DEVELOPMENT AND EVALUATION OF WASTE STABILIZATION POND (WSP) FOR ABATTOIR WASTEWATER TREATMENT

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Abstract- **Waste Stabilization Pond for Abattoir Wastewater Treatment in Makurdi was developed and evaluated under laboratory-scale into ratio 40:1. WSP is a natural biological wastewater treatment facility designed to reduce organic contents and remove pathogen levels from wastewater to protect public health and sustenance of the ecosystem. The system consists of anaerobic, facultative and maturation ponds which were made up of three sets arranged in series. Influent concentration was characterized and compared with that of the final effluent. Pollutant parameters characterized were COD, TSS, TDS, Turbidity, Conductivity and E. coli. Others are Ca, Mg, Na, pH, Salinity and Temperature. NH_4, BOD, PO_4, and NO_3 were also characterized in the laboratory using standard methods. It showed that E. coli, COD and TDS indicated high level of presence; hence their removal was monitored for three weeks. Removal efficiency for E.coli in the Anaerobic ponds were 30.77%, 7.69% and 15.38% in the first, second and third cycles respectively. In the Facultative ponds; it was 69.23%, 76.92% and 69.23%, while removal efficiency was 100%, 100% and 92.31% in the Maturation ponds. COD removal in the Anaerobic was 49.76%, 67.54% and 78.47%. In the Facultative; it was 72.43%, 70.64%, 53.99%. And in the Maturation ponds it was 74.23%, 77.81% and 75.86%. TDS removal recorded 29.17%, 20.83% and 33.33% in the Anaerobic, 35.42%, 29.17% and 33.33% in the Facultative, in the maturation; it was 37.50%, 37.50% and 41.67%. Statistical results obtained showed significant improvements particularly in Anaerobic and Maturation ponds. Pathogen removal level was achieved that complies with recommended effluent discharge quality.**

Keywords: **Evaluation, Pathogen, Waste stabilization pond, Abattoir wastewater.**

1.0 INTRODUCTION

Wastewater generation and handling in abattoirs pose an adverse environmental impact resulting from its poor management practices. [13] affirmed in a 2012 Water and Sanitation Report by the WHO that estimated sanitation coverage in many countries of sub-Saharan Africa was below 50%, and as a result; the quality of water resources is highly degraded and huge sections of the population in these regions are at risk of water-borne diseases. Most Nigerian abattoirs are situated close to surface water bodies to have access to water needed for slaughtered animal processing and to provide a sink for the run-off from meat processing activities [21]. [12] stressed that sustainable wastewater treatment systems for developing countries should focus on meeting local needs, being less sophisticated to operate, and should require minimal investment. However, overlooking the above explained issues in the selection of treatment systems falls to the common practice of discharging untreated wastewater directly into water bodies in the surroundings [24].

[3] described WSPs as large shallow basins enclosed by natural embankments in which decomposition of organic matter in wastewater is processed naturally (biologically), thereby making bacteria and algae in the WSP to stabilize the organic waste and lower the effluent pathogen levels. They are natural wastewater treatment facilities employed for treatment of agricultural, industrial, domestic and animal wastewaters; which require neither energy source nor additives to function [16]. Influent wastewater from animal production and meat processing have been reported by [2] to pollute soil, natural water resources and the entire environment, knowing that abattoir wastewater has a complex composition and can be very harmful to the environment for instance, *escherichia coli* infection from abattoir faeces containing the bacterium [6]. Also [20] reported that abattoir activities are responsible for the pollution of surface and underground waters, reduction of air quality as well as quality of health of the inhabitants of the residents within the surrounding environment that depend on stream or river as their source of domestic and irrigation water. [7] said that faeces of livestock consist of undigested food, most of which is a cellulose fibre, undigested protein, excess nitrogen from digested protein, residue from digested fluids, waste mineral matter, worn-out cells from intestinal linings, mucus and bacteria. It could also lead to eutrophication of the receiving system and an increased rate of toxins accumulation in biological systems [19].

Studies have revealed that improper disposal of these abattoir wastewaters could lead to transmission of pathogens to humans which may cause an outbreak of water-borne diseases such as diarrhea, pneumonia, typhoid fever, asthma, respiratory and chest diseases etc [18]. These issues have the provided groundwork to consider a proper act of disposing of and management of abattoirs wastewater in Nigeria, thereby minimizing possible public health effects.

1.1 Types of Waste Stabilization Ponds

WSP may consist of a single pond or several ponds with each pond playing a different role in the removal of contaminants or pathogenic organisms as seen in Figure 1 and Plate 1. The wastewater treatment for removal of contaminant depends on the pond types such as Anaerobic, Facultative and Maturation and number of ponds in configuration employed for a holistic treatment. Their operations are highly dependent on environmental factors such as temperature, wind and light intensity [8]. Anaerobic pond serves as a pre-treatment pond for Biochemical Oxygen Demand (BOD), Suspended Solids (SS) and Chemical Oxygen Demand (COD) removal. It can achieve about 40% removal of BOD at 10ºC and more than 60% at 20ºC [11]. It works extremely well in warm climates with the removal of BOD ranging from 60-85% in a very short retention time [4]. Facultative pond is designed to retain wastewater for a period long enough for the natural organic matter stabilization process to take place. The technology associated with facultative lagoons has been in widespread use in the United States for at least 90 years, with more than 7,000 facultative lagoons in operation today (USEPA, 2002). It utilizes aerobic bacteria present in the superior zone and anaerobic in the lower zone [14]. Maturation pond is commonly referred to as Aerobic or Finishing pond, organic matter in the wastewater is broken down by aerobic bacteria and oxygen found in the wastewater treatment ponds before being reused or discharged into the natural environment. It should exhibit high coliform removal efficiency of E >99.9% so that the effluent can comply with most uses of the water in the receiving water body or direct usage for unrestricted irrigation [28].

