Full Paper

PERFORMANCE EVALUATION OF SELECTED MACROPHYTES AND FILTER MEDIA IN TERTIARY HOSPITAL WASTEWATER TREATMENT

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ABSTRACT

Biologically-based on-site pollution-prevention and recycling technologies that require low energy and labour costs are more economically attractive in wastewater treatment. This research work investigates the efficiency of constructed wetland using granite and sand as substrate on the removal of pollutants from wastewater. The experimental setup consists of eight microcosms planted with the locally available macrophytes using fine and coarse substrate. The microcosms were irrigated using wastewater from a tertiary hospital, pollution parameters were measured using the standard APHA method and growth rate was monitored. Phosphate removal was high in Constructed Wetland microcosm planted with *P. Karka* than *V. nigritana* (66.88 % and 68.65 % reductions respectively). The experimental studies also revealed a 68.18 % and 66.36 % reduction in TSS for *V. nigritana and P. Karka* respectively. Percentage BOD_5 reduction of 58.39 % and 65.77 % in *V. nigritana* and *P. karka* was also observed. The design of Constructed Wetland for the tertiary hospital, based on the preliminary analysis shows four Vegetated Submerged Bed Constructed Wetland cells each 63.73 x 75 m. Coarse aggregates are suitable as filter media in Constructed Wetlands than fine aggregate in treating wastewater from a tertiary hospital.

Keywords: *Constructed Wetlands, V. nigritana, P. Karka, substrate, wastewater*

1. INTRODUCTION

Construction of central wastewater treatment plants usually consists of mechanical systems that have high construction, energy and labour costs. The advanced mechanical treatment systems require higher level of operation skills and communities that operate such systems are constantly faced with the annual energy and labour costs. These costs represent a significant portion of the budgets for small communities. Central wastewater treatment plants can never solve the problem of water pollution; they only create more complex pollution problems to solve (Rockefeller, 1997).

Ademoroti (1983) in his work on trickling filter and activated sludge plant performance in Ibadan was of the opinion that at the early stage of use, the conventional treatment plant was found to reduce many of the named characteristics considerably but noticed some deficiencies in the area of high level of odour which develops in the primary settling tanks and the insect nuisance which makes working on the site unattractive. The sludge produced by central treatment plants when not adequately handled, may have disastrous effects both on the agricultural soils and the ecosystem.

Biologically-based on-site pollution-prevention and recycling technologies that require more land and have lower energy and labour costs are more economically attractive. Wastewater treatment by such treatment systems involving vegetation is also environmentally friendly (Coker *et al*., 2009; Badejo *et al*., 2012).

For a long time researchers have pointed out the high pollution removal capacity of natural environment (soils, wetlands, etc) and studies have been ongoing on the possibility of using natural environment in order to purify or complete wastewater purification (Cooper *et al*., 1989; Chen *et al*., 2008; Chung *et al*., 2008). Aslam *et al*. (2004) acknowledged wetlands as ecosystems of primary importance with very special functions and values. Wetlands are highly dynamic ecosystems which exist in many forms: marshes, estuaries, mudflats, mires, ponds, swamps, deltas, coral reefs, billabongs, lagoons, shallow seas, bogs, lakes, and floodplains (Aslam *et al*., 2004). They are areas where the water level is near the ground surface, this level of water maintained long enough to sustain saturated soil condition round the year along with the vegetation. Natural wetlands according to USEPA (2004) is the "earth's kidneys", due to the fact that they filter pollutants from water that passes through them on its way to receiving lakes, streams and oceans. Engineers and scientists construct systems that replicate the functions of natural wetlands because these systems can improve water quality.

Constructed wetlands (CW) are wastewater treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality. A CW is a wetland specifically constructed at a location other than existing natural wetlands for the purpose of pollution control and waste management. The size of a CW might be small and remain constant but that of natural wetland is large and increases with time. CWs develop desired diversity of plants and associated organism more quickly than the natural wetlands (Erakhrumen, 2007).

