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Performance Evaluation of Waste Stabilization Pond for Treatment of Wastewater from a Tertiary Institution Campus Located in Jos North Local Government Area, Plateau State, Nigeria

[1,2*]ALFA MI; [3]OWAMAH, HI; [4]ISHAQ, A; [1]ENOKELA, PA; [5]OLUWASEUN, D; [5]CHIKEZIE, AO

*[*1]Department of Civil Engineering, University of Jos, Jos, Nigeria*
[2]Department of Civil Engineering, College of Engineering, Covenant University, Ota, Nigeria
[3]Department of Civil Engineering, Delta State University, Abraka, Oleh Campus, Delta State, Nigeria
[4]Department of Water Resources & Environmental Engineering, Ahmadu Bello University, Zaria, Nigeria
[5]Department of Agricultural and Bio-Environmental Engineering Technology, Federal Polytechnic, Nasarawa, Nigeria

**Corresponding Author Email: meshilalfa@gmail.com, Tel: +2347030288424*
Other Authors' Emails: owamah.hilary@gmail.com; aleeruks4real@gmail.com; petenokson15@gmail.com; bakodoofan2011@gmail.com; adaokeychikeziejr@yahoo.com

ABSTRACT Appropriate treatment of wastewater before disposal into the environment or reuse is very important in the quest to protect the environment and safeguard public health. This paper investigated the performance evaluation of a waste stabilization pond (WSP) for treatment of wastewater from a tertiary institution campus located in Jos North Local Government Area of Plateau State in North Central Nigeria. The waste stabilization pond of the tertiary institution campus was designed for a wastewater flow rate of 12,945 m^3/day. In order to evaluate the performance of the WSP, a model was developed following the Froude's number dimensional analysis technique. The model was evaulated based on a wastewater flow of 0.4 m^3/day. The final effluent from the maturation pond had 80 mg/L BOD, 195 mg/L COD, 75 CFU/100ml Total Coliforms, 610 mg/L Total solids, 19 mg/L Total Nitrogen, 210 mg/L Chloride, 28 mg/L Phosphate, 1.3 mg/L Ammonia and 7.0 pH. The WSP was able to achieve an overall efficiency of 77.78% reducing all quality parameters to recommended limited with exception of total nitrogen and phosphate. The implementation of this design will go along way to aid the treatment of wastewater from the campus of the university.

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Production of waste is an unavoidable part of the activities of human, a significant part of which will end up as wastewater (Henze and Comeau, 2008). Generally speaking, wastewater refers to the water supply of a community after it has been used which now contains objectionable constituents that make it unfit for intended use. Depending on the source of generation, the characteristics of wastewater varies significantly. Wastewater comprises of liquid waste discharged from domestic, commercial, industries and agricultural properties (Lee *et al.*, 2019). Treatment of wastewater before disposal or reuse is very important for many reasons. According to Tchobanoglous *et al*. (2003), the accumulation of untreated wastewater will undergo decomposition which can constitute serious nuisance conditions such as but not limited to the production of malodorous gases. More so, untreated wastewater usually contains pathogenic microorganisms that are natural habitat of the human intestinal tract which when in contact with municipal water source can result in outbreak of water borne diseases (Alfa *et al.*, 2014; Iorhemen *et al.*, 2016; Owamah *et al.*, 2021). In order to protect public health and the environment therefore, the immediate and nuisance-free removal of wastewater from its source of generation, followed by appropriate treatment, reuse, resource recovery or disposal into the environment becomes very necessary (Safoniuk, 2004; Ogbozige and Alfa, 2019).

**Corresponding Author Email: meshilalfa@gmail.com*

Wastewater treatment systems can either be decentralized or centralized (Jung *et al.,* 2018). While the decentralized treatment system which involves on-site treatment is preferred particularly for communities with improper zoning (Massoud *et al.,* (2009), the centralized system offers a lot of advantages including the recovery of resources at a large scale which makes it more appropriate for a tertiary institution campus such as the Naraguata campus of the University of Jos (Peter *et al.,* 2017). The centralized treatment system which is an off-site treatment involves primary, secondary and tertiary processes (Jung *et al.,* 2018). Waste stabilization pond is one of such centralized systems that has been used extensively especially in hot climates like Nigeria largely due to the simplicity of their design, low cost and the use of low-skilled operators (Edokpayi *et al.*, 2021). This paper therefore, explored the development and performance evaluation of a waste stabilization pond (WSP) for treatment of wastewater from a tertiary institution campus located in Jos North Local Government Area of Plateau State in North Central Nigeria.