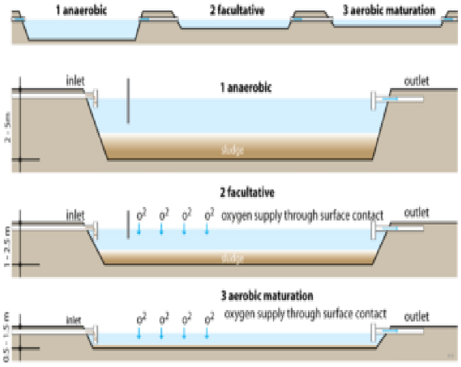


Figure 1: Waste Stabilization Ponds set up
Source: http://www.en.wikipedia.org

Plate 1: A Stabilization Pond.
Source:https://www.iwk.com.my/do-you-know

1.2 Wastewater composition

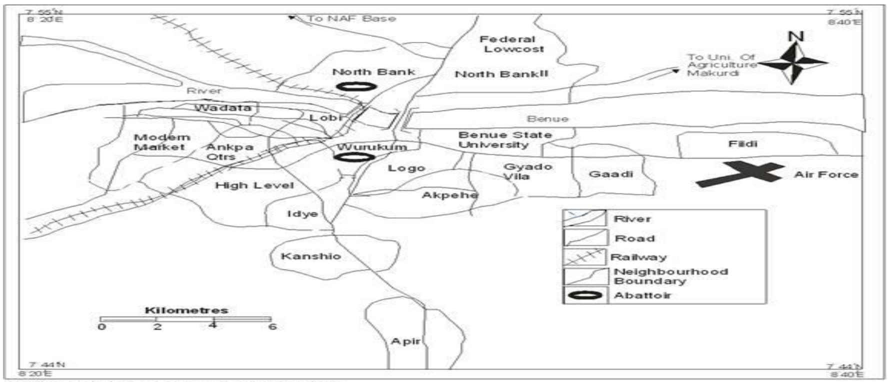
A wastewater is composed of many and varied substances either dissolved or suspended in it, with various degrees of existence in the water. Some of these compositions are listed as follows:

- Water consisting of >95% obtained from flushing and washing.
- Pathogens such as bacteria, viruses, parasitic worms and non-pathogenic bacteria.
- Organic particles; examples feaces, plant materials, fibers etc.
- Inorganic materials; for examples metals, ceramics, grit, trace metals (Mg, Na and Ca).
- Soluble organic materials such as proteins, urea, pharmaceuticals and other hormones.

2.0 MATERIALS AND METHODS

2.1 The Study Area

The sample was collected at the Main Cattle Market, NorthBank, Makurdi, in the Benue State of Nigeria. Makurdi is the capital city of Benue State and is geographically located at latitude 7˚44' North and longitude 8˚31' East (Figures 4). Rainfall is moderate, Mean Monthly Rainfall (MMR) ranges of 900mm –1500mm between April to October and an Average Monthly Temperature (AMT) of 28˚C – 35˚C. The city is 104m elevation above the sea level along the River Benue [9, 23].



Source: Ministry of Lands and Survey Makurdi

Figure 4: Map of Makurdi showing NorthBank Abattoir
Source: Ministry of Lands and Survey, Makurdi.

2.2 Design Considerations

Adoption of treatment systems without taking into consideration certain local conditions accounts for a considerable number of wastewater management facility failures. Consequent upon this; there is a need to consider certain factors in the designing process which may influence the performance of the ponds, they are; hydrology, topography, public health and safety concerns; bearing in mind that the ponds should not be constructed to create nuisance rather solve a problem in the environment.

2.3 Collection of Raw Water Sample and Laboratory Analysis

To have representative samples for the whole season; raw water used for this study was collected at the study site twice in two months during the rainy season (June and July), also twice during the dry season (December and January) for initial characterization before treatment at the Laboratory to determine their Physico-chemical parameters such as COD, BOD, pH, Temperature, TSS, TDS, Turbidity, Salinity and Conductivity, Bacteriological parameters such as E.coli, Nutrients such as PO_4-, NO_3- and NH_4, others are Trace metal elements such as Na, Ca and Mg were all tested to ascertain their pollutant level. See point of collection of raw samples in Plate 2. The seasonal sampling of the raw water before treatment during dry and rainy seasons was necessitated to ensure even distribution of pollutant parameters used for a holistic design of the pond system and monitored for treatment efficiency in the treatment facilities. The wastewater undergoing treatment was monitored on weekly basis in Laboratory-scale ponds to ascertain its stabilization level suitable for discharge based on standards.

Plate 2: Collection of wastewater samples at the abattoir for analysis.

2.4 Design parameters

- Estimation of the quantity of water demand: Data on water demand was collected during an interaction with Management and operatives of the abattoir to establish an approximate water demand which was useful in estimating the daily per capita usage of water resources for the abattoir activities. Information from the abattoir operatives indicate that about 25 litres of water are used to clean a cow and about 10 litres can go for a goat, sheep or ram. About 10 – 15 cows and 15 goats, sheep, and ram are slaughtered daily, therefore; an average of 20 cows × 25 litres = 500 litres and additional 200 litres was taken into consideration for excess inflow from run-off water which may come unexpectedly. Also, 15 goats/sheep/ram ×10 = 150 litres. Flushing slab, washing and other usage = 150 litres.

The quantity of water demand = 500 + 150 + 150 + 200= 1,000 litres.