CWs are complex matrix of distinct aerobic and anaerobic treatment zones. They are artificial wastewater treatment systems consisting of shallow ponds or channels planted with aquatic plants, and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater. CW incorporates a tolerant plant species that is locally available at minimal cost (Aluko *et al*., 2003; USEPA, 1999). CW is a wastewater treatment facility duplicating the processes occurring in natural wetlands. It is a complex integrated system in which water, plants, animals, microorganisms and the environment; sun, soil and air interact to improve water quality. Constructed wetlands can be classified based on the type of macrophytic growth (emergent, submerged, free floating and rooted with floating leaves) or the water flow regime (surface flow, sub-surface, vertical or horizontal flow). The two main types of CWs, are the Free water surface (FWS) wetlands or surface-flow (SF) constructed wetlands, and Vegetated submerged bed (VSB) systems or subsurface-flow (SSF) constructed wetlands (USEPA, 2004).

CW systems have been favoured for wastewater treatment as they tolerated a broad range of loadings (Parkes *et al.*, 1998). CW is a form of passive composting, the design loading rate ranges from 30 to 60 kg/m^3yr and loading rates as high as 100 kg/m^3yr have been used, depending on the nature of the sludge and climatic conditions (Metcalf and Eddy, 2004).

Distinctive feature of this CW system according to Cooper *et al.* (1989) includes the roots of the plants that grow vertically and horizontally to provide maximum contact with the wastewater and substrate. Effluents are treated by aerobic biological activity at the rhizophere and inlet zone while anoxic and anaerobic treatment takes place at the middle and base of the system.

CW serves as sedimentation basins and physical filters for particulates; providing retention time for destruction of pathogens; physico-chemical reactors for precipitate formation and biological reactors for organic matter decomposition. The treatment efficiency of CW is attributed to the retention time of the wastewater in the CW and to the development of microbial film and its diversity, which mineralizes and degrades wastewater components to satisfy energy and biochemical requirements (Brock and Madigan, 1988). Constructed wetland systems are designed to maximize the physical, chemical and biological abilities of natural wetlands; to reduce the biochemical oxygen demand (BOD), total suspended solid (TSS), total nitrogen (TN), phosphorus, and pathogens as wastewater flows slowly through the vegetated subsurface. Constructed wetland technology offers an economic and sustainable solution for removing BOD, particulates, nutrients and bacteria from domestic and industrial wastewater (Ayaz, 2008).

More than 20 years now, quantifying the effectiveness and improving the design of constructed wetland in treating wastewater has been a major source of concern, both at the secondary and tertiary stages. The main difficulty in creating general design guidelines is that many factors can affect their behaviour, among which are: climate, type of vegetation, substrate materials, effects of the local environment and operating strategies. This research work therefore investigated the efficiency of Constructed wetland using granite and fine sand as substrate on the removal of pollutants from wastewater generated in a health Institution in Ibadan, Oyo State.

2. MATERIALS AND METHODS

Ibadan, the study area is the capital of Oyo State, Ibadan is a tropical city with two seasons, the raining and dry season. It has a daily temperature ranging from 21.1^{0}C to 33.9^{0}C, in the months of February/March the temperature could rise to 36.7^{0}C. Ibadan has an average relative humidity of 90% at 06:30hrs and 65% at 12:30hrs. It is situated at an average height of 200 m above sea level, drained by four river basins and surrounded by secondary rainforest as well as a savannah. The University College Hospital (UCH) is situated on longitude 4^0 54' east and latitude 7^0 24' north, right in the heart of Ibadan city. Small streams to the north and south of UCH enhance its drainage. Each of these streams flows from the west to the east and discharges into Ogunpa stream.

This discharge system enhances gravity flow in the collection of wastewater through pipes and obviates pumping stations in the wastewater pipes (Okunromade, 2002, Ademoroti, 1983). The University College Hospital (UCH) Ibadan, central wastewater scheme was constructed over 5 decades ago, to treat 350,000 metric tones of wastewater. The treatment plant has completely broken down, the physical and biological methods it employs at inception include: Primary Settlements, Trickling filtration, Activated sludge digestion, Secondary sedimentation, Anaerobic sludge digestion, Disinfection of final effluent and Drying of digested sludge on the filter beds (Fig. 1).

