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Performance Evaluation of Sand-based Surface flow Constructed wetland in Domestic Wastewater Treatment using Typha Orientalis as Macrophyte

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Abstract
A laboratory-scale free water surface-flow constructed wetland was set up at the Department of Civil Engineering; Ladoke Akintola University of Technology (LAUTECH) Ogbomoso, Nigeria in May 2013 to demonstrate the performance of sand- based constructed wetland, using Typha Orientalis as a viable low-cost efficient treatment option for domestic wastewater from kitchen. The nutrient removal and performance evaluation of the constructed wetland in treatment of kitchen wastewater against retention period of ten days was investigated.

During the 10-day retention period, the sand- based constructed wetland set up with Typha Orientalis had improved the wastewater quality significantly as it had reduced 94.9% of Turbidity, BOD_5 by 79.0%, NO^-_3 by 66.7%, 87.9% of SO^-_4 , 70.24% of Cl^-, Conductivity by 70.8% and Magnesium by 80.62%. The pH value and Dissolve Oxygen increased by 28.3% and 64.01% respectively and the initial offensive odour of the raw water was no more noticeable. The final effluent was found to be suitable for non-drinking purposes like crop irrigation and keeping aquatic animals. However, it was noted that a 7- day detention time was optimal for the treatment of domestic wastewater from kitchen.

The treatment system was found to be economical, as the cost of construction only was involved and maintenance cost very minimal. It was environmentally friendly as it was free from offensive odour and insect invasion. The prototype scale is recommended for in-situ use, especially for wastewater from kitchen.

Keywords: Constructed wetland, Domestic wastewater, Nutrient removal, Retention period, Typha Orientalis

1. Introduction

In recent years, increasing production and disposal of wastewater have caused an accelerated pollution of receiving water bodies. Hence, to reduce the harmful impact of the wastewater discharge, there is the need to remove the main nutrients such as nitrogen and phosphorus as well as the organic content of the wastewater prior to disposal. This can be effectively achieved by the conventional treatment technology, but the working expenses and energy requirements of such treatment systems are rather high and in many cases hinder by economic constraints which often leads to the desertion of such various treatment plants in the country (Nigeria) due to lack of funding and consequently maintenance on the part of the responsible agency. However, several investigations have shown that wetlands may act as efficient water purification systems and nutrient sinks (Dolan *et al.,* 1981; Brix, 1987and 1993; Vinita *et al.*, 2008; Jun-jun Chang *et al.,* 2012).

Constructed wetlands are artificial wastewater treatment system consisting of shallow (usually less than 1 m deep) ponds or channels, which have been planted with aquatic plants, and rely upon natural microbial, biological, physical and chemical processes to treat wastewater (Sandeep *et al.,* 2005). These systems of wastewater treatment offer several potential advantages as compared to conventional treatment system, this include; simple construction (can be constructed with local materials), require less skill to operate and maintain, process stability under varying environmental conditions, Utilization of natural processes, and lower construction, operation and maintenance costs. There are two basic types of constructed wetland namely; free water surface flow constructed wetland in which the flow of water is above the sediment surface, and subsurface flow constructed wetland in which the flow of water is primarily below the sediment surface.

These systems use wetland plants, soils and their associated microorganisms to remove contaminants from wastewater (Borkar and Mahatme, 2011; Baskar *et al.*, 2009). The pollutant removal mechanisms in a constructed wetland plant comprise several physical, chemical, biological and biochemical processes (Brix, 1993; UN-HABITAT, 2008), and this include; sedimentation, filtration, aerobic and anaerobic microbial degradation, plant uptake, soil sorption, precipitation and so on.

