Ain Shams Engineering Journal 9 (2018) 3179–3185

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Development and evaluation of a constructed pilot-scale horizontal subsurface flow wetland treating piggery wastewater

I.J. Udom [a], C.C. Mbajiorgu [b], E.O. Oboho [c]

[a] Department of Agricultural Engineering, Akwa Ibom State University, Ikot Akpaden, Akwa Ibom State, Nigeria
[b] Ecohydrological Systems Research Unit (EHSRU), Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka, Nigeria
[c] Department of Chemical Engineering, Akwa Ibom State University, Ikot Akpaden, Akwa Ibom State, Nigeria

ARTICLE INFO

Article history:
Received 8 December 2017
Revised 20 March 2018
Accepted 14 April 2018
Available online 10 November 2018

Keywords:
Constructed wetland development
Piggery wastewater
Pennicetum clandestinum
Pennisetum purpureum
Removal efficiency
Pollution

ABSTRACT

This paper reports on the development and evaluation of a pilot horizontal subsurface flow constructed wetland (HSSFCW) for removal of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total nitrogen (TN) and total phosphorus (TP) from primary piggery wastewater. Two locally available plants, *Pennisetum clandestinum* and *Pennisetum purpureum*, were planted in two of three cells while the remaining unplanted cell served as the control. Monitoring of the wetland influent and effluent wastewater was carried out every two weeks for 7 months. The study revealed successful treatment of the wastewater by the wetland in terms of BOD, COD, TDS, TN and TP effluent compliance with Nigerian discharge standards. Average removal efficiencies were 66.53, 64.95, and 60.27% for BOD_5; 44.85, 41.61 and 36.37% for COD; 63.61, 58.27 and 52.88% for TDS; 62.49, 58.89 and 50.14% for TN and 48.53, 44.91 and 41.27% for TP for the three wetland cells including the control respectively. Planted cells achieved the highest removal efficiency with no significant difference in pollutant removal between the two planted cells indicating their suitability for use as wetland plants. Effluent concentrations were within FEPA discharge limits except TP. The performance of the constructed wetland suggests that HSSFCW could be a suitable alternative technology for on-farm treatment of piggery wastewater in Nigeria. The study has provided a starting point for the use of HSSFCW and gives insight of the potential application of this technology for on- farm pollution control in Nigeria.

1. Introduction

Pig farming has become increasingly intensive with corresponding production and concentration of large volumes of manure in small areas. On-farm treatment methods like land spreading and composting is land intensive and, the use of piggery waste as organic fertilizer is not popular among Nigerian farmers due to difficulty in transport of piggery effluent from point of production to point of demand [1,2]. The result is the discharge of untreated piggery wastewater into the environment.

Poor removal of nutrients from piggery wastewater by existing conventional systems such as septic tanks, waste stabilization and oxidation ponds, are thought to contribute to declining water quality and high cost of operation due to technical and energy demands. Methods that are practical and affordable are needed to improve performance of on-farm wastewater systems. Constructed wetlands (CWs) are one proven solution that have been successfully used worldwide for many years with high removal efficiencies both in tropical and temperate countries [3–9]. But its application should be tested locally and data on various designs of constructed wetlands are needed for effective application of these systems to treat wastewater to meet discharge limits.

Also, there is need to identify locally available plants that are suitable for use in our constructed wetlands.

The right approach to testing the efficiency in the design and application of CWs is to evaluate the performance of pilot constructed wetlands, which then serves as the basis for the detailed design of real systems [10]. HSSFCW development cycle involves wetland selection, design, construction, operation and maintenance, monitoring and evaluation [10].

This study aims to develop and evaluate the performance of a pilot HSSFCW for piggery wastewater treatment and investigate

E-mail addresses: ikpeudom@aksu.edu.ng (I.J. Udom), constantine.mbajiorgu@unn.edu.ng (C.C. Mbajiorgu).
Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.asej.2018.04.002
2090-4479/

the effects of two locally available plants, *Pennisetum purpureum* and *Pennisetum clandestinum*, on wastewater treatment efficiency.

