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The Dynamics of Solids Removal in Waste Stabilization Ponds

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Waste generation at Nigerian slaughterhouses poses a serious threat to the environment because of poor handling practices which results into adverse impact on land, air and water. The aim of this research is studying the dynamics of solid removal in waste stabilization pond at different hydraulics retention times (HRT). The characteristics of wastewater in Kwata slaughterhouse were 991 mg/l, 3427 mg/l and 4419 mg/l. For total suspended solids (TSS), total dissolved solids (TDS) and total solids (TS) respectively. The slaughterhouse wastewater was treated using waste stabilization pond which comprises one anaerobic pond, one facultative pond and one maturation pond. The physio-chemical analysis conducted at the end of the treatment, shows that the total suspended solids (TSS), total dissolved solids (TDS) and total solids (TS) in an effluent leaving the maturation achieved 97%, 92% and 93% removal efficiencies. The physio-chemical analysis results were also subjected to statistical analysis using one-way analysis of variance and two-way analysis of variance without replication. The results show the statistically significant difference exists in the quality of raw wastewater, effluent from anaerobic, facultative and maturation pond.

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1. INTRODUCTION

Pollution of environment by wastewater from slaughterhouse has exacerbated by accelerated human activities such as urbanization, industrialization and population needs for also proteins such as meats (because of high demand for food) and as such poses a serious environmental threat to sustainable development leading to potential environmental pollution [1]. Rapid growth of slaughterhouses has not only enhanced the productivity but also resulted in the production and release of toxic substances in the environment, creating health hazards. These wastewaters generated from slaughterhouse are potential pollutants that produces harmful effect if discharge untreated. The discharge of untreated wastewater into surface water bodies such as streams, rivers, lakes and oceans results in the pollution of such water environments [2,3]. In a typical Nigerian slaughterhouse, the surrounding land is often marshy due to improper channeling of wastewater arising from the dressing of the slaughtered animals and washings at the lairage. Land pollution also occurs when solid wastes such as bones, pieces of flesh and dung are left unattended in open spaces. When precipitation takes place, these wastes leave the land in a polluted state while part of it get washed into nearby streams. Most Nigerian slaughterhouses are situated close to surface water bodies in order to have access to water supply needed for slaughtered animal processing and to provide a sink for the run-off from meat processing activities [4]. Within a series of processes, slaughterhouses produce large amounts of different wastes and wastewaters. Human activities which lead to pollution of the environment and a disruption of ecosystem functionality contribute impurities in the form of industrial, domestic, agricultural, and chemical waste to the environment [5]. The term wastewater (WW) is defined as the spent or used water of a community or industry which contains dissolved and suspended matter and about 99% of which is liquid while the remaining 1% is solid waste. The composition of wastewater depends on the source of generation [6]. Slaughterhouses produce substantial amounts of wastewater containing high amounts of biodegradable organic matter, suspended and colloidal matter such as fats, proteins and cellulose [7]. Treatment of wastewater by means of biological processes has been widely implemented from urban to industrial wastewater (Seswoya et al. 2012). The meat processing sector produces large volumes of slaughterhouse wastewater due to the slaughtering of animals and cleaning of the slaughterhouse facilities and meat processing plants [8]. Slaughterhouse effluent is characterized by the presence of high concentration of slaughtered animal's blood and high suspended solids from rumen and stomach content, undigested food, feathers, flesh pieces and pieces of bone making it very strong [9]. The slaughterhouse wastewater is