Furthermore, these treatment systems have been widely employed in the treatment of wastewater, and a brief summary of few of such studies include; Borkar and Mahatme (2011) study on constructed wetland with and

without *Typha Orientalis* plant for a detention time of 3,5,7 and 9 days indicated that the beds with *Typha Orientalis* produced effluents of better quality than the bed without *Typha Orientalis,* as the result shows a reduction of 75% in total solids, 86 % in BOD, 63% in COD using *Typha Orientalis* compared to that without *Typha Orientalis* with 70% reduction in total soilids, 62% in BOD and 53% in COD. Jun-jun Chang *et al.* (2012) study on Two pilot-scale integrated vertical-flow constructed wetlands (IVCWs) in parallel at a loading rate of 250 mm/d, and each planted with two different plant species (*Typha orientalis* and *Arundo donax var. versicolor* (Plot 1), *and Canna indica* and *Pontederia cordata* (Plot 2)) showed that the mean removal efficiencies associated with Plot 1 and Plot 2 were 59.9% vs. 62.8% for COD, 15.0% vs. 12.8% for TN, and 52.0% vs. 51.1% for TP, respectively.
The aim of this study is to evaluate the treatment performance of a laboratory scale free water surface flow constructed wetland using *typha orientalis* for the treatment of domestic wastewater while the objectives are to; analyze the wastewater generated and evaluate the suitability of treating wastewater by root zone technology, determine the effect of detention period on treatment efficiency and recommend a low-cost and environmentally friendly techniques for wastewater treatment.

2. Material and Methods

2.1 *Study Site*

The laboratory scale free water surface flow constructed wetland was set-up at the department of civil engineering Ladoke Akintola University of Technology which was established in September 1990 and located in the agrarian town of Ogbomoso in Oyo state which lies between latitude 8^{o} 08' 01''N and longitude 4^{o} 14' 48''E. The town is characterized by an average daily temperature of between 25^{o} and 35^{o} almost throughout the year.

2.2 Experimental Setup

The wetland cell which was made of a transparent plastic was 0.9 m deep, 0.6 m long and 0.6 m wide to give a total volume of 0.324 m^3 (Fig. 1). The outlet is a plastic tap fitted to the bottom side of the basin while the inlet is excluded as water will be fed into the wetland system manually. The basin was lined to prevent leakages, and encased with a wooden frame to give it the required rigidity and support to prevent outburst of the plastic basin (Fig. 2). Furthermore, the inlet of the tap was covered with screen during substrate filling to prevent the passage of sand with the water, the substrates were properly washed to eliminate the undesired particles and dust, and sieved to obtain the desired grain size (granite 13.5 mm and 8mm, gutter sand and humus < 2mm), and the basin was filled as follow:

The first layer of 100mm depth consisted of granite of 13.5 mm size.
The second layer of 150mm depth consisted of granite of 8mm size.
The third layer of 200mm depth consisted of washed gutter sand.
The fourth layer of 150mm depth consisted of humus soil to support plant growth.
300mm free board was provided.

2.3 *Planting of the Vegetation*

Live plant transplant was employed for this setup, the planting density was nine plants (six of 62cm height and three of 38cm height) per 0.54 m^2, the depth of planting was 10 cm below the surface of the humus soil and the plant was cultured in the setup with tap water by wetting it manually every day . After a period of seven months (19th of August 2013 to 17th of March 2014), the nine *Typha Orientalis* plants that were planted initially have multiply to cover the entire setup forming a thick vegetation with profuse roots (Fig. 3). The plant growth was also monitored and the plant was found to have a rapid rate of growth with an average growth rate of 0.31 meter per week.

Figure 1: Wetland Unit

Figure 2: Wetland Unit with Lining

2.4 Wetland Operation

Draining of the Setup:- All the water present in the setup was drained two days before the introduction of the wastewater by keeping the outlet widely open. This is necessary to avoid the dilution of the wastewater by the fresh water used in nurturing the plant and therefore eliminate error during analysis.
Wastewater Collection:- The wastewater used for this research work was collected from an eatery located in Aroje area of Ogbomoso along Ilorin road with the aid of six 25 liters kegs to make the total volume of the waste water collected 150 liters.

Figure 3: Setup Before and After Seven Months

Pretreatment and Introduction of the Wastewater into the Setup:- A total volume of 75 liters of wastewater was screened using a 75µm sieve and introduce into the setup manually from the open roof at top of the basin on 17^{th} of March 2014.
Sample Collection and Qualitative analysis
75cl sample each was collected from the setup for detention time of 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 days respectively including that of the raw waste water, and qualitative analysis carried out according to APHA standard on each of the sample collected to determine the effect of detention period on the wastewater.
The parameters tested for are; Colour, pH and odour, Temperature, Turbidity, Conductivity, Dissolved Oxygen (DO), Biochemical Oxygen Demand ($BOD_{5,20}$), Magnesium (Mg), Chloride (Cl^-), Sulphide (SO_4) and Nitrate (NO_3).