Approximately 1,000 litres ($1m^3$) of water demand is required per day for the abattoir activities.

- Estimation of the quantity of wastewater generated (Q): It has been stipulated that about 80% of water per capita usage constitutes a suitable wastewater design flow value [17]. The type of flow source understudy was identified to be a point source that is fed into the wastewater reservoir before treatment.

Given that Q = 80% of water demand.

$$\text{Therefore; quantity of wastewater (Q)} = \frac{80}{100} \times 1{,}000\ l/d = 800\ l/d$$
$$= 0.80 m^3/d$$

- Organic Loading Rate (B): This was determined based on the calculated quantity of wastewater and the influent BOD_5

Therefore; $B = Q \times BOD_5$

$$= 800\ l/d \times 12\ mg/l$$
$$= 9.6\ gBOD/d$$

- Biochemical Oxygen Demand (BOD): The result from Lab analysis showed that BOD after 5 days incubation period at a temperature of 28.5℃ of the influent wastewater was 12 mg/l. Therefore, the Total Influent BOD_5 concentration given as (L_i) was confirmed as; $L_i = \frac{B}{Q}$ [14, 22]. Where; L_i = Influent BOD, B = Organic loading rate and Q = Wastewater quantity. Therefore, $L_i = \frac{9.60}{0.80} = 12 g/m^3$

- Volumetric Organic Loading (λ_v): Anaerobic ponds are designed based on volumetric loading rate at a permissible range of between 100 $mg/m^3/d$ at temperature <12℃ and 400 $mg/m^3/d$ at temperature >25℃ which was determined using the relation given by [22], $\lambda_v = \left(\frac{400\ (T - 12)}{18}\right) + 100$ (since $T > 25^0C$)

$$\text{Therefore, } \lambda_v = \left(\frac{400\ (28.5 - 12)}{18}\right) + 100$$
$$= \left(\frac{6600}{18}\right) + 100 = 467 mg/m^3$$

- Temperature (*T*): The temperature is an important factor to consider in the design of each pond. It is that which was gotten from the result of the raw sample before treatment which gave $T = 28.5℃$

2.5 Design calculations

To ensure holistic and efficient system performance, design calculations were carried out for each of the ponds with their specifications as follows:

- **Design of Anaerobic Pond**

An anaerobic pond was designed based on the permissible volumetric organic loading (λ_v) which is related to the wastewater flow (Q), influent BOD_5 (L_i), and the pond volume (V). The volume of the anaerobic ponds (V_a) in m^3 is always computed using the formula; [15, 22].

$\lambda_v = \frac{Li\ Q}{Va}$ where; V_a = Volume of Anaerobic pond, L_i = Influent BOD_5, Q = Wastewater flow, and λ_v = Volumetric loading. If $\lambda_v = \frac{Li\ Q}{Va}$, therefore; $\lambda_v V_a = L_i Q$

$$\therefore V_a = \frac{Li \times Q}{\lambda v}$$

Substituting; $V_a = \frac{12 \times 0.80}{467} = 0.02m^3$ Therefore, Volume of the pond = $0.02m^3$

Dimension of the Anaerobic pond: Since the total volume of each pond is $0.02m^3$, and the appropriate sizing to achieve treatment efficiency is 3:1(length: width) [17] or 2:1 [14].

Taking Depth (d) of the pond = 0.5m,

Area of the pond (A) = $\frac{Va}{d} = \frac{0.02}{0.5} = 0.04m^2$

Using Length and Width ratio of 3:1 for efficiency,

Let y = Width of the pond and L = $3y$

Area of the pond → $3y^2 = 0.04m^2$

$y^2 = \frac{0.04}{3} = 0.013$

$y = \sqrt{0.013}$

$= 0.12m$

Length (l) = $3y$, = 3 x 0.12m

Volume of the pond = $l \times w \times d$

= Length 0.36*m*, Width 0.12*m* and Depth 0.5*m*

Therefore, dimension of the pond was length 0.36*m*, width 0.12*m* and depth 0.5*m*

Also, BOD removal in the anaerobic ponds was calculated using the relation:

$\%$ BOD removal = $2T + 20$.

= 2(28.5) + 20. Therefore, % BOD Removal = 77%

- **Design of Facultative pond**

The Facultative pond was designed by considering the maximum BOD loading per unit area in the pond (λ_s) because biological activities are dependent on temperature. It was designed using the given relation below by [14]:

$\lambda_s = 20T$ – (% BOD Removal in the Anaerobic pond)

= 20 (28.5) – 77

= 493*kg/ha/day*

Since the BOD Removal in the Anaerobic pond is 77%, then the remaining percentage was used to calculate the influent BOD into the Facultative pond, which is 23%. Therefore, the influent BOD into Facultative pond (L_i) becomes;

L_i (facultative) = $\frac{23}{100} \times 12$

= 2.76*mg/L*

Also, the design for facultative ponds volume (V_f) is calculated using the relation [22].

$V_f = \frac{(10 \times Li \times Q)}{\lambda s}$ where: V_f = Volume of facultative pond, Li = Influent BOD to facultative pond, Q = Wastewater quantity, and λs = Maximum BOD loading in facultative pond.

The length and width ratio of a facultative pond is also designed as 3:1 [17].

$\therefore V_f = \frac{10 \times 2.76 \times 0.80}{493}$

$= 0.044m^3$

Taking Depth (d) of the pond = 0.30m,

Area of the facultative pond (A) = $\frac{Vf}{d} = \frac{0.044}{0.30} = 0.15m^2$

Let y = Width of the pond and Length (L) = $3y$

That is; $3y^2 = 0.15m^2$ (Taking Length and Width ratio of 3:1)

$y^2 = \frac{0.15}{3} = 0.05m$

$y = \sqrt{0.05} = 0.22m$

L = 3 x 0.22 = 0.66m

Therefore, Capacity of Facultative pond was calculated to be $0.044m^3$, having dimension of length 0.66m, width 0.22m and depth 0.30m.