well suited for anaerobic treatment because of the presence of high concentration of biodegradable organics, alkalinity and adequate phosphorus. Anaerobic digestion provides high organics removal while producing recoverable source of energy in the form of methane. Excess nutrients or organic matter present in the effluent can cause the water body to become choked with organic substances and organisms. Slaughterhouse wastewater also contains insoluble and slowly biodegradable suspended solids. Increased suspended particulate matter can reduce light penetration into water body and might also alter benthic spawning grounds and feeding habitats [9]. When organic matter exceeds the capacity of the micro-organisms in water that break down and recycle the organic matter, it leads to eutrophication and encourages rapid growth or blooms of algae. Discharging slaughterhouse wastewater without treatment contributes to greatly degrading the aquatic environment. The problem of effective treatment of wastewater is more acute in underdeveloped or developing countries due to the high cost of conventional treatment systems and such treated or poorly treated wastewater eventually find its way to agricultural farm land which have deleterious long-term effect on soil, groundwater and human health (Abdullah 2018). Selection of proper treatment technology is needed in developing tropical and sub-tropical countries where the high cost of conventional treatment plants is not affordable [10]. The simplest method of slaughterhouse wastewater treatment is through the use of waste stabilization ponds. Waste stabilization pond technology is one of the most appropriate extensive wastewater treatment methods due to their low operation and maintenance costs coupled with effective pathogens removal. Waste stabilization ponds are biological treatment systems, which process and operations are highly dependent on the environmental conditions such as temperature, wind speeds and light intensity. The highly variable (or any given combination of these) environmental parameters is usually unique to a given location [11]. Waste stabilization ponds rely on lengthy detention times and environmental factors (wind, solar, radiation) for treatment efficiency. Waste stabilization ponds (WSPs) are usually the most appropriate method of domestic and municipal wastewater treatment in developing countries, where the climate is most favourable for their operation. WSPs are low-cost (usually least-cost), low-maintenance, highly efficient, entirely natural and highly sustainable. Edris et al. [12] used poly-aluminium chloride (PACL) in coagulating small particles of slaughterhouse wastewater into larger flocs that can be efficiently removed through subsequent separation process of either sedimentation or filtration he achieved 64% removal efficiencies for total suspended solids. Giri et al. [13] used Anaerobic fixed film fixed bed reactor packed with special media to treat slaughterhouse wastewater and at 0.8 OLR, 1 day HRT was able to reduce total suspended solids from 1484 mg/l to 120 mg/l. Tansengco et al. [14] treated slaughterhouse wastewater using ASBR and Activated Carbon as Post treatment and recorded a reduction of 53 mg/l in total suspended solids. Hadi et al. [15] achieved 78% removal efficiency in treatment of TSS in urban wastewater using waste stabilization pond. Abdel-rahman et al. [16] treated municipal wastewater using WSP and recorded percentage removal efficiency of 70% and 26% for TSS and TDS respectively. This research work is aimed at studying the dynamics of solid removal in waste stabilization pond at different hydraulic retention times.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The sample was collected from Kwata slaughter site located at Awka. Awka is the capital of Anambra State, Nigeria and shares shares the latitude of 6.07°N and 6.17°N and longitude of 7.00°E and 7.10°E. Awka is in the tropical rainforest zone of Nigeria and experiences two distinct seasons brought about by the two predominant winds that rule the area: the southwestern monsoon winds from the Atlantic Ocean and the northeastern dry winds from across the Sahara Desert. Awka temperature is generally 27℃ - 30℃ between June and December but rises to 32℃ - 34℃ between January and April, with the last few months of the dry season marked by intense heat (Nigeria Meteorology Agency, 2014).