3. Results and Discussion

The results of the Physico-chemical analyses carried out on the samples daily for a retention time of ten (10) days were presented are as shown in Table 1 below.

3.1 Colour

Although, there was a significant change in the appearance of the water (Fig. 4) but the value of the colour remain the same for all the detention periods except for day 10 when it reduced colour by 3.64% (Table 1, Fig. 5 and 8).

3.2 pH and Odour

The acidity of the water reduce with increase in detention period and almost become neutral on day 7 (Table 1 and Fig. 6) after which it started to fluctuate. The increase in PH ranges between 11.70 to 39.49% and the highest being on day 7 with an increase of 39.49% (Table 2 and Fig. 8). The odour of the treated water was a light offensive one throughout the detention period and can only be perceived when the water is brought closer to the nose at a distance of 5 centimeter.

Figure 4: Appearance of the Water Before and After Treatment

3.3 Temperature

There was no significant change in temperature with increase with detention period as it was fluctuating between the ranges of 27.8 to 31.4^{o}c compared to that of the influent which was 31.2^{o}c (Table 1 and Fig. 6).

3.4 Turbidity and Conductivity

The constructed wetland system is highly effective in the removal of both turbidity and conductivity (Fig. 8) as both decreases significantly with increase in the detention period. The turbidity ranging between 40.53 to 259 FTU compared with that of the influent which is 1000 FTU and reduction in the range of 74.10 to 95.95% with the highest reduction being on day 7 with 95.95% (Table 1, Fig. 5 and 8). The conductivity reduced continuously with increase in detention period up to day 3 after which it increased continuously (Table 1). The conductivity ranged between 19.9 to 50.7µs (Table 1 and Fig. 6) and the reduction ranged between 48.94 to 79.96% with the highest reduction being on day 3 with 79.96% (Table 2 and Fig. 8).

3.5 Dissolved Oxygen and Biochemical Oxygen Demand

There was an inverse relationship between DO and BOD_5 in relation to the detention periods (Fig. 7), as DO concentration increased continuously with increase in detention period while the BOD_5 decrease continuously. The DO concentration ranges between 5.70 to 7.68ppm with increase in the range of 21.80 to 64.10% and the highest concentration on day 10 with an increase of 64.10% (Table 2 and Fig. 8). Also, the progression line indicated that 70.4% of the increase in DO is explained by the detention time (Figure 12) and there is a strong positive correlation between DO and detention time with a correlation coefficient of 0.84.
The BOD value ranges between 0.57 to 2.49 mg/L with the reduction was in the range 10.75 to 79.57% and the lowest value on day 10 (Table 1 and 2).

This indicates a depletion in the amount of aerobic microorganisms in the setup, and significant increase in dissolved oxygen brought about by high rate of oxygen transfer by the leave and stem above the water surface to the submerged part of the plant and hence the effectiveness of the plant, and consequently a reduction in organic loading.

Table 1: Effluent Characteristic for the various Detention Periods

Parameters	Detention period										
	0	1	2	3	4	5	6	7	8	9	10
PH value	4.70	5.25	5.38	5.55	5.70	5.75	5.87	6.18	6.04	5.98	6.03
Temperature (^oC)	31.2	29.1	28.6	29.5	29.0	28.5	31.4	27.8	30.3	28.0	30.1
Colour	550	550	550	550	550	550	550	550	550	550	530
Turbidity (FTU)	1000	259	120	93	90	83	52	40.53	65	45.96	51
Conductivity (µS)	99.3	50.7	33.3	19.9	24.4	24.7	28.0	28.3	28.7	28.9	29.0
DO (ppm)	4.68	5.70	5.94	7.24	7.44	7.53	7.59	7.63	7.65	7.67	7.68
BOD_5 (mg/l)	2.79	2.49	2.25	1.93	1.67	1.45	1.20	1.07	0.91	0.73	0.57
Mg (mg/l)	313.47	225.99	170.10	148.23	128.79	102.06	92.34	85.05	80.19	65.71	60.75
Cl^-(mg/l)	1680	870	810	760	700	640	600	580	550	530	500
SO_4^-(mg/l)	66	26	22	20	18	14	12	14	10	12	8
NO_3^-(mg/l)	132.9	132.9	132.9	132.9	132.9	44.3	44.3	44.3	44.3	44.3	44.3