One of the existing disused concrete walled drying beds was used as the Constructed Wetland prototype. The sludge drying bed was divided into two equal parts and the first half of the bed was partitioned into five cells. Each of the included cells was rectangular in cross-section and the cells at the edges were trapezoidal in cross-section. The cell at the centre was used as the control bed, to either side were two beds planted with *Vetiveria nigritana* and *Phragmites karka*.

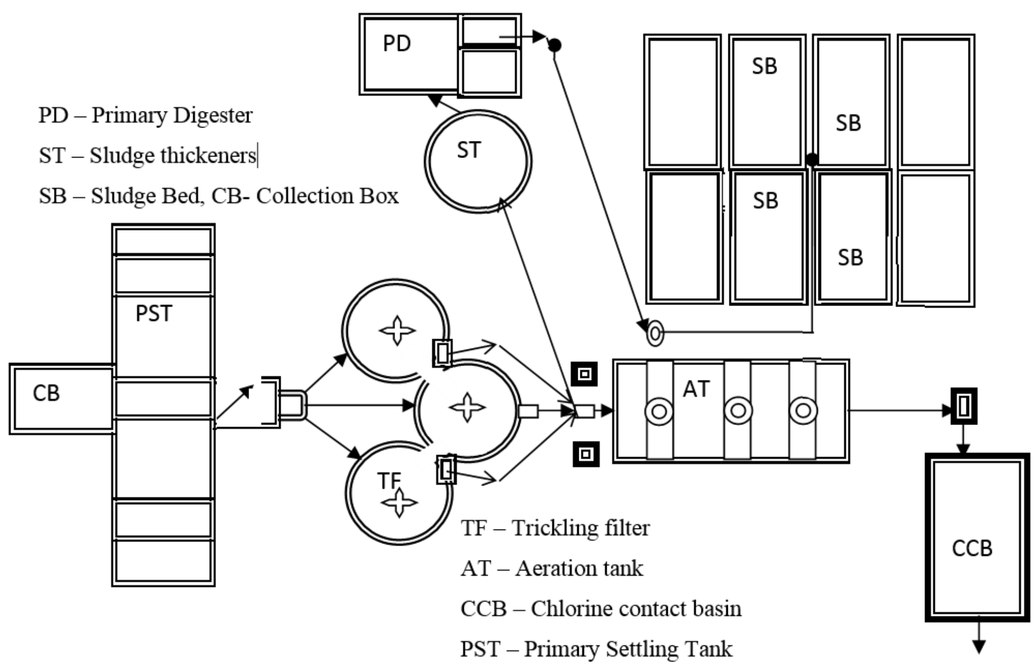


Fig. 1 Schematic diagram of UCH wastewater treatment plant

All the beds have a uniform depth of 0.7 m; the two cells at the edges were 310 x 340 cm while the remaining three were 250 x 340 cm each. They were separated by sandcrete blocks, well rendered to prevent percolation of wastewater. Each of the beds has a slope of 2% to allow the wastewater pass through the bed under gravity with ease. Transplanted rhizomes of the two macrophytes, *Phragmites karka* (commonly known as reeds) and *Vetiveria nigritana* (the Nigerian specie of Vetiver) were used. The experimental setup consists of eight microcosms, six of which were planted with the locally available macrophytes under study using the fine substrate and two planted without the fine substrate. The eight microcosms were irrigated using the same quantity of sewage, pollution parameters were measured using the standard APHA method and growth rate was monitored by counting the number of leaves and offshoots; measuring the width and stem thickness, height and length with vernier caliper and a measuring tape at weekly intervals. Samples were stored at 4^0C and analysis conducted within three hours of sample collection. Parameters like the Dissolved Oxygen and temperature were determined *in situ.*

Fine substrates obtained from Ologuoro stream, beside UCH (C_u = 2.435 and C_c = 1.094) were replaced with granite (10 mm – 15 mm) from Capital Quarry, Ibadan, Oyo State, Nigeria.

Vetiveria nigritana was collected from the Department of Agronomy, University of Ibadan. *Phragmites karka* was obtained from Igbobele watercourse in Badagry, Lagos State and maintained at UCH sewage farm. Transplanted rhizomes of *V. nigritana* and *P. karka* were planted at 500 mm centre to centre.