- **Design of Maturation Pond**

The design of the maturation pond system depends on the bacteriological quality required of the effluent wastewater to reduce the E.coli bacteria in the system. The number of bacteria in the wastewater expressed as (Be) was determined using the following equation. [14. 22];

$$Be = \frac{B_i}{[1 + K_{B(T)}\, t]}$$

where: Be = Number of E.coli bacteria per 100ml of the effluent, B_i = Bacterial concentration in the wastewater before treatment, t = Detention time (taking 7 days for each of the pond), and $K_{B(T)}$ = First order E.coli removal rate constant in T℃ given as $K_{B(T)} = 2.6\,(1.19)^{T-20}$

$$\text{Substituting; } K_{B(T)} = 2.6\,(1.19)^{28.5-20}$$
$$= 2.6 \times 4.39$$
$$\text{E.coli } = 11.40 \text{ per day}$$

Knowing that Maturation pond is designed for E.coli bacteria per 100ml removal which can be determined from this equation [15];

$$Be = \frac{Bi}{[1 + K_{B(T)}\, t_a][1 + K_{B(T)}\, t_f][1 + K_{B(T)}\, t_m]^n}$$

where: t_a , t_f and t_m are the detention times of the anaerobic, facultative and maturation ponds respectively and n is the number of maturation ponds.

$$Be = \frac{13x10^2}{[1 + (11.40x7)]\,[1 + (11.40x7)]\,[1 + (11.40x7)]^1} = 2.5x10^{-3}cfu$$

Since calculated Be = < 100cfu/100ml, one pond each is considerable for the treatment of the wastewater.

Total Volume of the pond (V_m) = Q x t_m

= 0.80 x 7 days = 5.6m^3

Taking Depth (d) of the pond = 1.2 m,

Area of the Maturation pond = $\frac{Vm}{d} = \frac{5.6}{1.2}$ = 4.67m^2

Let y = Width of the pond and Length (L) = 3y

$y^2 = \frac{4.67}{3}$ = 1.56m

$y = \sqrt{1.56}$ = 1.25m

L = 3 x 1.25 = 3.75m

Therefore values of length = 3.75m, width = 1.25m and depth = 1.2m (3:1)

The system completed the treatment within 21days per cycle, and it was constructed according to the designed and recommended sizes and dimensions.

2.6 Laboratory scale-down ponds

It was suggested to go on a small scale before committing full-scale design of ponds [25], therefore from the results obtained in the design calculations, laboratory-scale model ponds were redesigned using dimensional analysis. For convenience; a ratio of 40:1 was adopted. This is to simulate a true representation of the prototype ponds for efficiency and cost-effectiveness. The existence of similar model ponds for WSPs was used successfully by [26] and concluded that it is the best approach to research scale-model ponds operated under controlled conditions in a laboratory. [22] carried out a similar study on laboratory-scale model ponds with baffles and it was successful. Also, [1] used a two-dimensional computational fluid dynamics (CFD) surface-water modeling system (SMS) on scaled WSP with various rectangular shape configurations to simulate hydrodynamics and water quality; the result demonstrated an increased BOD removal efficiency.

The approximate quantity of water demand used was 1,000 litres per day; which gave 800 litres estimated wastewater generated in the design process. Using the same rectangular shape configured containers to simulate the pond types having same dimensions of length, width and depth ratio of 3:1:1 respectively. Under normal conditions, the quantity of water is expected to reduce in the facultative and maturation ponds as the treatment takes effect. The dimensions of the scaled-down ponds in the ratio 40:1 are listed as; Water demand (V_t) = 1m^3/d = 0.025m^3/d, Wastewater generated (Q) = 0.80m^3/d = 0.02m^3/d, Length (L) = 0.36m, Width (w) = 0.12m and Depth (d) = 0.5m

2.7 Description of the laboratory-scale WSP

Before treatment in the WSP, the influent was first subjected to a preliminary treatment using screens to trap large suspended solids, fats, particles of bones, feaces etc to ensure free flow devoid of pipe clogging. The preliminary treatment was connected to a plastic bucket having an outlet valve to the first set of ponds in parallel and serves as a raw wastewater tank (Plates 3a and b). The pond systems are made of rectangular shape plastics of 20 litres (0.02m^3) capacity each, with dimensions of 0.36m length, 0.12m width and 0.5m depth. The use of plastic materials is necessary to avoid reactions with the wastewater thereby making validation of data collected for laboratory analysis to be inaccurate. They are thoroughly linked to each other to prevent leakage that could affect the treatment processes of the wastewater under study.

Plates 3a and b: Experimental set up

2.8 Loading and Laboratory Experimentation

Loading of the laboratory-scale WSP starts from the pre-treatment stage. All the analyses were carried out using appropriate water testing instruments and in accordance with the standard methods for temperature, BOD, pH, TSS, TDS, COD, turbidity, conductivity, E.coli, Ca+, Mg^+, Na^+, Salinity, NH_4, PO_4, and NO_3. Removal of pathogenic is the primary objectives of WSP. The results of the above tested parameters are presented in the result section.