Table 2: Treatment Performance of the Wetland Plant

Parameters	Treatment Performance (% Reduction)									
	Detention periods (days)									
	1	2	3	4	5	6	7	8	9	10
PH	11.70*	14.47*	18.09*	21.28*	22.34*	24.89*	31.49*	28.51*	27.23*	28.30*
Temperature	6.73	8.33	5.45	7.05	8.65	0.64*	10.90	2.89	10.25	3.53
Colour	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.64
Turbidity	74.10	88.00	90.70	91.00	91.70	94.80	95.95	93.50	95.40	94.90
Conductivity	48.94	66.47	79.96	75.43	75.13	71.80	71.50	71.10	70.90	70.80
DO	21.80*	26.92*	54.70*	58.97*	60.90*	62.18*	63.03*	63.46*	63.89*	64.10*
BOD_5	10.75	19.36	30.83	40.14	48.03	56.99	61.65	67.38	73.84	79.57
Mg	27.91	45.71	52.71	58.92	67.44	70.54	72.87	74.42	79.07	80.62
Cl^-	48.21	51.79	54.76	58.33	61.91	64.59	65.48	67.26	68.45	70.24
SO_4^-	60.61	66.67	69.70	72.73	78.79	81.82	78.79	84.85	81.82	87.88
NO_3^-	0.00	0.00	0.00	0.00	66.67	66.67	66.67	66.67	66.67	66.67

