Evaluation of a constructed wetland for removal of some physicochemical and microbiological contaminants from wastewater in a residential tertiary institution in Nigeria

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Abstract: Covenant University is a residential tertiary institution in Canaan land, a large faith based facility, whose population can be more than 75,000 during Sundays religious activities in Ota, Ogun State, Nigeria. Sewage from this community is treated by a series of constructed wetland located in the University, with its effluent discharging into a canal that empties into River Iju. This river is used by several hundreds of thousands of people downstream. The effluent flows through six sets of constructed wetlands, each with four chambers and the treatment process in the wetlands was evaluated by its adequacy and efficiency. Input and output of the system were monitored. Results indicated that the series of wetland reduced the total dissolved solids (TDS) by only 8% and conductivity by 11%, while the pH was constant at 6.8. The microbiological test results indicated a 99% reduction in the most probable number of coliforms (MPN) from 1,600 cfu/100 mL. The constructed wetland achieved 85%, 79%, 52%, 79%, 66% and 83% reduction for coliform, staphylococcus, salmonella, salmonella and shigella, total viable count, and fungi, respectively. Results of the colony units/mL, cfu/mL, for these parameters, obtained at both upstream and downstream and at the point of discharge into the canal compared with those at the effluent point showed adequacy of removal of contaminants by the constructed wetland series. The efficiency of the wetlands can be enhanced further by slowing the flow rate and increasing the number of wetland chambers. Further work is required to determine the rate of recovery of the polluted canal water.

Keywords: sewage, wastewater, influent, effluent, wetland, water hyacinth

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1 Introduction

One major concern of stakeholders in the development of hydrological basins is the conservation of the ecosystem. Canaan land is located within latitude 60 40′ North and longitude 3010′ East. It is on an area of 214 hectares in the Ado-Odo/Ota Local Government area of Ogun State. Ota is the Industrial nerve center of the State. Covenant University and a large faith facility are located within the Canaan land with a population of more than 75,000. The hydrological basin to which Canaan land belongs is in the Iju river drainage basin. Activities downstream of this basin include fishing, farming, commercial, industrial activities and educational institutions.

Wastewater originates mainly from domestic, industrial, groundwater, and meteorological sources. Karadi and Huang (2009) indicated that these forms of wastewater are commonly referred to as domestic sewage, industrial waste, infiltration, and storm-water drainage, respectively. Sewage in Canaan land is discharged for treatment through two anaerobic septic tanks in the sewage treatment plant (constructed wetland). The effluent from the constructed wetland series in Canaan land is expected to contain limited biological contaminants.

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Generally, septic tank – soak away systems are provided for most of the buildings in Canaan land to take care of their environmental sewage sanitation requirements. Septic tanks are sufficient for the treatment of household wastes. However, this cannot be the case for the faith-based facility with a weekly population of more than 50,000. The septic tank arrangement is not suitable for a university community because of its large population. Even the Imhoff tank, an advanced modification of the septic tank is not suitable to treat the effluent from the facility. Oginni (2008), indicated that the Imhoff tanks are best suited to small municipalities and institutions where the tributary population is 5,000 or less, and where a greater degree of treatment is not needed. Obviously, Covenant University community can only consider the use of sewage treatment plant in dealing with its environmental sanitation requirements. The treatment plant in Canaan land had been so designed to handle sewage from the faith-based facility alone.

The sewage treatment site in Canaan land is located at the westernmost wing of Covenant University campus remote but opposite to Daniel Hall. This location is indicated as WWTP in Figure 1. The waste treatment plant was for both solid and liquid wastes. These were later separated. Human wastes are treated at the waste treatment plant using biological process. Layout of the treatment plant is as sketched in Figure 2. A chamber in the constructed wetland is 20 m long × 6 m wide. The effluent is discharged through the concrete lined open channel leading to the canal where it flows into River Iju.