2. Materials and methods

2.1. Site description

The pilot HSSFCW was located close to the effluent source behind a piggery facility at the Obio Akpa campus of Akwa Ibom State University. Fig. 1 shows location of constructed wetland (24a).

Obio Akpa is located in the humid tropics between longitudes 07° 3″E and 07° 3″E and latitude 04° 45″N and 04° 55″N. The average minimum and maximum temperatures range between 18 and 27 °C and 24–36 °C respectively. Relative humidity ranges between 55 and 86%. Rainfall has a bimodal distribution lasting from April to October with a short break in August. Average rainfall ranges from 2050 to 2450 mm. The piggery produces an estimated 9.46 m^3/day and discharges the wastewater without treatment onto the flood-plain of Obio Akpa stream; a perennial stream which serves as a major source of water to over 150,000 people [11] in three villages which the stream traverses before emptying into the Qua Iboe River at Ekpene Obo in Oruk Anam L. G. A. of Akwa Ibom State.

2.2. Wetland design

The design of HSSFCW was based on an assumption of plug flow movement of water through the wetland with first-order reaction kinetics primarily for biological degradation. Specifically, the sizing of the wetland was in accordance with the equation proposed by Kikuth [12],

$$A = \frac{Q(InC_{in} - InC_{out})}{K_{BOD_5}} \tag{1}$$

where A = Surface area of HSSFCW (m^2)

C_{out} = Effluent BOD (50 mg/l-FEPA standard for discharge into open water)

C_{in} = Influent BOD (from measurement mg/l)

K_{BOD_5} = Area-based BOD rate constant.

The cells were built to ensure that wastewater and rain were the only inputs in the system. The dynamic wetland water balance Eq. (2) was used to estimate the average daily wastewater flow rate,

$$Q_i - Q_{out} + PA - ETA = \frac{dV}{dt} \tag{2}$$

where Q_i = Input wastewater flow rate, m^3/day

Q_{out}t = Output wastewater flow rate, m^3/day

P = Precipitation, mm

A = Surface area of HSSFCW (m^2)

ET = Evapotranspiration, mm/day

V = Water storage in wetland, m^3

Darcy's law was used to determine the capacity of the wetland to conduct the flow through it.

$$Q = K_s AS \tag{3}$$

where Q = flow capable of being passed through the SSCW, m^3/s

K_s = Hydraulic conductivity of a unit area of the wetland media

S = Hydraulic gradient of the water surface in the system, m/m

A = Surface area of HSSFCW (m^2)

Detention time was based on Equation [4],

$$\tau = \frac{Ah}{Q} = \frac{V}{Q} \tag{4}$$

where τ = Detention time, days.

A = Surface area of HSSFCW (m^2)

h = Hydraulic depth, m

Q = Water flow rate ($m^3\ h^{-1}$)

V = Maximum volume of the wetland and (m^3)

2.3. Construction

Fig. 2 shows wetland construction layout (a), lining (b), inlet and outlet regions (c), wastewater supply at inlet (d) macrophyte establishment (e) outlet pond for wastewater collection (f arrowed)

The construction process involved excavation, earth moving, backfilling and grading. The treatment area comprised three wetland cells laid out in concrete blocks and coarse sand media as substrate. The walls of the wetland were laid out in five courses of 127 mm sandcrete blocks on a concrete foundation with 1:2:4 ratio mix of cement, sand and gravel, all measured by volume [13]. A floor slab of 75 mm thick was cast on the containment structure at 1% slope to stabilize the sandy soil and provide a damp-proof membrane. A 2.5 mm thick polyethylene liner was then laid to cover the entire wetland floor (Fig. 1b).