Note: * percentage increase

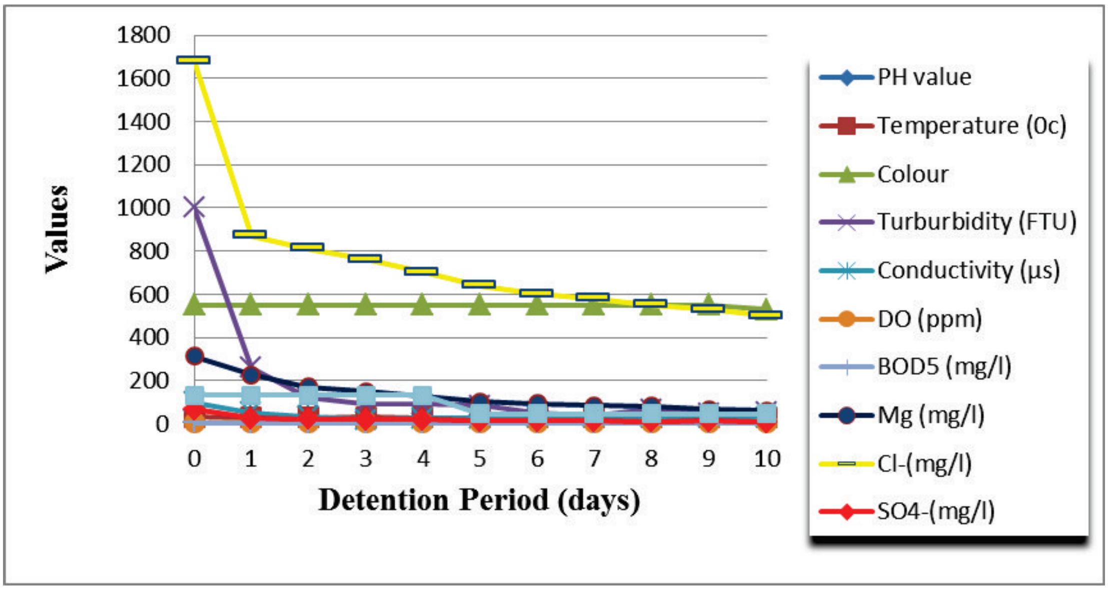

Figure 5: Effluent Characteristic for the various Detention Periods

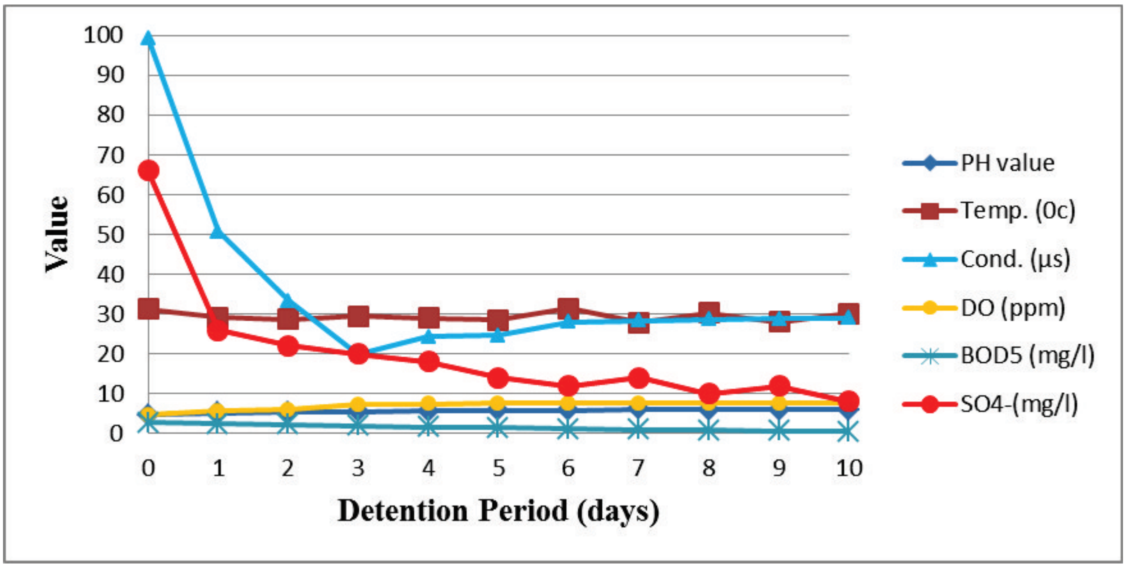

Figure 6: Enlarged Version of the figure 1 for Some Effluent Characteristic

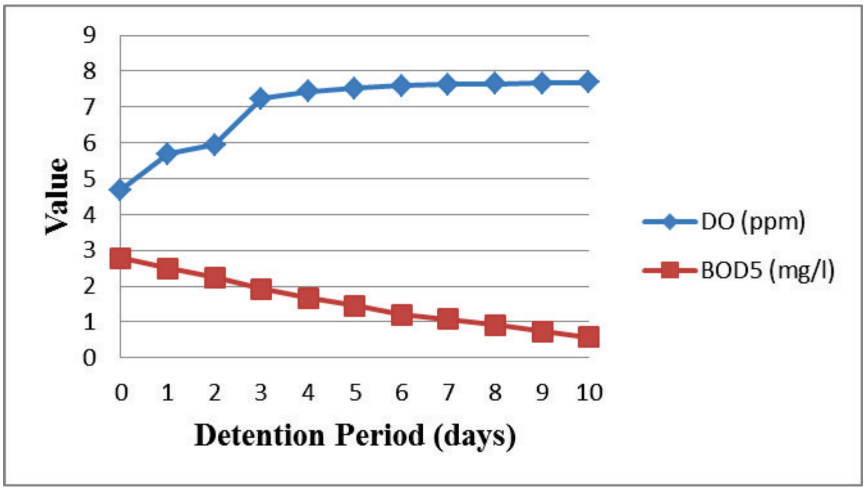

Figure 7: Comparison of Dissolved Oxygen and BOD_5 Values

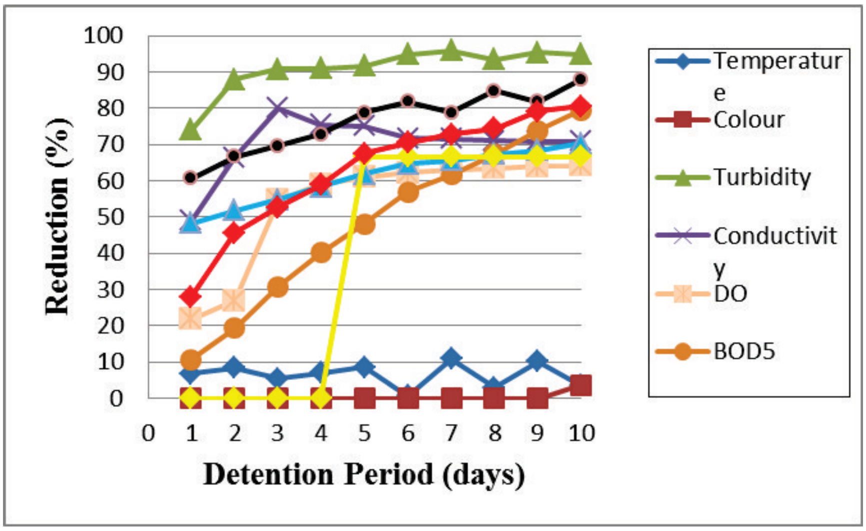

Figure 8: Treatment Performance of the Wetland Plant

3.6 Magnesium

The effectiveness of the constructed wetland was high with respect to magnesium reduction as it continuously reduced it concentration with increase in detention period (Fig. 8). Magnesium concentration throughout the detention periods ranged between 60.75 to 225.99 mg/l compared to that of the wastewater which was 313.47 mg/l (Table 1 and Fig. 5) and the removal ranged between 27.91 to 80.62% (Table 2 and Fig. 8) indicating a significant reduction in the concentration.

3.7 Nitrate (NO_3^-)

The Nitrate concentration remain unchanged for the first four days after which it reduces by 66.67% and remain constant at the new concentration for the subsequent detention periods (Table 1 and 2).

3.8 Chloride

The performance efficiency of the system with respect to chlorine shows a consistent decrease. The chloride concentration decreases continuous as the detention period increases (Table 1 and Fig. 5 and the reduction is in the range of 48.21 to 70.24% with the highest reduction on day 10 (Table 2 and Fig. 8).

3.9 Sulphite

The wetland system is highly efficient in removal of sulphite, as the sulphite concentration decreases continuously with increase in the detention period up to day 6 after which the concentration fluctuated for the next four days (Table 1 and Fig. 6). The reduction in concentration was in the range of 60.61 to 87.88% with the highest reduction being on day 10 (Table 2 and Fig. 8).

3.10General Performance