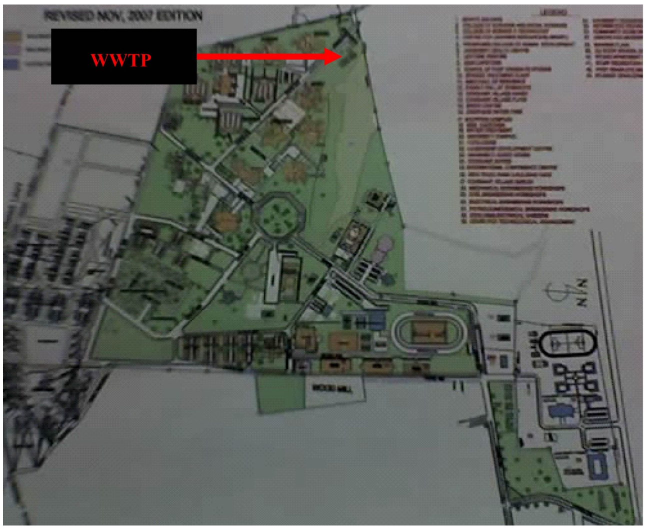

Figure 1 Covenant University map

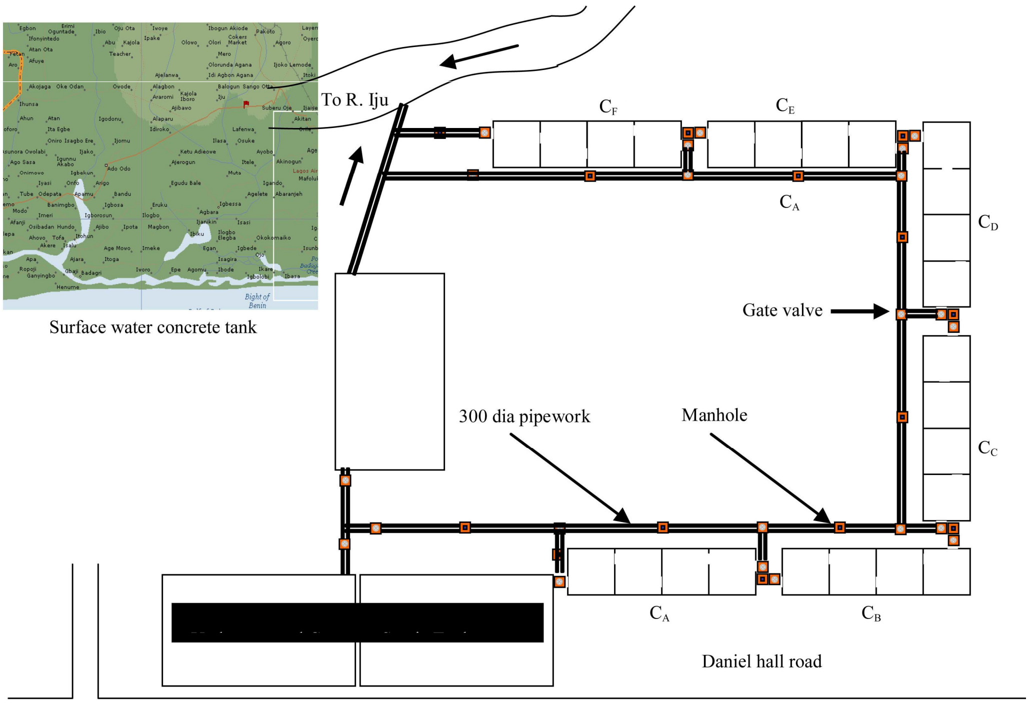

Figure 2 Layout of Canaan Land sewage treatment plant

Between 12,000 to 18,000 L of sewage is removed from the faith-based facility weekly by sewage disposal tanks. Wastewater generated per day by the University community was considered based on the rate of water supplied per day on the campus. With eight boreholes and four reservoirs (with a combined 1,054,000 L capacity) and four refills per day, the estimated water usage is 4,216 m^3/day. This consumption included water use in the laboratories, workshops, gardening and other uses such as ongoing construction works on the campus. Of this 4,216 m^3/day water consumption, 80% is considered to return as wastewater. The wastewater was pretreated in an underground concrete septic tank. Maintaining wetland in urbanized areas has a lot of considerations. Isiorho (2006) discussed some challenges of maintaining urban wetlands that includes their being seen as nuisance and as obstacles to development. Bruch et al. (2011) had considered improvement of the efficiency of constructed wetlands with Zeolite-Containing filter sands. Sewage flows by gravity into the underground septic tanks, where complex organic materials are anaerobically decomposed to simple organic molecules and fermentation gases. When the buildup gets to a specific level it flows into the constructed wetland by gravity. The operating principle is the same as that of the septic tank flowing into the soak-away chamber. Workers in this field include Kivaisi (2001), Lorion (2001), Konnerup et al. (2009), Nilsson et al. (2012), Langergraber (2013), Villalobos et al. (2013). The adequacy of the constructed wetland in removing physicochemical and microbiological contaminants is the main focus of this paper.