The substrate materials used in this study were granite and fine sand. The fine sand was subjected to sieve analysis to determine the grade sizes. The coarse substrate was made up of 200 mm deep 10-15 mm granite, while the fine sand layer was 200 mm thick.

The Valeport 'Braystoke' BFM002 miniature current meter designed for the measurement of flow velocities in effluent water was used to measure the wastewater flowrate. Readings were taking at interval of 50 seconds, average of four readings were computed for each study time. The velocity of flow was computed using the miniature current meter calibration chart. Determination of the discharge was then obtained with the area and uniform cross-section of the flow path. The rating curve was also plotted.

3. RESULTS AND DISCUSSION

The discharge and mass loading of wastewater is an essential stage in the conceptual process of the design of wastewater treatment plant. The hydraulic characteristics, sizing and operational consideration of the treatment plant depends to a large extent on the flow rate and constituent mass loading of the wastewater. Koskiaho (2006) noted that the driving forces behind the existence and functions of the natural treatment found in constructed wetland are closely linked to hydrology and hydraulics of the wastewater. The sewage generated at the University College Hospital varies during the time of the day and season of the year. The mathematical model representing the discharge during the wet season is given by the equation

$$y = 3.7939x^2 - 54.789x + 406.71 \quad (1)$$

During the dry season the mathematical model representing the discharge at the University Teaching Hospital is given by the equation

$$y = 2.4697x^2 - 43.381x + 279.57 \quad (2)$$

where x represents the time of the day between 7am and 7pm

The rating curve for the discharge is represented by the equation

$$y = 0.0212x - 1.1436 \quad (3)$$

3.1. Percentage changes in physico-chemical parameters tested in Constructed Wetlands

3.1.1. *Temperature*

Temperature plays a significant role in wastewater treatment, as it affects microbial activity and vegetation functions. It has been observed that generally for all pollutants, lower removal efficiencies correspond to lower temperatures and higher efficiency corresponds to higher temperature (Akratos and Tsihrintzis, 2007; Ayaz, 2008). Plant uptake of nutrients has been shown to be significantly affected by the temperature. The average temperature for the influent wastewater into the CW during the study period was 30.34 ± 0.97 ^{0}C while average temperature of effluent from the CW was 30.16 ± 0.42 ^{0}C. The temperature dropped slightly to 29.4 ^{0}C and had a maximum of 33.3 ^{0}C, this temperature range according to Kadlec and Knight (1996) is adequate for efficient removal of nutrients and pathogens. Removal of sand substrate brought a slight increase in temperature in the effluent (Table 1). In a tropical region like Nigeria that has constant sequence of solar energy all the year round, the high temperature provides a good environment for rootzone technology. This range of temperature would be suitable to a CW technology. The analysis of variance shows no significant difference in the mean temperature at each collection point between treatment with *V. nigritana* and *P. karka*.

3.1.2. *pH*

The Federal Environmental Protection Agency (FEPA, 1992) stipulated a pH tolerance limit of 6.0 - 9.0 for effluent to be discharged through sewers into stream and WHO recommended a range of 6.5 – 8.5 for water meant for full contact recreation. The EU also sets protection limits of 6-9 for fisheries and aquatic life (Ogunfowokan, *et al*., 2005). The pH of the effluent for the experimental pots has an average of 7.38 ± 0.16. The influent used for irrigating the CW has an average pH of 7.63 ± 0.16. The pH of effluent from pots with granite substrate only shows a decrease in the percentage reduction, this is similar to what was observed in the temperature (Table 1). The result shows a reduction of about 3.28 % in the value of the pH. These results lie within the stipulated values of FEPA and WHO for wastewater discharge into stream and water meant for full recreation respectively.

