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Atmospheric air pollution associated with macrophyte and algal-based wastewater stabilization ponds in Kumasi, Ghana.

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Abstract
Domestic wastewater treatment is strongly recommended for developing countries because of the high incidence of enteric disease and its associated high mortality rates. In Ghana, waste stabilization ponds have been recommended for urban centres. Macrophyte-based ponds have also been recommended because of their economic importance. The large scale environmental effects on air quality of these ponds are yet to be fully explored. The study was carried out by measuring the amount of hydrogen sulphide and ammonia volatised from the ponds 4 times in each month during the study. Sludge accumulation after 451 days of pond operation was also measured. The results showed that the ammonia and hydrogen sulphide concentrations in the air around the treatment plant where the pilot plant was mounted was above the WHO recommended guidelines. The study further showed that, the anaerobic pond had the highest production of ammonia and hydrogen sulphide. Sludge accumulation was also highest in the first ponds of each treatment system followed by the subsequent ponds in series. It is therefore recommended that operators of the treatment plants must be protected from the hydrogen sulphide and ammonia gases by planting odour absorbing plants as well as employing the appropriate nose masks.

Keywords
Macrophytes — ammonia — hydrogen sulphide — sludge accumulation

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Introduction

Sanitation for urban and rural centres in developing countries is now very critical in view of the current rapid population growth. The WHO [1] report showed that, in developing countries, only 67% of the combined urban population had adequate facilities for excreta disposal. In the rural areas, however, only 19% had adequate excreta disposal facilities [2]. However, some of these existing sanitation facilities and technologies are not suitable for developing countries since they are expensive to construct. In addition, these facilities are not only complex and difficult to maintain, they are also hardly accessible.

It has been reported previously Awuah et al.[3] that, only about 55% of the Ghanaian population have access to adequate sanitation facilities. Also, most of the wastewater treatments constructed in the late 1960's have broken down due to the high cost of maintenance. The development of wastewater treatment technologies is on one hand towards high technological fields and on the other, substantially towards low-cost, energy saving, easy operation and maintenance aspects [4]. This means that more of these low-cost technologies would be needed in the near future to address the wastewater generated in the urban centres.

As in the latter case, wastewater stabilization pond (WSP) has great reputation for its low capital investment, less energy consumption and operation cost and therefore has found great application in municipal and industrial wastewater treatment. According to statistics, there exist over 7,000 WSP in the U.S

[5] and more than 3,500 in Europe distributed in 16 countries still in use and the numbers keep escalating. WHO [1] described WSP as the cheapest and simplest of all treatment technologies and as s result capable of providing high quality effluent. Several researchers including Lansdell [6] and Polprasert [7] recommend WSP as the best option for liquid waste treatment in developing countries.

Wastewater stabilization ponds are undoubtedly the most widely applicable and advantageous methods of waste treatment in hot climates. With these high temperatures, ponds are the cheapest, simplest of all treatment technologies and capable of providing high-quality effluent. They are easy to maintain, require no routine operation, able to absorb organic load shock and are flexible systems which can be extended to new capacity. Its greatest disadvantage is space. In a hot and sunny area one might estimate that a total area of 0.3 – 0.4 ha/1000 persons is required [8].

Mara et al. [9] have studied algal-based WSP extensively and recommended same. Metcalf and Eddy [10], however recommend the use of macrophyte-based WSP since the macrophytes can be put to other uses like production of fish, preparation of feed compost after being used in the stabilization ponds.

Currently, the Kumasi Metropolitan Assembly has three ponds in operation, all very close to residential areas while others are still under construction. Macrophyte-based technologies are gaining recognition worldwide as a result of resource recovery. In accordance with Ghana EPA [11] guidelines, the introduction of a new technology into Ghana must be assessed to know the suitability and its environmental impacts. A technological feasibility study is therefore relevant to ensure that it does not encounter the same problems of other technologies in the country. It is in the light of this that studies aimed at the determination of the extent of air pollution that characterise these pond system prior to nation-wide construction. I this present study, we sought to investigate some gaseous pollutant markers produced by these waste stabilization ponds as well as the amount of sludge accumulation and how these affects the air quality.