2 Materials and Methods

2.1 Wastewater treatment assessment criteria

The biological process in the constructed wetland was to be evaluated for its adequacy and efficiencies. Wastewater quality was monitored from input to the constructed wetland through the various chambers and to its discharge into the canal. To establish the adequacy of the wetland treatment system, an upstream and downstream point below the discharge point (location) into the canal should also be monitored.

Since water hyacinth, (Eichhornia Crassipes) is used in the constructed wetland, its responses and effectiveness in wastewater treatment was compared to expected surface water quality. Surface water quality standards are obtainable in the literature. Hammer (1977) classified the surface water criteria for public water supplies into the following characteristics:

(i) physical (ii) microbiological (iii) Inorganic chemicals (iv) organic chemicals (v) radioactivity

The water quality parameters as indicated by MoDNR (2008) gave a comprehensive list of 22 different water quality parameters. These are acidity, alkalinity, ammonia, BOD, CBOD, COD, conductivity, dissolved oxygen (DO), fecal coliform, hardness, metals, nitrate, nitrite, nitrogen as total kjeldahl (Organic Nitrogen and Ammonia), TKN, nitrogen, nitrogen as a mmonia, phosphorus, pH, total solids, temperature, and turbidity. Some of the parameters are related to themselves. For instance record of pH can give insight into acidity or alkalinity. Ammonia, nitrate, nitrite, TKN, nitrogen and nitrogen as ammonia are all nitrogen related parameters.

Karadi and Huang (2009) stated that the composition of wastewater is analyzed using several physical, chemical, and biological measurements. In this paper, we examined the variations of the following physical, chemical and microbiological parameters along the constructed wetland:

(i) pH (ii) Total Dissolved Solids (TDS)
(iii) Conductivity (iv) Coliform colonies counts
(v) Nitrogen and (vi) Nitrates

2.2 Sampling and laboratory tests

The pH, total dissolved solids and conductivity were tested in the field along the wetland beds (labeled 1-12 (SPOT) in Table 1). Samples were taken from each cell within the first chamber, C_A to reveal the possibility of variation within chambers.

Table 1 Results of pH, total dissolved solids and conductivity

Spot	Description	Parameters			Remarks
		TDS, ppm	Conductivity, mL/s	pH	
1	Influent Tank	397	610	6.8	
2	Chamber C_A – Cell 1	390	580	6.8	
3	Chamber C_A – Cell 2	400	600	6.8	Entrance to Cell2
4	Chamber C_A – Cell 2	390	580	6.8	Mid-way
5	Chamber C_A – Cell 3	400	590	6.75	Entrance to Cell3
6	Chamber C_A – Cell 3	400	590	6.75	Exit from Cell 3
7	Chamber C_B – Cell 4	370	540	6.75	
8	Chamber C_C – Cell 4	380	570	6.75	Exit
9	Chamber C_D – Cell 4	380	560	6.7	Exit
10	Chamber C_E – Cell 4	370	550	6.75	Exit
11	Chamber C_F – Cell 4	365	543	6.75	Exit
12	Effluent channel	355	530	6.8	2.5m away

Eleven water samples were collected for the bacteriological and chemical tests. Eight of the water samples (two per chamber) were from the wetlands. Water samples G, H and I were from the effluent discharge channel point, a location on the canal at some 300 m upstream of the discharge point and 300 m downstream of the discharge point respectively (Table 2). This is to enable us assess the effect of the treated wastewater on the water flow in the canal leading to River Iju.