3.0 RESULTS AND DISCUSSION

3.1 Water quality parameters before treatment

Laboratory result showing the raw water pollutant parameters before treatment can be seen in Table 1. It was discovered that some of the parameters tested for compared well with their respective recommended levels for wastewater effluent discharge. They are; Total Suspended Solids, Turbidity, Conductivity, Calcium, Magnesium, Sodium, pH, Salinity, Temperature, Ammonium, Biochemical Oxygen Demand, Phosphate and Nitrate. Whereas, E.coli, chemical oxygen demand (COD) and total dissolved solids (TDS) were seen to be high above the recommended standard. Therefore, can pose threat to environmental health, hence these three listed pollutants were monitored for treatment in this study. The presence of E. coli concentration as a type of bacteria in the raw water was found to be $13x10^2$ cfu which is high, knowing that an effluent with high concentrations of such bacteria have high potential of endangering public health [18]. Similarly, the initial COD and TDS concentration in the raw water was very high; reading 613 mg/l and 4800mg/l respectively (Table 1).

Table 1: Mean raw water pollutant before treatment

S/N	Parameter	Experimental Reading	Recommended discharge level (USEPA, 2002)	Unit
1.	COD	613	160 – 250	mg/L
2.	TSS	75	< 90	mg/L
3.	TDS	4800	< 3000	mg/L
4.	Turbidity	66	< 75	NTU
5.	Conductivity	6420	<1500	µs/cm
6.	E. Coli	$13x10^2$	0 – 10	Cfu
7.	Ca	62	50 – 80	mg/L
8.	Mg	18	< 20	mg/L
9.	Na	80	< 150	mg/l
10.	pH	7.4	6.5 – 8.5	-
11.	Salinity	0.8	0.5 – 15	%
12.	Temperature	28.5	< 35	ºC
13.	NH_4	3.53	< 10	mg/L
14.	BOD	12	< 30	mg/L
15.	PO_4	2.5	10 – 30	mg/L
16.	NO_3	30	< 50	mg/L

3.2 Variation of Final Effluent Concentrations with Pond Type and Treatment Cycle

Pond types and the cycles for each of the three ponds were monitored per week to adjudge the efficacy of the treatment. Each of the ponds has three replications; their mean values showing the extent of treatment levels are given in Tables 2 – 4. Mean concentration for the treatment from first week to the third week for E.coli, COD and TDS is shown on Figures 5 – 7 respectively.

Table 2: Mean results of pollutant removal in Anaerobic ponds for the number of operating cycles

Pollutants	Operating cycles		
	A_1	A_2	A_3

E.coli (cfu)	9x10^2	12x10^2	11x10^2
COD (mg/l)	308	199	132
TDS (mg/l)	3400	3800	3200

A_1 = First cycle, A_2 = Second cycle, A_3 = Third cycle

Table 3: Mean results of pollutant removal in Facultative ponds for the number of operating cycles

Pollutants	Operating cycles		
	F_1	**F_2**	**F_3**
E.coli (cfu)	4x10^2	3x10^2	4x10^2
COD (mg/l)	169	180	280
TDS (mg/l)	3133	3200	3400

F_1 = First cycle, F_2 = Second cycle, F_3 = Third cycle

Table 4: Mean results of pollutant removal in Maturation ponds for the number of operating cycles

Pollutants	Operating cycles		
	M_1	**M_2**	**M_3**
E.coli (cfu)	0	0	0.6x10^2
COD (mg/l)	158	136	148
TDS (mg/l)	3000	3000	2800

M_1 = First cycle, M_2 = Second cycle, M_3 = Third cycle

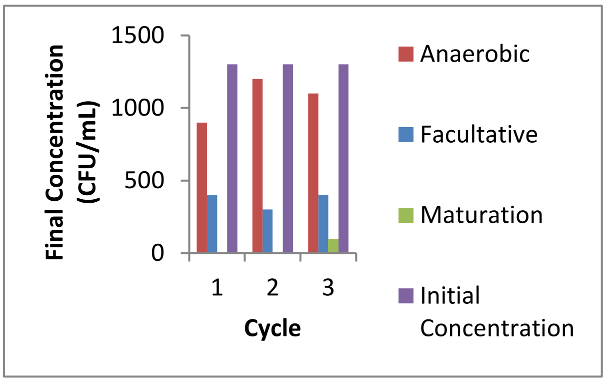


Figure 5: Mean E.coli concentration after treatment for one week in each cycle.

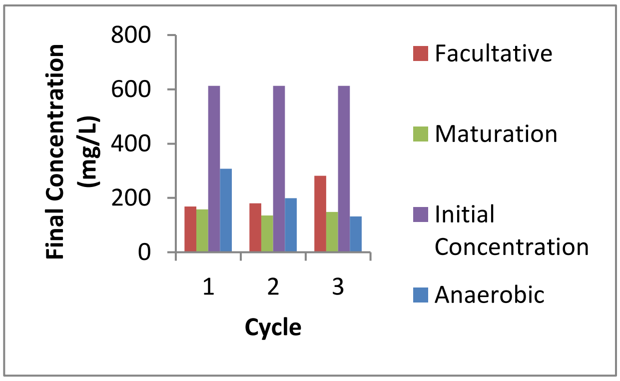


Figure 6: Mean COD concentration after treatment for one week in each cycle.

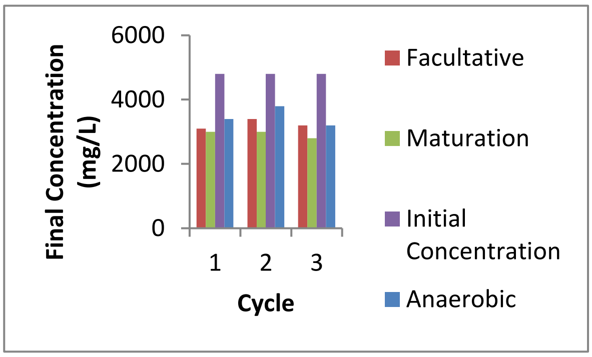


Figure 7: Mean TDS concentration after treatment for one week in each cycle.