2.4. Wetland cells

The wetland cells comprised of the inlet and outlet regions and the wetland treatment area. The inlet region comprised of 0.6 m depth of 30 mm crushed rock and extended 1 m from the inlet wall structure into the wetland treatment area to receive, distribute and control the flow path of the wastewater through the wetland.

The outlet structure consisted of a 2.5 cm diameter adjustable pipe mounted on a swivel elbow arrangement installed at a depth of 10 cm below the floor bed to access the effluent in the wetland

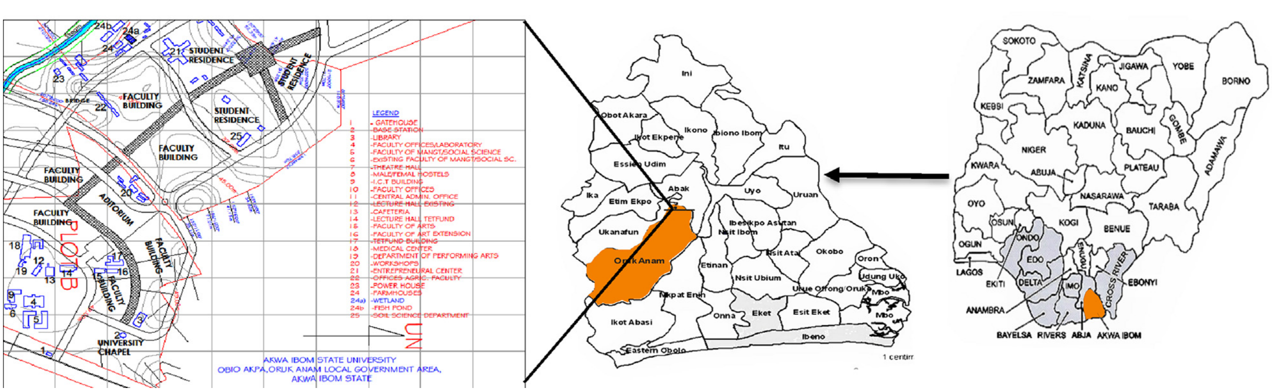

Fig. 1. Map of Akwa Ibom State University (AKSU) showing location of constructed wetland (24a).

Fig. 2. Constructed wetland layout (a), Lining (b), inlet and outlet regions (c), Wastewater supply at inlet (d) Macrophyte establishment (e) Outlet pond for Wastewater collection (f arrowed).

basin. The outlet pipe was in contact with the 0.6 m depth of outlet end granite chippings and captured the flow through the wetland as well as regulates the water depth in the wetland. A protected area (0.5 × 0.36 × 0.50) m on the outside of the outlet end of the wetland wall served as the outlet pond (Fig. 2f arrowed) to receive the effluent for discharge. The wetland was then filled with 0.6 m depth of coarse sand medium to provide the matrix for the wastewater as well as the medium for the growth of the macrophyte.

2.5. Plant selection and sources

PC and PP were selected because both are active colonizers in the Obio Akpa floodplain. Moreover, they are already being used as browsing plants for the pigs and are adapted to the local environmental conditions. Propagules of the plant (15 cm high) were planted at the rate of 11 plant/m^2 in two of the three wetland cells during the dry season of 2016 while one cell was left as control.

2.6. Wastewater delivery to the wetland

On daily basis, wastewater moved through the treatment train shown in Fig. 3. Wastewater flushed into shallow concrete drains moves by gravity into 101.6 mm diameter PVC pipe through a sandwich of netted filter and metal mesh where it is filtered of solids and debris before delivery to a detention pond located 25 m from the piggery house.

The detention pond ensured accurate flow measurement and regulated uniform application of wastewater to the wetland at a rate determined by the tank orifice configuration according to Eq. (5),

$$T = \frac{2A\sqrt{H_i}}{C_{a.}a\sqrt{2g}} \qquad (5)$$

where T = Time to empty the detention tank (sec.)
A = Cross sectional area of detention tank (m^2)
H_i = Depth of wastewater in the tank (m)
a = Area of orifice from tank to wetland cell (m^2)
C_a = Coefficient of orifice discharge (0.8 for short tube)
g = Acceleration due to gravity.