3.1.3. *Nutrients*

Excessive discharge of nutrients into wastewater leads to ecological imbalance which results in overgrowth of plants and animals leading to water quality deterioration. High nutrient value results in the growth of blue-green algae which could release toxic cyanotoxins into the receiving water (Ogunfowokan *et al*., 2005). Ademoroti (1983) obtained a percentage increase in nitrate and 5.4 % decrease in phosphate. The result of the CW revealed a reduction of 74.29 % and 70 % nitrate in *P. Karka and V. nigritana* CW respectively, showing that CW has a tendency of reducing the nutrients in the wastewater. This agrees with Brisson and Chazarenc (2008) where it was observed that there was a difference in removal between plants species and when this occurs it mostly involves nitrate.

Phosphate removal was also high in CW planted with *P. Karka* than *V. nigritana*, 66.88 % and 68.65 % reductions were observed in *V. nigritana* and *P. Karka* respectively. Brisson and Chazarenc (2008) concluded that there is no clear trend in phosphorus removal in CW. However, this result agrees with the findings of Chung *et al*. (2008) and Bubba *et al*. (2003).

3.1.4. *Suspended Solids*

A reduction in suspended solids was noticed in CW planted with *P. karka and V. nigritana.* Percentage reduction of 69.09 % was observed in both *V. nigritana* and *P. karka*. This agrees with Brisson and Chazarenc (2008) where it was stated that plants contribute little to suspended solid removal in CW since the primary mechanisms involved are filtration and sedimentation. Experimental studies with only 10-15 mm granite as substrate also affirms the conclusion that suspended solids removal in CW is by flocculation, sedimentation and interception. In the experimental studies 68.18 % and 66.36 % reduction was obtained for *V. nigritana and P. Karka* respectively, the effect of the upper substrate sand (Cu = 2.435 and Cc = 1.094) in filtering and sedimentation was noticed.

Table 1: Changes in Physico-chemical parameters (with and without sand substrate)

Macrophytes / Parameters	Temp ^0C	pH	TS mg/l	TDS mg/l	TSS mg/l	DO mg/l	NO_3 mg/l	PO_4-P mg/l	PO_4 mg/l	BOD mg/l
Influent	31.4	7.40	656	425	231	0.17	0.135	0.752	2.303	317
Granite and sand substrate										
V. nigritana	31.4	7.11	410	337	73	1.72	0.044	0.086	0.266	127
V. nigritana	31.6	7.08	397	330	67	1.16	0.045	0.065	0.200	122
P. karka	31.4	7.20	386	314	72	1.26	0.037	0.045	0.194	101
P. karka	31.4	7.12	353	281	72	1.08	0.037	0.060	0.184	99
Granite substrate only										
V. nigritana	30.9	7.24	280	210	70	4.40	0.100	0.294	0.905	98
P. karka	32.0	7.23	282	206	76	3.08	0.087	0.203	0.660	110

3.1.5. Biochemical Oxygen Demand

The two major parameters taken into consideration in the design of CW are the TSS and the BOD. Biochemical oxygen demand removal only occurs when the material causing the BOD is completely converted by anaerobic biological processes to gaseous end products. *Phragmites karka* showed higher treatment efficiency in BOD removal than *V. nigritana* (Table 1). Results show a percentage reduction of 58.39 % and 65.77 % in *V. nigritana* and *P. karka*.

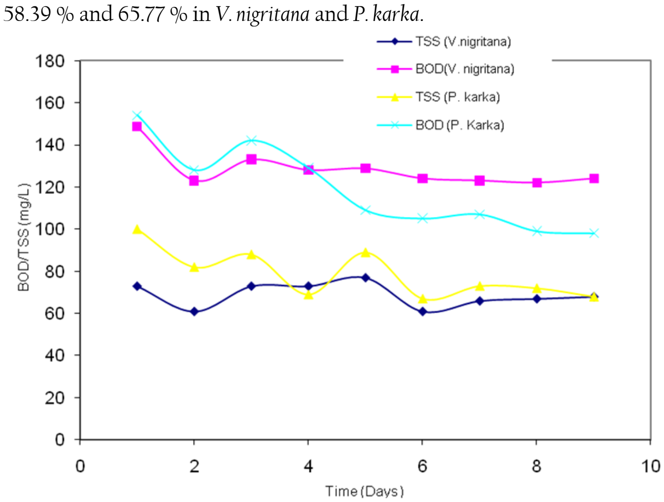


Fig.2 Variation of BOD and TSS in CW planted with V. nigritana and P. Karka

3.2. Design of a Vegetated Submerged Bed for UCH

Constructed wetland consists mainly of a properly designed basin that contains water, a substrate and most commonly vascular plants, other important components of wetlands, such as the communities of microbes and aquatic invertebrates develop naturally.