Table 2 Results of presumptive test for coliform most probable number of coliform in 100 ml of water

S/NO	Sample	Coliform counts/ 100 mL (cfu/mL)	Remarks (Obtained from the MPN Table)
1	A_1	1,600	Entrance into Chamber A, C_A
2	A_2	1,600	20m from entrance
3	B_1	550	20m from entrance
4	B_2	250	40m from entrance
5	C	275	60m from entrance
6	D	250	80m from entrance
7	E	50	100m from entrance
8	F	13	120m from entrance
9	G	-	Effluent channel
10	H	-	300m Upstream Effluent Discharge Point
11	I	-	300m Downstream Effluent Discharge Point

For the bacteriological quality and chemical characteristics analyses, water was collected in sterilized 250 mL conical flasks, filtered and incubated at 37^0C for a 24-hour period. In accordance with the Standard Methods for the examination of water & wastewater (American Public Health Association. 1998; Feng et al., 2002), the resulting colonies that formed during the incubation were counted and recorded as the number of colony producing unit per 100 mL of water.

Presumptive tests for coliform were first undertaken. The most probable number of coliform in 100 mL of water, MPN/100 mL, was obtained. The table of most probable number was used. After inoculation of positive plates, from presumptive test at 37^0C for 24 hours on Eosin methylene blue agar, a bluish black with a metallic sheen was observed. This serves as a confirmatory test for Coliform. A complete test is carried out on Colonies from confirmatory test result above by inoculating in a tube of lactose broth with inverted Durham tube and nutrient agar sealant. This was incubated at 440^0C for 24 h.

Explanations on the confirmatory and complete tests are that if lactose broth culture produces acid and gas, it implies positive i.e. positive test that E. coli is present. If sealant culture gives a gram negative, non-sporulating bacilli, this confirms that coliform (E. Coli.) is present. This is used to test the quality of the water.

The media used for bacteriological analyses were MacConkey Agar for Coliform; Mannitol Salt Agar for Staphylococcus; Brilliant Green Agar for Salmonella; Salmonella Shigella Agar for Salmonella and Shigella. Others are Nutrient Agar for Total Viable Count, TVC; and Potato Dextrose Agar for Fungi, mainly Yeast.

Testing for the nitrogen and nitrates concentrations in the water sample was undertaken using the Palin test photometer following the standard kits and procedures. In this method, nitrate was first reduced to nitrite, which is determined by a diazonium reaction with sulphanilic acid in the presence of N-(1-naphthyl)-ethylene diamine to form a reddish dye. This reduction stage was carried out using the unique zinc-based Nitratest powder and Nitratest tablet which aids rapid flocculation after a one-minute contact period. The intensity of the color produced in the test is proportional to that of the nitrate concentration and is measured using the photometer.

Measurements were replicated and averages were taken. The resulting concentrations are presented in Table 4.

3 Results and discussion

The results of the pH, TDS and conductivity are presented in Table 1.

Total Dissolved Solids (TDS) averaged 397 ppm at the influent into the constructed wetland. This value was reduced to 390 ppm in the first cell of the first chamber. A variability of 2.5% in the TDS was observed within the cells of the first chamber. The second chamber, C_B dropped to 370 ppm to rise to 380 ppm in the third chamber, C_C. Overall, there was an 8% reduction in TDS within the wetland and this trend is shown in Figure 3. Conductivity ranged from 600 to 543 mL/s. as shown in Figure 3. The reduction rate was 10% only. This trend is similar to that of the TDS.

This portrays the system as inefficient. The pH over the entire range remained constant at 6.8. Generally, a range of 6.5 to 9.5 is tolerable. The pH of 6.8 is considered low and may be due to high levels of free CO_2 in the water samples (Okonkwo et al., 2008).

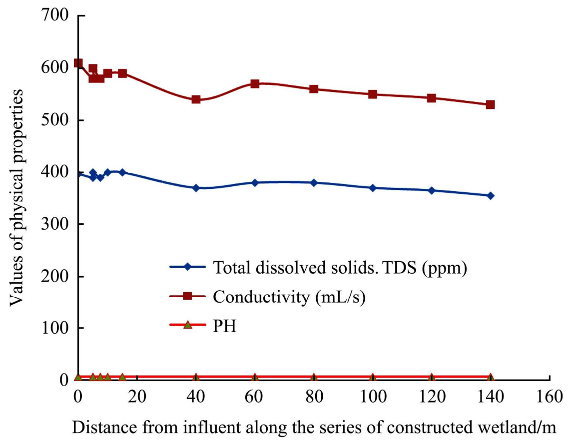

Figure 3 Comparison of trends of TDS, conductivity and pH along the constructed wetlands.