2.2 Laboratory Setup and Wastewater Generation

A field scale prototype pond which comprises of anaerobic, facultative and maturation pond were designed and reduced to a laboratory-scale model using dimensional analysis. The laboratory-scale model was constructed and arranged serially in the Nnamdi Azikwe university civil engineering workshop, the anaerobic pond was positioned on a steel stand of 1.2 m high which was done to allow a free flow of slaughterhouse wastewater by gravity to facultative pond while the two ponds, facultative and maturation pond were positioned on a laboratory work bench. Samples of wastewater were collected from Kwata slaughterhouse on a daily basis and were sent to equalization tank before it passes through the model ponds at different hydraulic retention times. The physio-chemical experiments such as total suspended solids, total dissolved solids and total solids were performed at Civil Engineering Department Laboratory.

2.2.1 Total suspended solids

The Total suspended solid was obtained by subtracting the value obtained for total dissolved solids from that obtained for total solid and result expressed as milligram/litre (mg/l) for both controls and treated effluent samples. Equation (1) shows the calculation of total suspended solids.

$$Total\ Suspended\ Solids = TS - TDS \quad (1)$$

TSS is total suspended Solids mg/l
TS is total Solids mg/l
TDS is total dissolved Solids mg/l

2.2.2 Totals solids

Total solids include total suspended solids and total dissolved solids, 50 ml of wastewater sample was measured into a pre-weighed dish and evaporated to dryness at 103°C on a steam bath. The evaporated wastewater sample was dried, cooled in a desiccator and recorded for constant weight. Total solids are calculated using Equation (2)

$$Total\ solids = \frac{(A - B)\ X\ 1000}{Sample(ml)}\ mg/l \quad (2)$$

Where

A is weight of dish + residue mg and
B is weight of dish mg

2.2.3 Total dissolved solids

50 ml of sample was filtered through a whatman filter paper (Whatman GF/F 0.45 µm). Filtrate was allowed to evaporate to dryness, stored in desiccators to cool. Total dissolved solid was calculated using Equation (3).

$$Total\ Dissolved\ solids = \frac{(A - B)\ X\ 1000}{Sample\ (ml)} mg/l \quad (3)$$

Where

A is weight of filter + dried residue mg and
B is weight of filter mg.

3. RESULTS AND DISCUSSION

The percentage removal efficiencies of total suspended solids, total dissolved solids and total solids were presented from Figs. 1 to 3 and Tables 1 to 3.

3.1 Total Suspended Solids

These occurs naturally in surface water as a result of erosion, transport of material from the bottom of the river and tributory inflows, they are also added by industrial effluent example slaughterhouse wastewater discharged directly to the surface water without treatment. TSS are solids in water that can be trapped by a filter, the discharge of effluents with high TSS concentrations can cause sludge depositions and anaerobic conditions in the receiving water body [17]. The percentage removal efficiency of total suspended solids in waste stabilization pond at different hydraulic retention times are shown in Fig. 3 and Table 1.