MATERIALS AND METHODS

Study Area: The Naraguta Campus of the University of Jos is located in Jos North Local Government Area (LGA) of Plateau State in North Central Nigeria. The campus lies between latitudes 9° 57ˈ 30” N to 9° 58ˈ 49” N and longitudes 8° 52ˈ 11” E to 8° 53ˈ 39” E (Fig. 1). The campus stands at a very high altitude ranging from a minimum of 1,099 m to a maximum of 1,150 m above mean sea level. According to the National Bureau of Statistics (NBS, 2012), the city of Jos has a mean annual rainfall of 1,261.16 mm, annual mean minimum temperature of 16.30 °C, annual mean maximum temperature of 28.10 °C, annual mean relative humidity ranging from 51.34% at 0900 hours to 46.88% at 1500 hours, annual mean radiation of 21.18 mm and an annual mean evaporation of 4.60 mm.

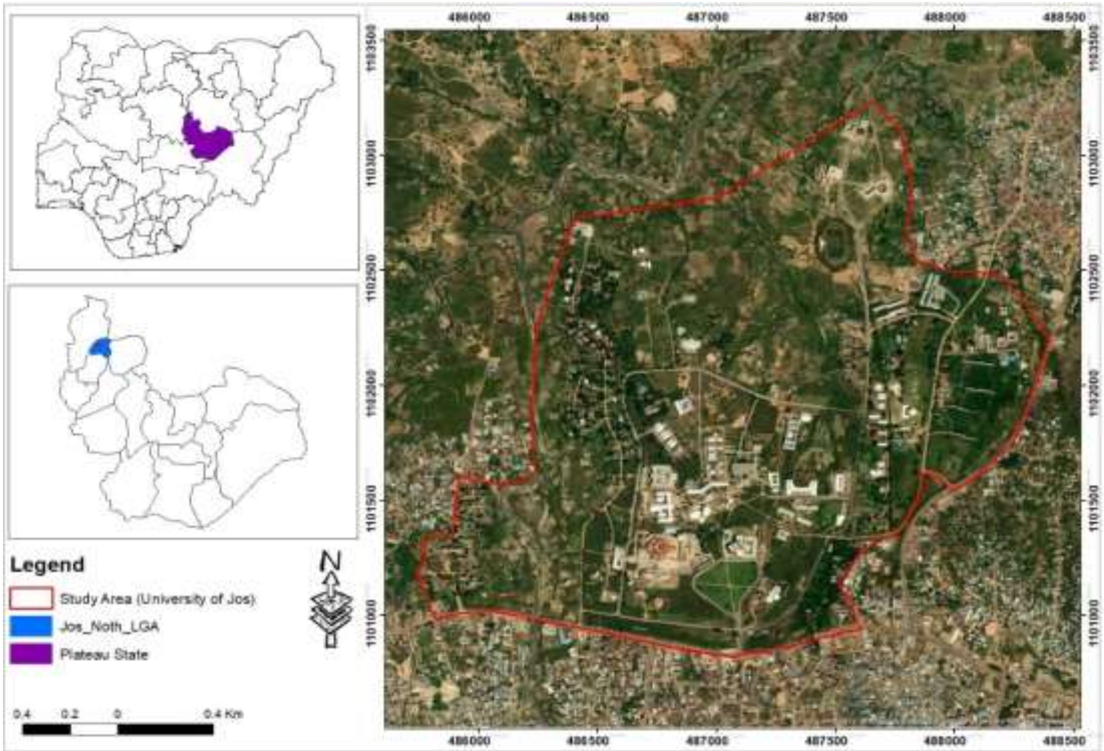

Fig. 1: Map of Study Area

Design of the Components of WSP: The population of staff and students of the University of Jos as at 2019 made available by the Directorate of Academic Planning and Management of the university were 3,644 and 41,084 respectively making a total of 44,728 persons.

With a design life of 20 years chosen for the WSP (Tchobanoglous *et al*., 2003), the population was projected using the geometric growth model expressed by equation 1.

$$P_2 = P_1 e^{k(t_2 - t_1)} \quad (1)$$

Where P_2 = projected population, P_1 is the current population, k is the growth rate while $t_2 - t_2$ is the design life of the project.