2.7. Sampling and analysis

Grab samples were collected from the inlet region of the wetland to determine the quality of the influent wastewater. Composite samples were collected from designated points in the wetland cells every forth night between the hours of 8 am and 11 am. Parameters measured to evaluate the performance of the wetland included pH, COD, BOD, TN, TP, TDS and Temperature. Environmental and some physical-chemical parameters were measured in-situ at the inlet and outlet of the wetland respectively. pH and total dissolved solids were determined with a HACH ECO 40 multi-probe and dissolved oxygen and temperature were measured using dissolved oxygen meter model HACH HQ40d multi probe. Sampling, sample handling and analysis were according to [14,15].

2.8. Statistical analysis

Statistical analysis of the data was carried out using Microsoft Excel 2007, MINI TAB 15 and SPSS software. Comparison of variables was performed using the analysis of variance (ANOVA) technique. SPSS was used to test the differences in the means while Minitab was used to compute the correlation between the treatments.

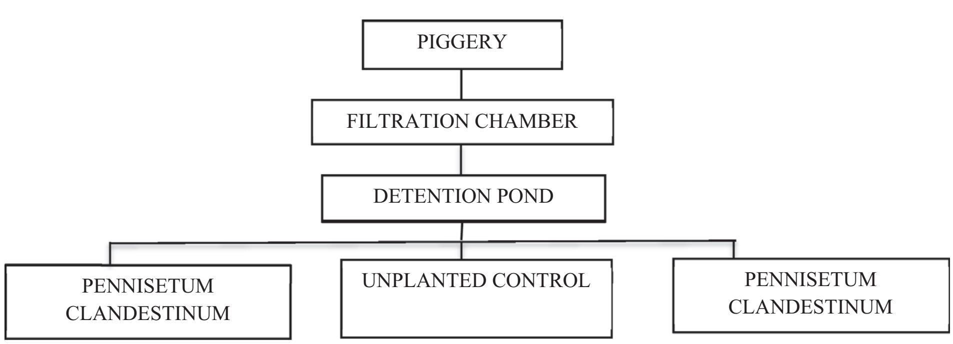

Fig. 3. Piggery wastewater treatment train.

2.9. Wetland water balance

Water balance and reference evapotranspiration (ET_0) was calculated using the standardized Penman-Monteith equation $ET_0 = -R_o + A_o$ [16] where R_o and A_o are the radiation and aerodynamic terms of the Penman-Monteith equation for short canopy reference ET with wind speed at 2 m height (U_2, ms^{-1}). ET was estimated by Eq. (7),

$$ET = \frac{Q_1}{A} + P - \frac{Q_2}{A} \tag{6}$$

where ET = Evapotranspiration of the macrophytes (mm/day),
Q_1 = Influent flow rate (m^3 day^{-1}),
A = Surface area of the HSSF CW bed (m^2),
P = Net precipitation (mm day^{-1}) and,
Q_2 = Discharge volume (m^3 day^{-1})

Plant coefficient (K_c) was calculated according to FAO 56 crop coefficient approach (Allen et al., 1998)

$$K_C = ET_C/ET_O \tag{7}$$

where ET_O = Reference evapotranspiration (mm d^{-1})

3. Results and discussion

3.1. Environmental conditions

Mean monthly day time air temperatures in the range of 25.2–27.8 were observed during the experimental period. Mean relative humidity was high (71.03–82.30).

Influent-effluent characteristics and mean pollutant removal efficiencies of AKSU-HSSFCW cells planted with two different wetland plants are shown in Tables 1 and 2.