3.3 Removal Efficiency

The removal efficiency of each of the pollutant under study was determined using:

R (%) = $\frac{Co - Ce}{Co}$ x100 where; R (%) = Removal efficiency, Co = Initial concentration, Ce = Final concentration

Mean Removal Efficiency (R%) for each of the three cycles in the various pond was summarized accordingly in Tables 5 – 7. The E. coli removal effect was plotted on a curve in Figure 8. COD removal curve was displayed in Figure 9. Similarly, that of TDS curve was shown in Figure 10. Effect of treatment cycle and pond type for the above pollutant parameters is on Figures 8 – 10 respectively. It indicates the level of stabilization from initial to final concentration within the three weeks of monitoring.

Table 5: Mean Removal Efficiency (R%) per week for E.coli (CFU/ml)

Pond type	First cycle (%)	Second cycle (%)	Third cycle (%)
Anaerobic	30.77	7.69	15.38

Facultative	69.23	76.92	69.23
Maturation	100	100	92.31

1 cycle = 1 week

Table 6: Mean Removal Efficiency (R%) per week for COD (mg/L)

Pond type	First cycle (%)	Second cycle (%)	Third cycle (%)
Anaerobic	49.76	67.54	78.47
Facultative	72.43	70.64	53.99
Maturation	74.23	77.81	75.86

1 cycle = 1 week

Table 7: Mean Removal Efficiency (R%) per week for TDS (mg/l)

Pond type	First cycle (%)	Second cycle (%)	Third cycle (%)
Anaerobic	29.17	20.83	33.33
Facultative	35.42	29.17	33.33
Maturation	37.50	37.50	41.67

1 cycle = 1 week

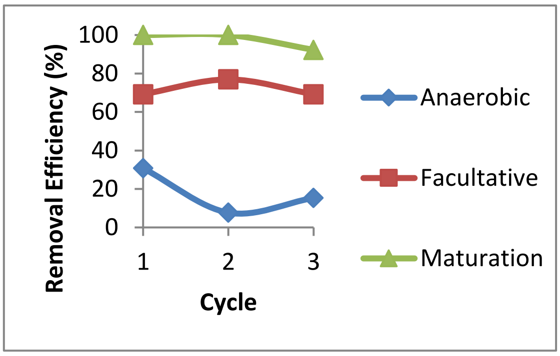


Figure 8: Effects of Treatment Cycle and Pond type on E. coli Removal

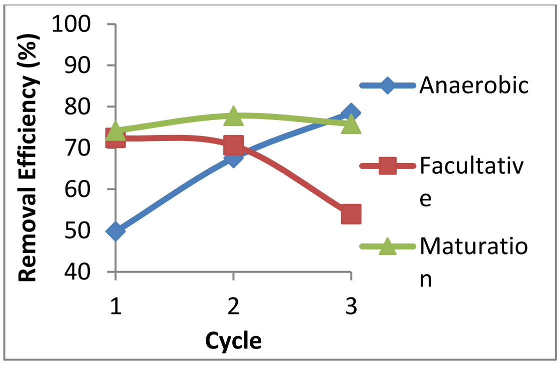


Figure 9: Effects of Treatment Cycle and Pond type on COD Removal

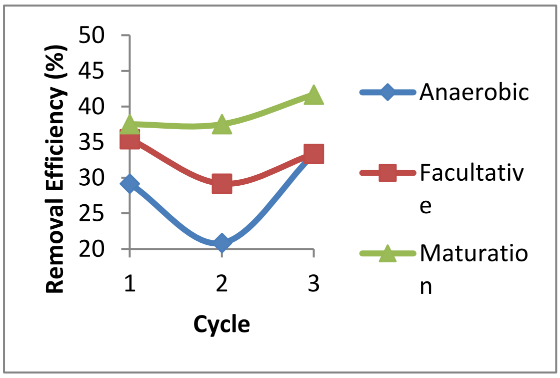


Figure 10: Effects of Treatment Cycle and Pond type on TDS Removal

3.4 E. coli

In the first week, there was decrease in the anaerobic pond; further decrease was observed during the following weeks of treatment in the facultative and maturation ponds; depicting efficiency in treatment process per time in the different pond types (see Tables 2 – 4). The indication of 0 cfu and 0.6x10^2 cfu removal levels for the three maturation ponds respectively and the corresponding mean removal efficiency as seen in Table 4 for the first, second and third maturation ponds were 100%, 100% and 92.31% respectively (Table 5). Accordingly, the noticed progressive removal of E. coli concentration showed that there was decrease in pathogen rate from the anaerobic pond to facultative pond to the final maturation pond as expected in the treatment series, this was consistent with the findings of [15]. This also satisfies the findings of [28] that certain amount of pathogen removal takes place in the anaerobic and facultative ponds. While greater amount of removal takes place in the maturation pond which is specifically designed for the purpose of removing pathogen; this effect is indicated in Figure 8. The study therefore justified that the WSP system is very effective in the overall treatment for removal of E. coli. Hence, the final pond effluent can be discharged into the natural environment without posing threat to humans and for direct reuse for unrestricted irrigation.