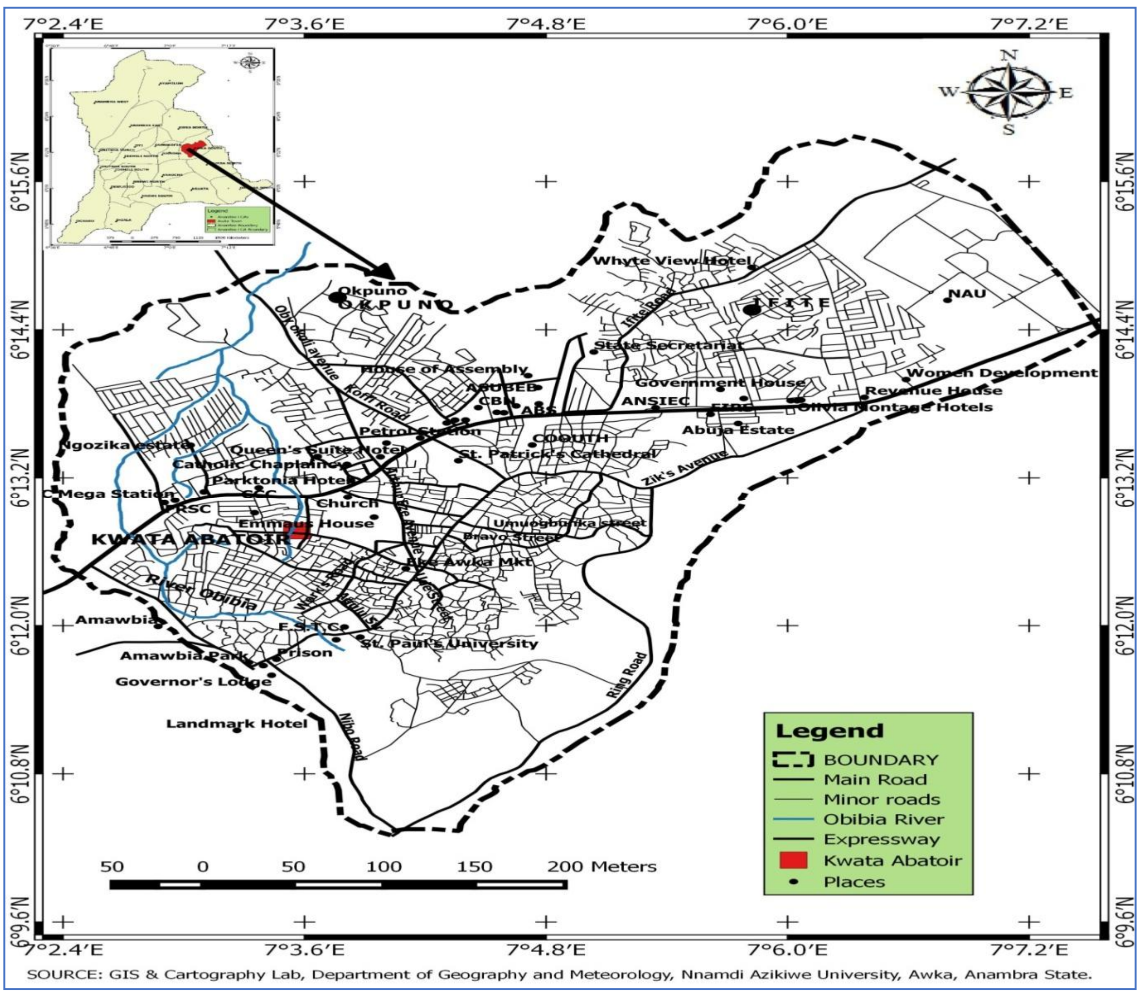

Fig. 1. Map of Awka

Table 1. Dimensions of laboratory scale models of waste stabilization pond

Description	Anaerobic pond	Facultative pond	Maturation pond
Volume (m^3)	0.30	0.09	0.07
Area (m^2)	0.19	0.35	0.35
Length (m)	0.75	1.03	1.02
Width (m)	0.24	0.34	0.34
Depth, actual (m)	1.67	0.25	0.19
Depth + freeboard (m)	1.72	0.3	0.21

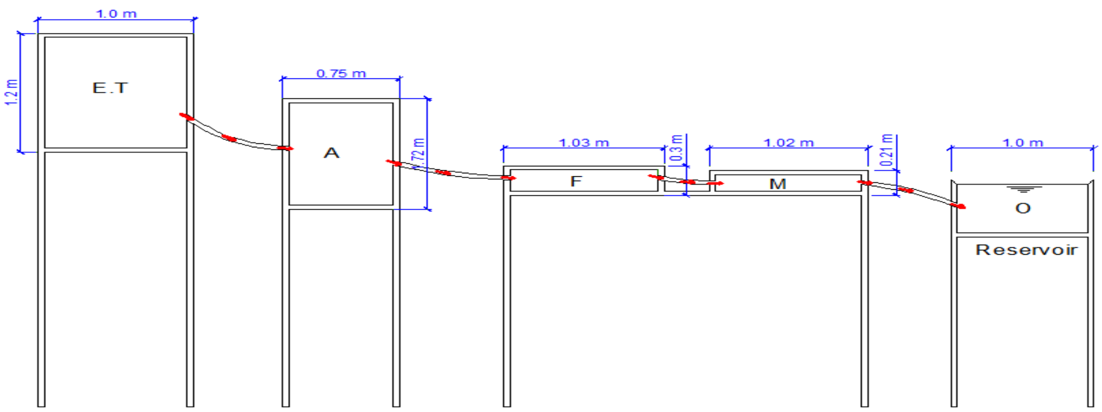

Fig. 2. Waste stabilization pond showing Equalization tank, Anaerobic pond and Facultative pond

Table 2. % removal efficiencies of total suspended solids in waste stabilization pond

Pond	5 days	10 days	15 days	20 days	25 days	30 days
Anaerobic pond (%)	88	89	91	92	86	91
Facultative pond (%)	92	93	93	93	91	93
Maturation pond (%)	93	94	94	96	97	97