3.2. Temperature and pH

The temperature of influent wastewater during the sampling period ranged from 24.4 °C to 27.2 °C

with a mean of 26.5 ± 0.8 and effluent temperatures varied from 22.3 to 25.60 °C, 22.60–25.60 °C and 23.20–26.3 °C with mean of 23.67 ± 0.92, 23.80 ± 0.9 and 24.58 ± 0.8 in the planted cells PC and PP, and control respectively. There was no significant difference between the temperature of the planted cells and the unplanted control. Wetland water temperature is directly related to the air temperature and do influence the overall treatment efficiency [17]. High temperatures affect the toxicity of some pollutants as well as the sensitivity of living organisms to toxic substances and low temperature slows chemical and biological rate processes [18]. Temperature of effluent wastewater samples from wetland fell within 40 °C limit hence, effluent temperature from the pilot wetland will not offset the homeostatic balance of the receiving environment.

Wastewater pH values ranged from a minimum of 6.30 to 8.20 in the influent wastewater to a maximum of 9.80 in the planted cells and 8.80 in the control. There was reduction in the acidity of the wastewater by the wetland system. High pH in wetland system can alter the solubility of other chemical pollutants, and cause elevated release of ammonia through mineralization of organic nitrogen source [19]. Results obtained in this study were similar to those observed by [20] and shows that the treatment processes in the wetland can improve the acidity of the piggery wastewater to acceptable limit of 6–9.

3.3. Wetland water balance and evapotranspiration

Piggery wastewater was the major source of inflow into the wetland. Mean inflow rate of 3.15 m^3/day and wetland cell area of 12.25 m^2 gave a mean hydraulic loading rate of 0.26 m/day and a mean hydraulic retention time of 1.94 days.

Evapotranspiration rates from the wetland cells were not found to have significant effect on wetland treatment. ET was found to increase from the first two weeks of sampling after establishment till the end of June during maturity (average 10 day value of 7.07 mm d^{-1}) and a tendency to decrease up to the end of late season in August (minimum value of 3.17) when the operation ended.

The highest value of cumulative ET was measured in the cells vegetated with Pennisetum purpureum (7.57 mm) followed by Pennisetum clandestinum (6.9 mm).

Table 1
Influent-effluent wastewater characteristics in the AKSU-HSSFCW.

	Unit	Influent			Effluent (Mean ± st.dev)						Discharge standard
		Range	Mean ± st.dev	n	PC	n	PP	n	Control	N	
pH	pH	6.3–8.2	7.04 ± 0.6	14	7.80±0.9	14	7.76±0.9	14	7.59±0.6	14	6.9
BOD	mg/l	102.4–162.3	125.26± 16.8	14	41.92±10.1	14	43.90±10.48	14	49.75±11.3	14	50
COD	mg/l	165.16–250.4	205.24±20.1	14	113.20±41.5	14	119.84±39.4	14	130.60±38.8	14	–
TN	mg/l	21.9–38.7	28.02± 4.6	14	10.50±3.2	14	11.51±3.6	14	13.97±4.0	14	20
TP	mg/l	7.94–13.32	10.42±1.6	14	5.36±1.5	14	5.74±1.5	14	6.12±1.6	14	5
TDS	mg/l	161.5–251.2	195.70 ± 24.3	14	75.09±20.0	14	81.66±19.3	14	92.21±21.2	14	2000
Temp	°C	24.4–27.2	26.05±0.8	14	23.67±0.92	14	23.80±0.9	14	24.58±0.8	14	<40 °C

Table 2
Mean influent and effluent removal efficiencies of aksu-hssfcw cells planted with two different wetland plants.

Pollutants	PC			PP			Control		
	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal
PH	7.05	7.86	11.53	7.05	7.76	10.12	7.05	7.59	7.67
BOD	125.26	41.92	66.53	125.26	43.9	64.95	125.26	49.76	60.27
COD	205.24	113.20	44.85	205.24	119.84	41.61	205.24	130.6	36.37
TN	28.02	10.51	62.49	28.02	11.52	58.89	28.02	13.97	50.14
TP	10.42	5.36	48.53	10.42	5.74	44.91	10.42	6.12	41.27
TDS	195.70	75.10	61.63	195.70	81.66	58.27	195.70	92.21	52.88
TEMP	26.05	23.67	9.13	26.05	23.8	8.64	26.05	24.58	5.64

-PC-Pennisetum clandestinum PP-Pennisetum purpureum.