CW basin was designed based on the assumption that pre-treated effluents are collected from the reactivated primary sedimentation tank and trickling filter. Four different compartments was used, each conforming to the CW design criteria, these include the inlet, outlet and two treatment zones. The two treatment zones consist of the initial and final treatment zones; the initial treatment zone which performs most of the treatment is 30% of the total area and have sharp decrease in hydraulic conductivity. The final treatment zone with little change in hydraulic conductivity was involved in the final clarification and occupies the remaining 70% of the treatment zone. The two locally available macrophytes under investigation (*P. Karka and V. nigritana*) were used for the design due to the performance efficiency obtained from the preliminary studies.

3.2.1. Substrate

The media materials were washed sand (Cu = 2.435 and Cc = 1.094) and washed granite (15 -25 mm sized) so as to take care of the TSS in filtration, sedimentation and interception required in TSS removal. For successful plant establishment 1:3 mix ratio (25 to 75 percent mix of water to wastewater) was also used, a sand material underlaid by 15-25 mm sized 600 mm deep rounded granite (hydraulic conductivity = 100,000 m/d) conducive for root growth was utilized for the treatment zone. The substrate provided the rooting materials for vegetation and the required surface area for plant growth. The flow distribution was also done by the substrates and the outlet and inlet of the CW was selected so as to avoid clogging or surfacing in the CW.

The Inlet and outlet zones were of granite between 30 and 60 mm diameter extending from top to bottom so as to avoid clogging. This would help to provide even distribution and collection of the wastewater without clogging.

3.2.2. Sizing of initial and final treatment zones

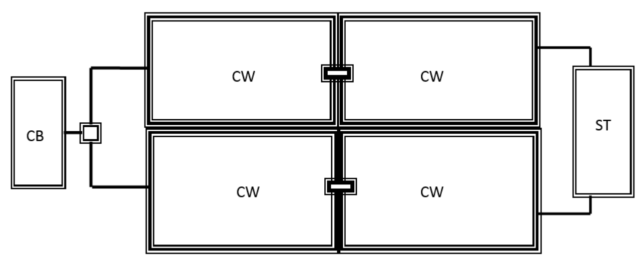
The sizing of the initial and final treatment zones was based on the requirement for effluent to be discharged into streams as stated by the Nigerian Federal Environmental Protection Agency. FEPA recommended BOD of 50 mg/l and TSS of 50 mg/l as the maximum for effluent discharge (FEPA, 1992).

UCH maximum flow rate Q = 370 m^3/day
UCH average BOD_5 = 310.56 mg/L
UCH average TSS = 204.1 mg/L

The design revealed four Vegetated Submerged Bed Constructed Wetland cells each 63.73 x 75 m, two connected in parallel to avoid untreated wastewater discharge during harvesting and maintenance of the CW (Fig. 3).

3.2.3. Substrate depth

A minimum depth-to-water of substrate was used throughout the CW, a drop of 0.1m from the substrate elevation at the inlet. An additional 0.1m was used as a top layer for the CW; this is to increase the performance efficiency of the CW in respected of filtration and sedimentation as observed from the experimental studies.



- Collection Box, CW- Constructed Wetland, ST – Storage tank

Fig. 3 Schematic diagram Constructed Wetland System for UCH Wastewater Treatment

4. CONCLUSION

Constructed wetlands using locally available macrophytes (*Vetiveria nigritana and Phragmites Karka*) are efficient for the treatment of wastewater from a tertiary healthcare facility.

The design and construction of this treatment facility did not entail the use of any mechanical component and, thus, the maintenance requirement would be minimal. This treatment facility could be used to replace the dilapidated trickling filter and activated sludge in the University College Hospital and other tertiary institutions having similar wastewater composition. Coarse aggregates and fine aggregates are suitable as filter media in Constructed Wetlands in treating wastewater from a tertiary hospital.

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