oxygen from the plant roots for nitrification.

4. Conclusion

Constructed wetland technology can be used for the treatment of wastewater in effective and low cost treatment strategies. Constructed wetland may have been implemented in poor and developing country like Nepal without huge investment where the availability of land is enough. From the study,

- The decay rates of TN,TP and $[K^+]$ was found to be in ranged from 0.009 to 0.024 m^{-1},0.029 to 0.038m^{-1},0.002 to 0.007m^{-1} respectively and the removal efficiency of TN, TP, $[K^+]$ and BOD ranged from 31 to 63.01,50 to 83, 5.56 to 25 and 60 to 88% respectively during the first 1 year's maturation period.
- The removal efficiency as well as decay rates may increase in further maturation.
- Though the decay rates as well as removal efficiency drops down the lower value in very colder month due to lower microbial activity, the constructed wetland technology acceptably removes the pollutants in all the season with maturity of the plant.

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