The average water loss through evapotranspiration process was about 16.5% of influent wastewater flow rate. The crop coefficient time patterns of the macrophytes were similar to the classic trapezium shape of K_C for agricultural crops. Crop factor for each month increased continuously from 0.32 and 0.4 post establishment, peaked at 1.12 and 1.20 during mid-season and showed a decrease at the onset of the late season to 1.07 and 1.04 for Pennisetum purpureum and Pennisetum clandestinum respectively.

Total ET losses for the two planted cells during the 7 months of monitoring were 484.5 mm and 519.9 mm for PC and PP respectively with daily average values of 6.92 mm and 7.43 mm respectively.

3.4. Macrophytes growth

Pennisetum clandestinum and *Pennisetum purpureum* had invasive characteristics with rapid increase in dense stands that covered the wetland surface extensively with the shoots measuring up to 3 m in height after six months of growth towards the end of the sampling period. Both the planted wetland cells and the unplanted had significant effect ($R^2 = 0.94$) on the wetland treatment efficiency

3.5. COD and BOD

Variation in influent-effluent COD and BOD concentrations in the different treatments during the monitoring period, are shown in Tables 1 and 2. The inlet COD and BOD concentrations ranged between 165.16 and 220.40 mg/l and 102.40–162.30 mg/l with mean inflow values of 205.24 ± 20.14 and 125.26 ± 16.79. The effluent values of COD and BOD at the outlet ranged between 60.12 and 178.74 mg/l and 26.62–60.20 mg/l with mean effluent values of 113.20 ± 41.5 and 41.92 ± 10.15 mg/l respectively for *Pennisetum clandestinum* (PC) wetland cell.

The outlet COD and BOD concentrations for *Pennisetum purpureum (PP)* ranged between 67.34 and 180.62 and 28.17–64.14 mg/l with mean of 119.84 ± 39.4 and 43.9 ± 10.49 mg/l respectively. The control (unplanted cell) outlet COD and BOD concentrations ranged between 72.80 and 192.4249 mg/l with mean effluent value of 130.60 ± 38.75 and 32.27–70.30 mg/l with mean value of 49.76 ± 11.349 mg/l respectively.

A high level of COD in water system leads to drastic oxygen depletion which adversely affects the aquatic life. High COD value is an indication of low degradation rate of organic matter due to low microbial activity. Treatment efficiency for this study (Table 2) ranged from 44.85%; 41.61% and 36.37% in PC, PP and control. Effluent concentrations of 113.20, 119.84 and 130.6 mg/l achieved for COD in the PC, PP and control cells in the wetland are all within the 50 mg/l limit for discharge into surface waters in Nigeria. These findings are in line with [25] who achieved 44% reduction in COD. Similarly, [21] achieved efficiencies of 60.1–65 and 59.2% in HSSF-CW planted with Cyprus papyrus in Kenya. Also, 68% removal efficiency has been reported in Nigeria under field conditions with sewage wastewater [22].

Biochemical oxygen demand is used to measure how much oxygen is consumed in breaking down organic pollutants. Constructed wetlands are known to be highly efficient in reducing BOD [4]. Removal efficiencies of 66.53%, 64.95% and 60.27% (Table 2) were achieved in the PC, PP, and control cells respectively. The BOD removal efficiency achieved in this study is lower than the average for different countries reported by [23].