A per capita water consumption of 120 litres/day as recommended by the Nigerian National Water and sanitation policy was adopted with 85% assumed to end up in the sewers (Mara *et al.,* 2001).

Based on the foregoing, the design criteria adopted in this study are itemized in Table 1.

Table 1: Design Criteria for WSP

Design criteria	Value	Unit
Population	107,871	Population Equivalent (PE)
BOD per PE	50	g/PE *day
TN per PE	8	g/PE*day
Temperature	27	°C
Per Capita Wastewater Flow	0.102	m^3/PE day
Total Wastewater Flow	11,002.84	m^3/day
Max. Effluent Fecal Coliform	<100	mg/100mL
Effluent BOD soluble	<50	mg/L
Effluent TSS	<50	mg/L
Effluent TKN	<25	mg/L

(Khowaja, 2000; Tchobanoglous *et al*., 2003)

The design of the anaerobic ponds, facultative ponds and maturation ponds was carried out following the detailed methods described previously (Mara and Pearson, 1986; Kayombo *et al.,* 2004; Mohammed, 2006; Hamzeh and Ponce, 2007). A summary is presented herein.

Design of Anaerobic Ponds: The design of the anaerobic ponds was done on the basis of the permissible volumetric organic loading λ_v which is a function of the temperature T as presented by equation 2 for a temperature range of 20 – 25°C. However, for a temperature >25°C, a value of 0.35 was recommended which was adopted in this design. Similarly, the volume of the anaerobic pond (V_{an}) is related to the wastewater flow rate (Q), influent BOD_5 (BOD_{in}) and the volumetric loading rate (λ_v) by equation 3.

Volumetric Loading rate,

$$\lambda_v = 0.01 \times T + 0.1 \qquad (2)$$

Where T is temperature (°C).

The volume of the Anaerobic Ponds,

$$V_{An} = \frac{BOD_{in} * P}{\lambda_v} \qquad (3)$$

The retention time,

$$t_a = \frac{V_{an}}{Q} \qquad (4)$$

Required time for sludge removal,

$$t_s = \frac{V_{An}}{N} * \frac{1}{PE * SAR} \qquad (5)$$

Where SAR is sludge accumulation rate and N is number of ponds

A depth of 3m was assumed with 2 identical ponds and a standby for desludging. The length and breadth of the identical ponds were estimated based on a ratio of 3:1 (Mohammed, 2006).

Design of Facultative Ponds: This pond was designed by considering the maximum surface organic loading rate which is a function of the temperature. Kayombo *et al. (*2004) gave the expression of the maximum organic loading rate for hot climate as expressed by equation 6.

$$\lambda_s = 20T - 60 \qquad (6)$$

It was assumed that 60% BOD removal was achieved in anaerobic ponds.

The mid-depth area of the facultative ponds (A_f) was calculated using equation 7 (Mara and Pearson, 1986; Mara and Pearson, 1998) expressed as a function of the influent BOD to facultative pond (BOD_{fa}), wastewater flow rate (Q) and surface BOD loading (λs).

$$A_f = \frac{(10 \times BOD_{fa} \times Q)}{\lambda_s} \qquad (7)$$

Retention time, $t_f = \frac{A_f D}{Q}$ (8)

A mid-depth, D of 1.5 m was adopted for the design with 2 identical ponds (Hamzeh and Ponce, 2007) and a length to width ratio of 3:1 (Mohammed, 2006).

Design of Maturation Ponds: The number and size of maturation ponds in a system depend upon the bacteriological quality required of the effluent. The expected effluent number of faecal coliform bacteria per 100 ml (B_e) was estimated using equation 9 (Mara and Pearson, 1986).

$$B_e = \frac{B_i}{(1 + KB(T)t)} \qquad (9)$$

Where B_i = influent bacterial concentration in FC/100ml, t = retention time in days, $KB\ (T)$ = First order FC removal rate constant in T^0C per day

$$KB(T) = 2.6(1.19)^{T-20} \qquad (10)$$

More so, the total number of faecal coliforms in the effluent from the last pond of the series was estimated using equation 11 (Mara and Pearson, 1986).

$$B_e = \frac{B_i}{(1 + \mathrm{KB(T)}t_a)(1 + \mathrm{KB(T)}t_f)(1 + \mathrm{KB(T)}t_m)^n} \qquad (11)$$

Where t_a, t_f and t_m are the retention times of the anaerobic, facultative and maturation ponds respectively while n is the number of maturation units in the series.