Results for the microbiological tests are shown in Tables 2 and 3 for the presumptive test for coliform most probable number in 100 mL of water and bacteriological analyses respectively.

The results of the presumptive test for coliform indicate that the most probable number of coliform in 100 mL of this wastewater in the first chamber is 1,600 cfu/100 mL. This value did not vary within the chamber but dropped sharply to 550 cfu at the entrance to the second chamber, C_B with a further drop of 250 cfu within the 20 m-chamber length. A reduction trend in this parameter is as shown in Figure 4.

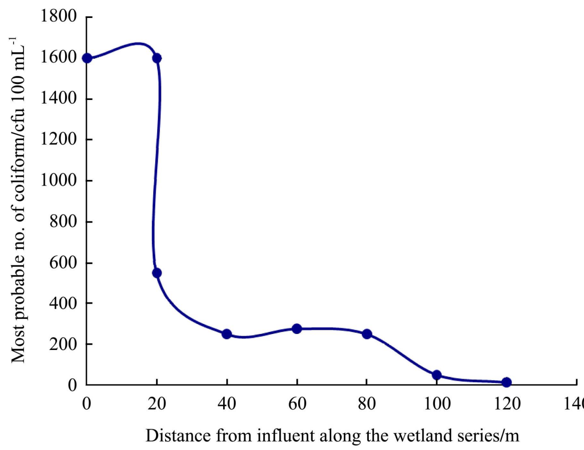

Figure 4 Variation of coliform counts along the wetland

Table 3 Treatments and results of bacteriological analyses

No	SAMPLES/ MEDIA (10^2)	MacConkey Agar/Coliform, cfu/mL*	Mannitol Salt Agar, cfu/mL	Brilliant Green Agar, cfu/mL	Salmonella Shigella Agar, cfu/mL	Nutrient Agar, cfu/mL	Potato Dextrose Agar, cfu/mL
		Colifom	Staphylococcus	Salmonella	Salmonella and Shigella	Total Viable Count (TVC)	Fungi (Mainly Yeast)
1	A_1	120	108	132	136	143	52
2	A_2	108	102	121	104	131	48
3	B_1	98	96	117	101	115	32
4	B_2	95	78	108	89	102	26
5	C	62	49	102	70	99	28
6	D	55	42	86	66	78	19
7	E	40	27	81	57	60	14
8	F	18	22	63	41	48	09
9	G	-	12	21	09	19	06
10	H	-	16	36	13	25	11
11	I	-	09	07	04	10	04

Note: *cfu/mL is colony unit per milliliter.

Results of the bacteriological analyses are shown graphically in Figure 5. Coliform counts reduced from 120 cfu/mL at the influent spot by the first chamber to 18 cfu/mL by the last chamber, C_F. Similarly staphylococcus, salmonella, salmonella and shigella, bacteria counts followed the same trend as the coliform presentation. The same trend was obtained for the Total Viable Count and Fungi. TVC at the last chamber C_F was 48 cfu/mL, which is below the 1.0×10^2 cfu/mL, Okonkwo et al. (2008) limit for water. FAO (1997) recommended E-coli standard for water is nil.

Results from locations G, H and I (in Table 2), indicate that the waters in the canal are not polluted by the effluent from the wetlands. However, the colony-forming units/mL, (cfu/mL) result for station H, 300 m upstream of discharge point, indicated higher pollution levels. Generally, from the records and trends presented, it can be said that the constructed wetland series has been able to remove contaminants from the wastewater adequately.