The average value of the total suspended solids for slaughterhouse wastewater entering the anaerobic pond were 991 mg/l, 1121 mg/l, 1212 mg/l, 1297 mg/l, 1248 mg/l and 1269 mg/l for 5 days, 10 days, 15 days, 20 days, 25 days and 30 days hydraulic retention times which are in agreement with [18-22]; [8] Dipti et al. [23] but parallel with [24,25] the values of total suspended solids are much higher than the 50 mg/l set limit recommended by WHO for discharge, the high total suspended solids can be attributed to algal bloom that produces oxygen and appears as total suspended solids in wastewater effluent. At the end of the wastewater treatment, the percentage efficiencies of solids leaving the maturation for 5-30 days HRT were 99%, 97%, 98% 99%,99% and 99% respectively. These values are comparable with the study conducted by Hadi et al. [15] and Orumieh and Mazaheri, [26] which recorded an average removal efficiency of 78% and 87%. The sharp decline of Total suspended solids in wastewater effluent can be attributed to the high level of contamination of the wastewater, hence causing the quick sedimentation of heavier particles due to gravitational forces and further reduction of total suspended solids can also be attributed to the agglomeration of the finer suspended particles into larger and hence heavier particles which were also pulled to the base as a sludge, this agglomeration effect are probably as a result of flocculation effects of bacterial discharge in the waste stabilization pond, the activities of algae in facultative and maturation pond, bacteria in the decomposition of suspended organic matter and the effect of time on settling of fine suspended particles by gravity. Towards the end of slaughterhouse wastewater treatment, the Total suspended solids became steady throughout the remaining treatment time without any further reduction, this implies that the remaining suspended particles are very fine and will require coagulation process for further reduction.

3.2 Total Dissolved Solids

These are referred to any minerals, salts, metals, cations or anions dissolved in water, they comprise inorganic salts and some small amounts of organic matter that are dissolved in wastewater. The total dissolved solids (TDS) concentration is an important parameter of the water quality in agriculture since the productivity and the quality of plants depends on the soil salinity levels, which may be determined by irrigation. A high concentration of dissolved solids increases the density of dissolving water and reduces the solubility of oxygen gas, creating danger for aquatic life. TDS directly relates to the electrical conductivity that measures the ionizable constitutes in wastewater. The percentage removal efficiency of TDS in waste stabilization pond at different hydraulic retention times are presented in Fig. 4 and Table 2.

The average value of total dissolved solids in slaughterhouse wastewater entering the anaerobic pond were 3427 mg/l, 3033 mg/l, 3301 mg/l 3070 mg/l, 3038 mg/l and 2983 mg/l for 5 days, 10 days, 15 days, 20 days, 25 days and 30 days hydraulic retention times, these values are comparable with the study conducted by Ameen and Ahmed, [27] and are above the World Health Organization standard for discharge and as such necessitate treatment before they are discharged to the environment. At the end of the wastewater treatment the concentration of TDS in wastewater effluent leaving the maturation pond were 180 mg/l, 160 mg/l, 130 mg/l, 130 mg/l, 270 mg/l and 240 mg/l representing 95%, 95%, 96%, 96%, 91% and 91% removal efficiencies for 5 days, 10 days, 15 days, 20 days, 25 days and 30 days HRT. These values are within the 500 mg/l WHO standard for effluent discharge.

3.3 Total Solids

The average values of Total solids in slaughterhouse wastewater entering anaerobic pond were 4419 mg/l, 4154 mg/l, 4513 mg/l, 4366 mg/l, 4286 mg/l and 4252 mg/l, these values are lower than values recorded by Sunder and Satyanarayan, [22] and Dipti et al. (2015) but are higher than the study conducted by Ameen and Ahmed, [27] and above the 1000 mg/l World Health Organization standard for effluent discharge, as such wastewater treatment is