Assuming 2 maturation ponds with 4-day-retention time each, the effluent bacterial concentration was calculated using equation 11.

The area of maturation ponds,

$$A_m = \frac{2Qt_m}{(2D + 0.001et_m} \quad (12)$$

Where *e* is net evaporation rate (mm/day). A pond depth of 1.5m was adopted. Using a length to width ratio of 3:1 with 2 ponds, the dimensions of the maturation ponds were estimated.

Method of Development of Waste Stabilization Pond Model: The development of the dimensions of anaerobic, facultative and maturation pond models was carried out following the Froude's number method of dimensional analysis expressed as follows.

Froude's number, $Fr = \frac{V}{\sqrt{Lg}}$ (13)

Where V = Velocity, L = Length and g = acceleration due to gravity

$$Fr_m = Fr_p \quad (14)$$

Where the subscripts *m* and *p* represent the model and prototype. Since acceleration due to gravity, g is constant, it implies that,

$$\frac{V_m}{\sqrt{L_m}} = \frac{V_p}{\sqrt{L_p}} \quad (15)$$

$$\frac{V_m}{V_p} = (\frac{L_m}{L_p})^{1/2} \quad (16)$$

From similarities, $\frac{A_m}{A_p} = (\frac{L_m}{L_p})^2$ (17)

More so, $\frac{Q_m}{Q_p} = \frac{A_m}{A_p} \times \frac{V_m}{V_p}$ (18)

$$\frac{Q_m}{Q_p} = (\frac{L_m}{L_p})^2 \times (\frac{L_m}{L_p})^{1/2} = (\frac{L_m}{L_p})^{2\frac{1}{2}} \quad (19)$$

Setting the wastewater flow rate for the model at 0.4 m^3/day, the dimensions of the model were estimated using equation 19 and maintaining the length to width ratio of 3:1.

Performance Evaluation of the WSP: A physical model of the WSP based on the model dimensions was fabricated using silicon glass material. Performance evaluation of the fabricated WSP was carried out using real time wastewater obtained from the hostel area of the university. The physicochemical and bacteriological characteristics of the raw and treated water were analysed in the Sanitary Engineering Laboratory of the Department of Civil Engineering, University of Jos following the standard methods of wastewater analysis described previously in APHA (2012). The parameters assessed are BOD, COD, Total coliform, Chloride, Sulphate, Total Nitrogen, Phosphorus, Total Dissolved Solids, Ammonia and pH. The results obtained were compared with the World Health Organization (WHO)/Food and Agriculture Organization (FAO) guidelines for reuse of wastewater for irrigation (Blumenthal *et al.*, 2000; Carr, 2005; Kotut *et al.*, 2011; WHO, 2015). In order to evaluate the overall efficiency of the WSP system in the treatment of the wastewater, the conformity of the final effluent parameters with the standards were used. Parameters that conformed to the standard were given a score of 1 while those that that did not conform were assigned a score of 0. The percentage conformity was used as the overall treatment efficiency of the system. This method has been used previously by Alfa *et al*. (2022).

RESULTS AND DISCUSSIONS

The dimensions of the designed prototype and model of the WSP are presented in Table 2 while the layout is presented in Figure 2.

Furthermore, the characteristics of the raw wastewater as well as those from the respective ponds are presented in Table 3. Table 2 shows that the length, breadth and depth of the anaerobic pond prototype are 92.3m, 30.8m and 3.0m respectively while those of the model are 1.9m, 0.6m and 0.1m respectively. The length, breadth and mid-depth of the facultive pond prototype are 121.3m, 40.4m and 1.5m respectively, while those of the model are 2.5m, 0.8m and 0.1m respectively. Similarly, the length, breadth and depth of the maturation pond prototype are 179.9m, 60.0m and 1.5m respectively while those of the model are 3.7m, 1.3m and 0.2m respectively.