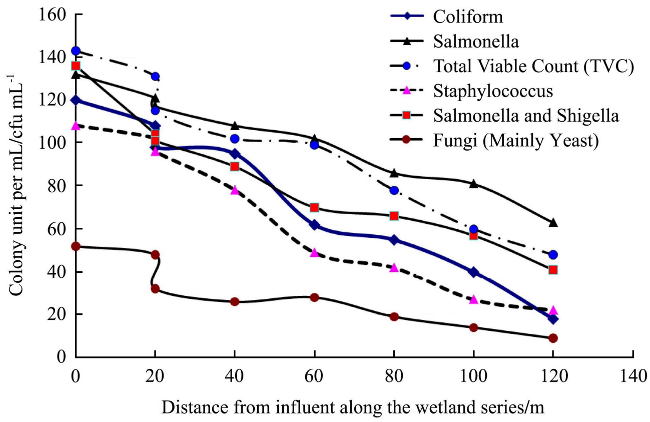

Figure 5 Variation of isolated bacteria species, TVC and fungi within the wetland

Results for the nitrogen and nitrates are presented in Table 4. The concentrations of nitrogen and nitrates in the samples range from 0.845 to 0.258 mg/L and from 3.718 to 1.135 mg/L respectively. The concentration of nitrogen and nitrite along the wetland is shown in Figure 6. Lowest values were recorded for Chamber C_A exit point while highest values were for the fourth chamber in both cases. Though the concentration of nitrate increased within the wetland series, (Figure 6), its values were far below the 50 mg/L limit which WHO guidelines (2000) recommended, Fawell (2007). The concern for both nitrate and nitrite is the potential for methaemoglobin formation in bottle-fed infants. WHO guideline (2000) is based on epidemiological evidence that indicates that methaemoglobinaemia is rarely found in water concentration below 50 mg/L.

Table 4 Nitrogen and nitrate concentrations

S/NO	Samples	Concentration, mg/L	
		Nitrogen	Nitrate, NO_3^-
1	A_1	0.268	1.177
2	A_2	0.258	1.135
3	B_1	0.541	2.378
4	B_2	0.733	3.223
5	C	0.513	2.255
6	D	0.845	3.718
7	E	0.778	3.421
8	F	0.615	2.706
9	G	0.415	1.826
10	H	0.305	1.340
11	I	0.270	1.188

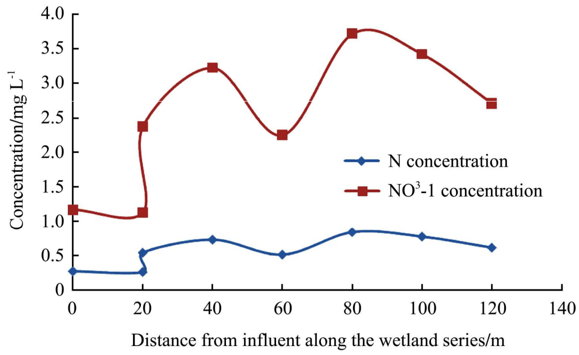

Figure 6 Variation of the nitrate and nitrogen concentrations within the wetland series

Result of these tests for the first chamber indicate inadequate nutrient removal rate, corroborated by the fact that the water hyacinth in the first cell of the first Chamber, C_A was weedy. Figure 7a is an indication of the present conditions of the first and second cells of chamber C_A. Figure 7b shows that the next chamber, C_B was not weedy so also were the remaining chambers.

Figure 7a Chamber C_A, Cells 1 and 2

Figure 7b Chamber C_B

4 Conclusions and recommendations

There were 8% of TDS and 11% of conductivity reduction while the pH remained constant at 6.8. This shows that the constructed wetland is not efficient and some modification or redesign of the wetland is warranted.

The microbiological test results indicate a 99% reduction in the most probable number of coliforms from 1600 cfu/100mL in the wetland. A 100% reduction in this contaminant would have been achieved if the water hyacinth plant in the first cell of the first wetland chamber had been maintained without weed (Figure 7a and its annex). The constructed wetland achieved 85% reduction for coliform, 79% for staphylococcus, 52% for salmonella, 79% for salmonella and shigella, 66% for total viable count and 83% for fungi. Results of the colony units/mL, cfu/mL, for these parameters, obtained upstream, at point H and downstream, point I of the point of discharge into the canal compared with figures for point G showed adequacy of removal of contaminants by the constructed wetland series. The contaminants removal trends indicated some linearity. Further work is being suggested on modeling of these trends.

The residing time of the material within the wetland will need to be improved in order to have more time to allow the hyacinth plant and microbes enough time to reduce the TDS.

Further work on water recovery from pollution will determine the actual recovery rate.

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