In Nigeria, BOD removal efficiencies achieved for different wastewaters include 83.43% for kitchen wastewater in laboratory scale study with water lettuce [24] and 70% for sewage wastewater in surface flow wetland with water hyacinth [22]. Similarly, [19] obtained up to 82.5% reduction of BOD in a HSSF-CW treating sewage effluent after 11 days of detention. In another study, [25] achieved a 50% reduction with pretreated wastewater in a pilot-scale constructed wetland. HSSF-CW's are inherently oxygen-transfer limited systems unless the system is very lightly loaded and the water depth is low.

As reported by [4], on variation of BOD removal efficiency with depth, 70–85% BOD removal efficiency was achieved with 0.27 m depth of wetland cell and 50–60% was achieved with 0.5 m depth. There was no significant difference in the organic matter removal efficiencies between the planted cells but the unplanted (control) cell showed significant difference from the planted cells. Effluent values in this study were always below allowed limits of 50 mg/l in Nigeria [26].

3.6. Total nitrogen (TN) and total phosphorus (TP)

The inlet TN concentration ranged from 21.90 mg/l–38.70 mg/l with a mean of 28.02 ± 4.649 mg/l. Reduction of TN concentrations in the cells ranged from 6.14 to 17.82 mg/l with mean 10.51 ± 3.2 mg/l, 6.08–18.75 mg/l with mean 11.51 ± 3.6 mg/l and 8.55–21.12 mg/l with mean 13.97 ± 3.9 for PC, PP and unplanted cells respectively.

Nitrogen reduction efficiency during the period of operation was 62.49%, 58.89% and 50.14% for PC, PP and control respectively as shown in Table 2.

The difference in treatment efficiency between the planted (PC and PP) and unplanted cells were 12.35% and 8.75% respectively. Wetland plants significantly affected wetland treatment efficiency.

Higher removal of TN in HSSF-CW is contributed by denitrification which is enhanced by anoxic conditions in HSSFCW. Wetlands with plants showed higher removal efficiency for TN than unplanted cells, but the difference was not significant which may be due to the small differences between each planted wetland cells.

In a study, [27] reported removal efficiencies for TN ranging from 1 to 22%. Also, [28] reported 30–40% removal rates. Removal rates as low as 30% [22] and as high as 92.73% [29] has been reported in Nigeria. The relatively high removal rates observed in this study may be linked to the periodic loading of the wetland which may have enhanced re-aeration of the granular medium after each sampling campaign. Effluent concentrations in this study (10.51, 11.52 and 13.97 mg/l) for PC, PP and control respectively were below acceptable limit of 20 mg/l set by [26].

Total phosphorus concentration in the influent wastewater ranged between 7.94 and 13.32 mg/l with mean 10.42 ± 1.65 mg/l. Effluent concentrations ranged from 3.42 to 8.66 mg/l with mean 5.36 ± 1.54; 4.17–9.06 with mean 5.74 ± 1.48 and 4.41–9.58 mg/l with mean 6.12 ± 1.60 mg/l for PC, PP and control respectively (Table 1). Removal efficiencies varied with the treatments. Removal efficiencies of 48.53%, 44.91% and 41.27% were observed in the treatment process in PC, PP and control cells respectively. The planted cells showed higher removal efficiencies with a difference of 7.26% and 3.64% between PC and PP and PC and control respectively.

The removal efficiencies of the pilot wetland of 48.53, 44.91 and 41.27% for PC, PP and control respectively (Table 2) compared favourably with typical average removal efficiencies for several European countries reported by [30] as 47, 32, and 42% for Europe, Denmark and Czech Republic respectively. Study carried out by [31] in a horizontal subsurface flow constructed wetland treating wastewaters produced by an organic farming activity obtained 29.35% and 23.76% removal efficiency for TN and TP respectively. Generally, one of the major limitation of all types of constructed wetlands are poor nutrient removal [31–34]. The limiting factor for the apparent low effluent quality might be the short evaluation period and hydraulic retention time of the pollutants in the wetland for each cell working in parallel. Research findings by

[8] on pollutant removal efficiencies in swine wastewater using a vertical subsurface flow constructed wetland planted with two species of Napier grass with 2 and 5 cm d^{-1} of hydraulic loading rates showed positive correlation between TP and retention time.