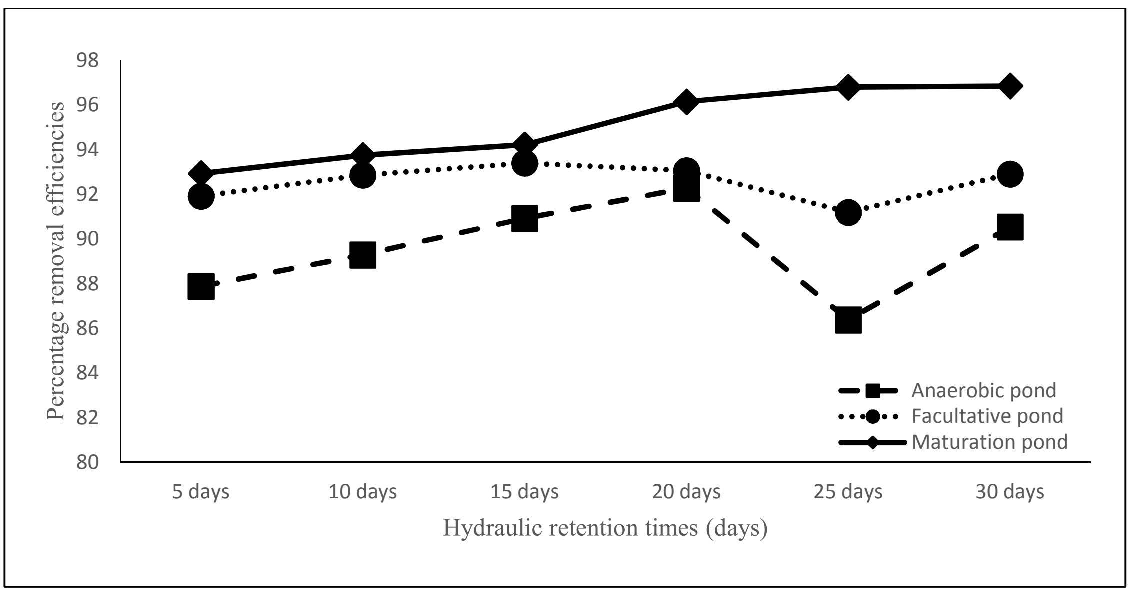

Fig. 3. Percentage removal of TSS in WSP at different HRT

Table 3. % removal efficiencies of total dissolved solids in waste stabilization pond

Pond	5 days	10 days	15 days	20 days	25 days	30 days
Anaerobic pond (%)	81	83	87	88	79	81
Facultative pond (%)	94	87	92	92	87	86
Maturation pond (%)	95	95	96	96	91	92

required before it can be safely discharged to the environment. Table 3 and Fig. 5 shows the percentage removal efficiencies of total solids in waste stabilization pond, after the wastewater treatment using waste stabilization pond, the value of total solids in an effluent exiting the maturation pond were reduced to 250 mg/l. 230 mg/l, 200 mg/l, 180 mg/l, 310 mg/l and 280 mg/l representing 94%, 94%, 96%, 96%, 93% and 93% removal efficiencies at 5 days, 10 days, 15 days, 20 days, 25 days and 30 days HRT. The total solids value in effluent leaving maturation pond after the treatment are generally below 1000 mg/l set by World Health Organization above which becomes significantly and increasingly unpalatable.

3.4 Statistical Analysis of Slaughterhouse Wastewater Parameters

Statistically significant difference between the raw wastewater, anaerobic, facultative and maturation pond results obtained ($p<0.05$) was observed using one-way analysis of variance and two-way analysis of variance without replication.

3.4.1 One-way analysis of variance (ANOVA)

One-way analysis of variance (ANOVA) conducted for Total solids, Total suspended solids and Total dissolved solids (Table 1), shows that statistically significant difference exists in the quality of raw wastewater, wastewater from anaerobic, facultative and maturation pond results obtained ($p<0.05$). The differences were much and agrees with the results of the percentage removal efficiency.

3.4.2 Two-way analysis of variance without replication (ANOVA)

Two-way analysis of variance without replication was conducted to examine the relationship of solids removal between the raw wastewater, anaerobic pond, facultative pond, maturation pond and their individual hydraulic retention times as shown in (Table 2).

The analysis of variance for two way without replication for total suspended solids in slaughterhouse wastewater conducted, shows a strong relationship between slaughterhouse raw wastewater, effluent from anaerobic pond, facultative pond and maturation pond, as the p-value obtained ($p = 0.0000000000000226$) shows that the total suspended solids in slaughterhouse wastewater depletes between pond this can be attributed to as agglomeration effect which are probably as a result of flocculation effects of bacterial discharge in the waste stabilization pond, the activities of algae in facultative and maturation pond, bacteria in the decomposition of suspended organic matter and