3.5 COD

COD treatment results were effective in the various ponds. However, there was an observed fluctuation indicating increase in concentration from 132mg/l to 280mg/l and finally reduced to 148mg/l in the anaerobic, facultative and maturation ponds respectively (Tables 2 – 4). Conversely, instead of steady reduction there was an observed fluctuation in the treatment series; the fluctuation that occurred was attributed to variation in algal activities in the different ponds. This effect is shown in Figure 9. The first, second and third cycles recorded steady improvements in treatment efficiency indicating 49.76%, 67.54% and 78.47% respectively in the anaerobic ponds. Whereas, in the Facultative ponds; there was drop in treatment efficiency of the system from the first to the third cycles with 72.43% to 70.64% to 53.99% respectively. Values in the Maturation ponds proved to experience slightly similar range of 74.23% during the first sampling, 77.81% during the second and 75.86% was achieved in the third monitoring (see Table 6). It is uncommon to find variations in WSP system, however; [11] in their research experienced similar variations in pollutant parameters and concluded that the main reason for the fluctuation in ponds was due to sunlight activating algal photosynthesis. Meanwhile, COD removal efficiency calculated to be 75.86% in the maturation pond can be described as appreciable, proving that it meets regulatory requirements because effluent with high concentration of COD in the receiving water body can cause depletion of natural oxygen resources. [5] agreed satisfactorily that the quality of this treated final pond effluent is not anticipated to have adverse effects on the environment when discharged into nearby surface water sources due to its achieved level of reduction in the final effluent pond.

3.6 TDS

Table 7 supports TDS removal efficiency in the anaerobic and facultative ponds which read 33.33% each per cycle. Maturation result recorded improved removal efficiency in the third cycle with 41.67%. Figure 10 showed consistent reduction of this pollutant correspondent to cycle and pond type. In the final maturation pond, it was found to have reduced to 2800 mg/l concentration proving success in the treatment process and therefore meets USEPA (2002) standard for unrestricted irrigation [26]. Table 8 summarizes pollutant concentration before and after treatment at Maturation.

Table 8: Summary of pollutant concentration before and after treatment at Maturation

Parameter	Before treatment	After treatment	Recommended USEPA (2002)
E. coli (cfu)	$13x10^{2}$	$0.6x10^{2}$	0 – 10
COD (mg/L)	613	148	160 – 250
TDS (mg/L)	4800	2800	< 3000

3.7 Analysis of Variance (ANOVA)

The experimental design adopted in this study was a Factorial design in Completely Randomized Design (CRD) consisting of two factors; that is Operating Cycle and Pond type, at three levels with three replications each, (3*x*3) Factorial Experiment. Analysis of Variance (ANOVA) of two ways was used to test for significant different at P = 0.05 using the SPSS Statistical software version 21. The Effects of Operating Cycles and Pond types on the Removal Efficiency (R %) of the abattoir wastewater pollutant shown in Table 9 was used for the ANOVA. Meanwhile, the ANOVA consists of the three pollutant parameters; E. coli, COD and TDS, and was presented on Tables 10 – 12 respectively. Significant Test result for E. coli was not statistically different on operation cycle as seen in Table 10, whereas Tables 11 and 12 shows highly significant difference for COD and TDS respectively in both cycles and pond types.

Table 9: Effects of Operating Cycles and Pond types on the Removal Efficiency (R%) of the abattoir wastewater pollutant

Operating Cycle/ Parameter	Pond type Anaerobic	Facultative	Maturation	Total
First Cycle				
E. coli (cfu)	30.77	69.23	100	200
COD (mg/L)	49.76	72.43	74.23	196.42
TDS (mg/L)	29.17	35.42	37.50	102.09
Total	**109.70**	**177.08**	**211.73**	**498.51**
Second Cycle				
E. coli (cfu)	7.69	76.92	100	184.61
COD (mg/L)	67.54	70.64	77.81	215.99
TDS (mg/L)	20.83	29.17	37.50	87.50
Total	**96.06**	**176.73**	**215.31**	**488.10**
Third Cycle				
E. coli (cfu)	15.38	69.23	92.31	176.92
COD (mg/L)	78.47	53.99	75.86	208.32

TDS (mg/L)	33.33	33.33	41.67	108.33
Total	**127.18**	**156.55**	**209.84**	**493.57**

Table 10: Result of ANOVA for E. coli (cfu/ml)

Source	**Type III Sum of Squares**	**Degree of Freedom**	**Mean Square**	**F**	**Sig. (5%)**
Corrected Model	5161851.852	8	645231.481	60.073	0.000*
Intercept	6502314.815	1	6502314.815	605.388	0.000*
Cycle	45740.741	2	22870.370	2.129	0.148^{ns}
Pond	4994629.630	2	2497314.815	232.509	0.000*
(Cycle x Pond)	121481.481	4	30370.370	2.828	0.056*
Error	193333.333	18	10740.741		
Total	11857500.000	27			
Corrected Total	5355185.185	26			

F = Fisher’s Significant Test Value
Sig. = Significance
* = Highly Significant ($P < 0.05$)
^{ns} = Not significant ($P < 0.05$)

Table 11: Result of ANOVA for COD (mg/L)

Source	**Type III Sum of Squares**	**Degree of Freedom**	**Mean Square**	**F**	**Sig. (5%)**
Corrected Model	96018.741	8	12002.343	875.847	0.000*
Intercept	973180.593	1	973180.593	71015.881	0.000*
Cycle	7377.852	2	3688.926	269.192	0.000*
Pond	25220.519	2	12610.259	920.208	0.000*
(Cycle x Pond)	63420.370	4	15855.093	1156.993	0.000*
Error	246.667	18	13.704		
Total	1069446.000	27			
Corrected Total	96265.407	26			

F = Fisher’s Significant Test Value
Sig. = Significance
*= Highly Significant ($P < 0.05$)

Table 12: Result of ANOVA for TDS (mg/L)