The overall performance of the wetland ranged between 3.53 to 95.95% throughout the detention periods. As the detention period increase, there was a continuous reduction in turbidity, conductivity, $BOD_{5,\ 20,}$ chloride, sulphite, and nitrate (NO_3^-), a continuous increase in pH and dissolved oxygen, colour remain almost constant but there was a fluctuation in temperature.
However, a comparison of the results for the various detention periods indicated that a detention period of 7 days with removal efficiency of between 31.49 to 95.95% (Table 4.2) is optimal for treating the wastewater as there is no significant improvement in the concentration of the various parameters after this period and this is in agreement to that proposed by Borkar and Mahatme (Borkar and Mahatme, 2011) and also fall within the range of that proposed by the United State Protection Agency (USEPA, 1988).
The experiment shows that there was a significant improvement in the quality of the treated water with increase in detention period. However, the treated water does not meet the requirement of the World Health Organization (WHO) standards and the Nigerian Standard for Drinking Water Quality (NSDWQ) as the concentration of some parameters are above those set by these standards, but may be suitable for other purposes such as irrigation and fishing pond.

4. Conclusion and Recommedations

Based on the finds from this study, the following conclusions are drawn:
The free water Surface flow constructed wetland using *Typha Orientalis* is effective and suitable for treating domestic wastewater. A detention period of seven days is optimal for effective treatment of the collected wastewater from kitchen. The treatment system is a low cost and environmental friendly technique, and it is suitable for use at the very point where the wastewater is generated. The treated water may be suitable for non-drinking purposes such irrigation and fishing.

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