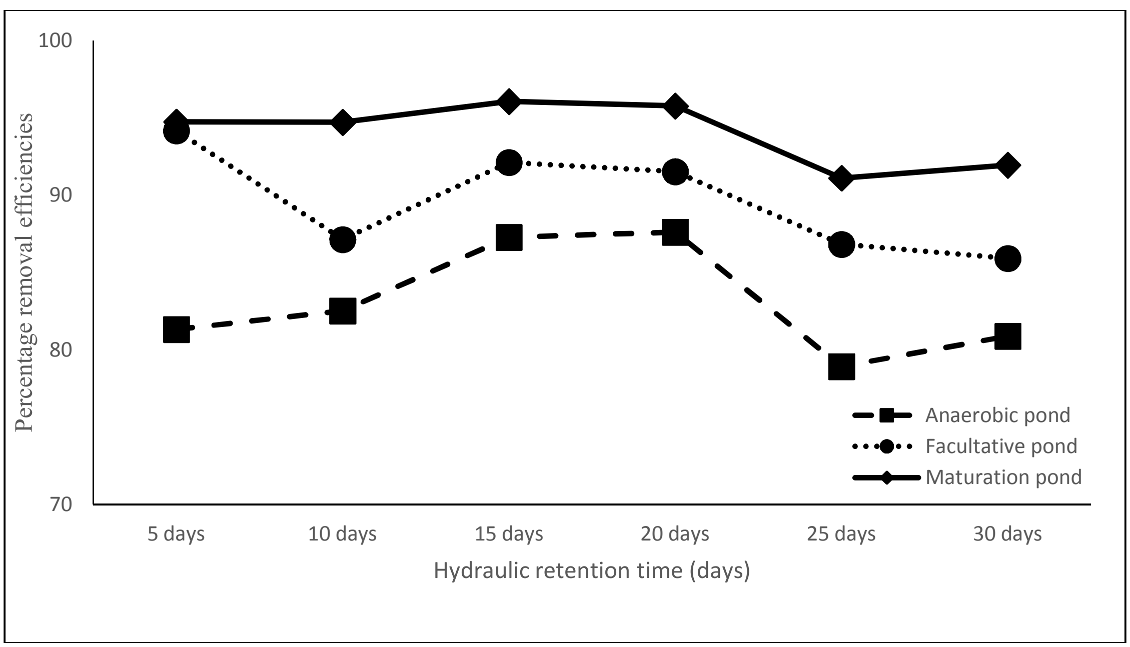

Fig. 4. Percentage removal efficiency of TDS in WSP at different HRT

Table 4. Percentage removal efficiencies of total solids in waste stabilization pond

Pond	5 days	10 days	15 days	20 days	25 days	30 days
Anaerobic pond (%)	83	84	88	89	81	84
Facultative pond (%)	94	89	92	92	88	88
Maturation pond (%)	94	94	96	96	93	93