Source	**Type III Sum of Squares**	**Degree of Freedom**	**Mean Square**	**F**	**Sig. (5%)**
Corrected Model	2047407.407	8	255925.926	16.651	0.000*
Intercept	279045925.926	1	279045925.926	18154.795	0.000*
Cycle	518518.519	2	259259.259	16.867	0.000*
Pond	1291851.852	2	645925.926	42.024	0.000*
(Cycle x Pond)	237037.037	4	59259.259	3.855	0.020*
Error	276666.667	18	15370.370		
Total	281370000.000	27			
Corrected Total	2324074.074	26			

F = Fisher’s Significant Text Value
Sig. = Significance
*= Significant ($P < 0.05$)

3.8 Mean separation for the final treated wastewater concentration

Duncan Multiple Random Test (DMRT) was used for Mean separation. For E. coli it shows statistical difference between the first and second cycles but there was no difference between the second and third cycles; meaning that further treatment in the third cycle can be neglected. Whereas, the test indicated corresponding statistical difference in the various pond types per week; showing effectiveness of the treatment processes from the first to the last ponds as seen in Table 13. There was slight significant difference for COD in the first cycle compared to the second and third cycles, but not different in the first and second ponds except in the third pond type (Table 14). Similarly, the test showed high statistical difference for TDS removal in the various cycles and pond types as seen in Table 15; this verified that TDS pollutant is necessary for treatment in the anaerobic, facultative and maturation ponds per cycle.

Table 13: Mean separation for E. coli (cfu)

Cycle (week)	Anaerobic	Pond type Facultative	Maturation	Mean (Cycle)
1.	900.00 ±100.00	400.00 ±50.00	0.00 ±0.00	433.33^{a} ±394.49
2.	1200.00 ±264.58	333.33 ±57.74	0.00 ±0.00	511.11^{b} ±553.27
3.	1100.00 ±100.00	383.33 ±28.87	100.00 ±0.00	527.78^{b} ±449.38
Mean	1066.67^{c} ±200.00	372.22^{b} ±50.69	33.33^{a} ±50.00	490.74 ±453.84

Values are Means ± Standard Deviations of triplicate experiments. Means with the same superscripts in the same row and columns are not significantly different at $p = 0.05$

Table 14: Mean separation for COD (mg/L)

Cycle (week)	Anaerobic	Pond type Facultative	Maturation	Mean (Cycle)
1.	308.00 ±2.65	169.00 ±3.61	158.00 ±1.73	211.67^{c} ±72.45
2.	199.00 ±1.73	180.00 ±5.00	136.00 ±6.00	171.67^{a} ±28.27
3.	132.00 ±2.65	280.67 ±1.15	146.00 ±5.29	186.22^{b} ±71.16
Mean	213.00^{b} ±76.95	209.89^{b} ±53.39	146.67^{a} ±10.38	189.85 ±60.85

Values are Means ± Standard Deviations of triplicate experiments. Means with the same superscripts in the same row and columns are not significantly different at $p = 0.05$

Table 15: Mean separation for TDS (mg/L)

Cycle (Week)	Anaerobic	Pond type Facultative	Maturation	Mean (Cycle)
1.	3400.00 ±50.00	3133.33 ±57.74	3000.00 ±100.00	3177.78^{b} ±187.27
2.	3800.00 ±264.58	3400.00 ±173.21	3000.00 ±0.00	3400.00^{c} ±380.79
3.	3200.00 ±100.00	3200.00 ±100.00	2800.00 ±50.00	3066.67^{a} ±213.60
Mean	3466.67^{c} ±301.04	3244.44^{b} ±158.98	2933.33^{a} ±114.56	3214.81 ±298.98

Values are Means ± Standard Deviations of triplicate experiments. Means with the same superscripts in the same row and columns are not significantly different at $p = 0.05$

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Wastewater generated from abattoir activities in Makurdi has been studied in a Laboratory-scale Waste Stabilization Pond (WSP). The influent wastewater pollutant parameters relevant for the effective design of the WSP were initially characterized considering seasonal variation; its performance is not expected to vary significantly throughout the year. The mean concentrations of each of the monitored contaminant were given, and it was observed that only E. coli, COD and TDS were found to be high compared to the standard set by USEPA (2002). Initial E. coli value was given as 13×10^{2} cfu, while it showed 0 cfu in the final effluent indicating 100% performance efficiency. The influent concentration of COD was 613mg/L and after the treatment it reduced to 148mg/L indicating 75.86% removal efficiency. Also, final TDS concentration has 2800mg/L as against 4800mg/L in the initial concentration. It took seven detention days in each of the pond to achieve these results. The system was however tested appropriately for treating influent abattoir wastewater to produce effluent that complies with recommended discharge standards without endangering the environment and public health. Statistical analysis carried out on the treatment showed significant improvement. Pollutant removal mechanisms occurring within the ponds are mainly attributed to sunlight and natural biological activities stimulated by algal photosynthesis. The system does not require special high technical skill to keep it functional with minimal operational cost and maintenance requirements.

4.2 Recommendations

Consequent upon this study, the following recommendations were made:

1. A hybrid system with other natural treatment systems such as Constructed Wetland as preliminary treatment is recommended to facilitate the removal efficiency.
2. Extending the detention time is necessary for effective performance.
3. Studying the system with Water Lettuce or other aquatic plant species found within our locality in the maturation ponds to see if it can improve the effluent quality.
4. The design specification is hereby recommended to be simulated on a pilot-scale to prove its true representation in further study.
5. The pond should also be designed to treat other influent from aquaculture and agricultural-based industrial influents for reuse in irrigation at the study area.

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