Furthermore, the results of the final effluent quality obtained from the Maturation Pond (Table 3) reveal that the system was able reduce the BOD by 81%, COD by 73.6%, Total Coliforms by 75.8%, Total Solids by 61.9%, Total Nitrogen by 70.3%, Chloride by 56.3%, Phosphate by 60%, and Ammonia by 71.1%

Table 2: Dimensions of the prototype and model WSP

Ponds	Anaerobic		Facultative		Maturation	
	Prototype	Model	Prototype	Model	Prototype	Model
Number	**2**	**2**	**2**	**2**	**2**	**2**
Discharge	6,472.5	0.4	6,472.5	0.4	6,472.5	0.4
Length(m)	92.3	1.9	121.3	2.5	179.9	3.7
Breadth(m)	30.8	0.6	40.4	0.8	60.0	1.3
Depth (m)	3.0	0.1	1.5	0.1	1.5	0.2
Area (m^2)	2,838.5	1.2	4,903.3	2.1	10,787.4	4.7
Retention time (days)	2	1	5	1	4	3

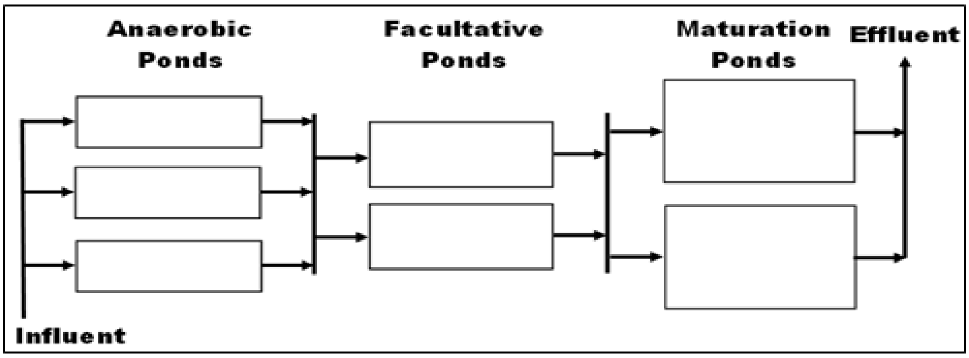

Figure 2: Layout of Designed WSP

Table 3: Results of the Performance Evaluation of WSP Model

Parameters	Raw Wastewater	Anaerobic Pond Effluent	% Removal	Facultative Pond Effluent	% Removal	Maturation Pond Effluent	% Removal	WHO Standard	Conformity to standard
BOD (mg/L)	420	160	61.9	120	71.4	80	81.0	45 – 90	1
COD (mg/L)	740	220	70.3	210	71.6	195	73.6	100 - 250	1
Total Coliforms (CFU/100ml)	310	104	66.5	92	70.3	75	75.8	45 - 100	1
Total solids (mg/L)	1600	850	46.9	790	50.6	610	61.9	650	1
Total Nitrogen (mg/L)	64	28	56.3	24	62.5	19	70.3	7 – 9	0
Chloride (mg/L)	480	260	45.8	240	50.0	210	56.3	250	1
Phosphate (mg/L)	70	35	50.0	32	54.3	28	60.0	2-8.2	0
Ammonia (mg/L)	4.6	1.8	60.9	1.6	65.2	1.3	71.7	5 - 10	1
pH	6.8	7.2	-	7.1	-	7.0	-	6.5 - 8.5	1
Overall Treatment Efficiency									**77.78**

This percentage removal not withstanding, the effluent quality did not meet the designated standard for Total Nitrogen and Phoshate removal. This corroborates the fact that WSP is not very efficient for nutrient removal (Sells *et al.,* 2018; Lahiri and Ghosh, 2018; dos Santos and van Haandel, 2021). More so, an overall system treatment efficiency of 77.78 % was achieved by the WSP model. However, the BOD removal of 81% obtained is lower than the expected for the effluent of the maturation pond (Achag*et al.,* 2021). The reason for this however is a subject of further investigation.

Conclusion: The performance evaluation of a WSP designed to treat wastewater from the Naraguta Campus of the University of Jos was carried out using a physical model. The WSP was able to efficiently reduce all effluent quality parameters to recommended limits with exception of total nitrogen and phosphate. The implementation of this design will go along way to treat wastewater from this campus of the university. The design presented in this study could also be implemented in similar University campus with appropriate modifications.

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