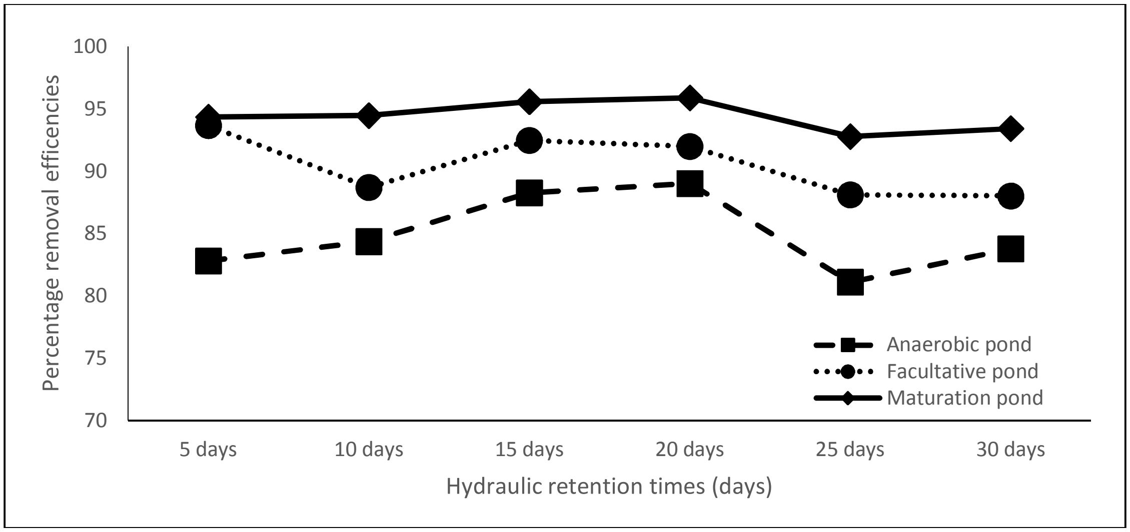

Fig. 5. Percentage removal efficiencies of TS in WSP at different HRT

Table 5. ANOVA results (One way) for 5 days to 30 days retention times for total solids, total suspended solids, total dissolved solids

Parameters	HRT (d)	F	p-value	F-critical
Total Solids (mg/l)	5	353.391	6.32×10^{-57}	2.685
	10	109.111	2.12×10^{-20}	2.816
	15	443.327	1.82×10^{-28}	2.866
	20	410.030	1.33×10^{-25}	2.901
	25	696.965	3.25×10^{-29}	2.901
	30	321.668	4.86×10^{-26}	2.866
Total Suspended Solids (mg/l)	5	278.226	9.80×10^{-52}	2.685
	10	66.079	2.47×10^{-16}	2.816
	15	445.112	1.69×10^{-28}	2.866
	20	400.002	1.96×10^{-25}	2.901
	25	773.844	6.26×10^{-30}	2.901
	30	223.147	2.63×10^{-23}	2.866
Total Dissolved Solids (mg/l)	5	339.047	5.12×10^{-56}	2.685
	10	499.595	5.47×10^{-34}	2.816
	15	232.432	1.31×10^{-23}	2.866
	20	311.482	9.48×10^{-24}	2.901
	25	340.952	2.34×10^{-24}	2.901
	30	454.489	1.17×10^{-28}	2.866

the effect of time on settling of fine suspended particles by gravity. It also that shows an appreciable treatment in waste stabilization pond and the results obtained between the hydraulic retention times (p = 0.81) failed significance test as the p-value obtained was > 0.05. Total dissolved solids were significantly removed in the ponds, this can be confirmed by (p = 0.0374). The total solids removal was not significant (p = 0.160) but significant differences exist between the hydraulic retention times this can be confirmed by (p = 3.39 x 10).

Table 6. ANOVA results (Two way without replication) for 5 to 30 days retention times for total suspended solids, total dissolved solids and total solids

Parameters	Variation source	F	p-value	F-critical
Total suspended solids	Columns (ponds)	0.44	2.26×10^{-14}	2.901
	Rows (HRT)	380.56	8.10×10^{-01}	3.287
Total dissolved solids	Columns (ponds)	3.18	3.74×10^{-02}	2.901
	Rows (HRT)	681.51	3.00×10^{-16}	3.287
Total solids	Columns (ponds)	1.86	1.60×10^{-01}	2.901
	Rows (HRT)	1242.81	3.39×10^{-18}	3.287

4. CONCLUSION

The discharge of untreated wastewater into surface water bodies such as the case of Kwata slaughterhouse in Awka, Anambra state results in the pollution of such water environments. The high level of solids in slaughterhouse wastewater from kwata slaughterhouse as obtained in this study revealed a very high contaminant, capable of endangering the environment and hazardous to human and animal health. Treatment of slaughterhouse waste using waste stabilization pond was able to achieve 99.05%, 97.57%, 98.66%, 98.88%, 99.19% and 99.23% removal efficiencies for total suspended solids, 94.75%, 94.72%, 96.06%, 95.77%, 91.11% and 91.95% removal efficiencies for total dissolved solids and 94.34%, 94.46%, 95.57%, 95.88%, 92.77% and 93.41% removal efficiencies for total solids at 5 days, 10 days, 15 days, 20 days, 25 days and 30 days hydraulic retention times respectively. One-way analysis of variance and two-way analysis of variance without replication shows that significant difference exits between the raw wastewater, anaerobic, facultative and maturation pond results except on total solids. The performance of the waste stabilization pond was found to be satisfactory in slaughterhouse wastewater solids removal.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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