According to [35], the minimum HRT to remove 50% of the bioreactive phosphate was 7 days. This is because contact time could play a major role in the distribution of pollutants within a constructed wetland [36].

3.7. Total dissolved solids

The mean influent TDS value was 195.70 ± 24.3. Mean effluent values were 75.10 ± 20.0, 81.66 ± 19.3 and 92.21 ± 21.2 for PC, PP and the control (Table 1) respectively. Removal efficiencies (Table 2) ranged from 61.63%, 58.27% and 52.88% in the PC, PP and the control cells respectively. PC cell showed a better TDS removal in terms of effluent quality compared to the PP and control cells in that order. However, there was no significant difference in the removal rates among the planted cells and between the planted cells and the unplanted.

TDS is used as a wastewater quality parameter to evaluate the effectiveness of constructed wetlands for the removal of organic matter and to quantify the degree of pollution in many industrial wastewater effluents.

TDS removal is very effective in HSSF-CW due to physical processes of settling, and filtration and chemical precipitation and absorption provided by the wetland medium. Plants have positive effect on TDS removal by reducing water velocity and encouraging filtration and biodegradation in the woven and entangled root network. When wastewater high in TDS is discharged to surface or groundwater, these dissolved solids may represent a significant pollution source. The effluent quality of the wastewater in this study was within the limit for discharge into aquatic systems in Nigeria.

4. Conclusions and recommendations

This study shows that the pilot HSSFCW can effectively treat wastewater with respect to organic matter (BOD_5 and COD), TDS and nutrients (TN and TP) removal. The vegetated cells showed better performance in the removal process for all the investigated parameters than the non-vegetated cells, underlining the active role of macrophytes in the wastewater treatment. Although the best performance was obtained in the bed vegetated with PC, there was no significant difference between PC and PP, confirming that these plant species are suitable for use in constructed wetlands for wastewater treatment. For the parameters of concern, except TP, the effluent quality met the admissible standard for discharge into open water sources in Nigeria at fairly short hydraulic retention time.

The short HRT time may not have provided adequate contact time between wastewater and wetland media responsible for the nutrient removal especially TP. Additionally, the short HRT in this study could have limited the nitrification/denitrification processes which enhance removal of nitrogen in HSSFCWs. Furthermore, the short monitoring period and probably high ET, for some part of the monitoring period may have increased pollutant concentration resulting in low TP effluent quality of 7.2, 15.8 and 22.4% above admissible value of 5 mg/l in the PC, PP and control wetland cells respectively. However, the removal efficiency compared favorably with results obtained in other studies in different countries with effluent values generally within acceptable limits.

The study concludes that HSSF-CW is a viable on-farm alternative technology for conventional treatment of piggery wastewater in Nigeria. Given the minimal maintenance requirements, the ease of operation and optimal performance with little energy input, constructed wetland technology can help alleviate wastewater management problems in developing countries and in particular, Nigeria.

For significant nutrient removal, longer detention time of wastewater in the wetland is necessary to allow for sedimentation, biotic processing and retention of more nutrients especially TP.

Nevertheless, these results provide a starting point for the use of HSSF-CW and PC and PP in Nigeria and gives insight of the potential application of this technology for pollution control.

Acknowledgement

The author wishes to acknowledge with gratitude the financial support provided by Tertiary Education Trust Fund (TETFund) for Institution Based Research (IBR) through Akwa Ibom State University Board of Research(AKUBOR).

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Ikpe J. Udom (M.Eng) Faculty in Agricultural Engineering, Faculty of Engineering, Akwa Ibom State university and Ph.D. candidate, Agricultural and Bioresources Engineering, Faculty of Engineering, University of Nigeria, Nsukka. Registered Agricultural Engineer (Soil and Water Engineering). Major research interest in pollution control, on-site treatment systems, Ecohydrology and phytoremediation.