1. Materials and Methods

1.1 Study Area

Kumasi, within the Ashanti Region of Ghana was chosen for this study.

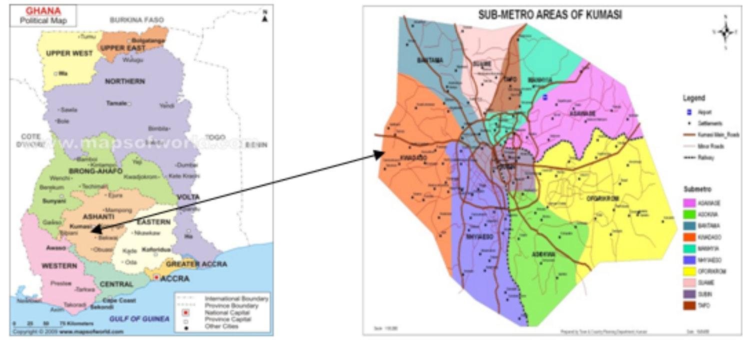

Figure 1. A map of Ghana (Left) showing Kumasi within the Ashanti Region of Ghana

1.2 Baseline Study

Air samples were taken from the atmosphere to determine the level of H_2S and NH_3 present. This was to serve as baseline data which indicates the level of pollution in the atmosphere.

1.3 Determination of Hydrogen Sulphide

Silicon tubes were connected from pressure pump into the ponds. Plain polythene sheets were used to cover the ponds, air-tight. The tubes were inserted into the containers but did not touch the surface of the wastewater.

The gas was siphoned into iodine solution (5-15ml). The colour of the iodine faded depending on the level of hydrogen sulphide present. The sample solution was taken to the laboratory and titrated against 0.025N $Na_2S_2O_3$ with starch as indicator [12]. 1ml 0.025N iodine solution reacts with 0.4mgS^{2-} from formula (A-C) x 0.4mg

mg S^{2-}/m^3 of air = $\frac{(A-C)\times 0.4}{m^3 of air \times 24}$ for 24hours

Where:

A = ml of iodine solution

C = ml of $Na_2S_2O_3$ solution

m^3 of air pumped = 0.199

1.4 Determination of Ammonia

The same procedure used in the hydrogen sulphide determination was applied but the reagent used was boric acid. 50ml of the boric was used to trap the gas which turns the pale lavender colour to green depending on the amount present in the wastewater. 0.02N H_2SO_4 was used for the titration until the original colour was obtained [12].

mg NH_3 -N/m^3 of air = $\frac{(A-B)\times 280}{m^3 of air \times 24}$ for 24h

Where:

A = Volume of H_2SO_4 titrated for sample ml

B = Volume of H_2SO_4 titrated for blank ml

m^3 of air pumped= 0.199

1.5 Sludge Accumulation

A graduated glass cylindrical tube of ten-millimetre diameter was sunk slowly into the pond till it touches the bottom and gets filled with sewage in exact layers as in the pond. The lower end was blocked with the thumb and pulled out, the lower end was then blocked with another thumb without spilling. The height of sludge in the cylinder represented the height of sludge in the pond. The volume was then calculated knowing the dimensions of the pond. The sludge measurement was done at five different positions in the pond. This procedure was then repeated for all the ponds in the treatment systems.

2. Results

2.1 Sulphide Volatilisation

The anaerobic pond recorded the highest sulphide value(i.e. 1.231mgm^{-3}/day). This decreased from the first, second, third and fourth series ponds. The data collected between November and December had the highest average sulphide (0.624mgm^{-3}/day) with that in January giving the lowest (0.51mgm^{-3}/day). There was no significant difference among the three treatment ponds. However, there was a significant difference between the values recorded between the anaerobic pond and all the three treatment systems, Figure 2. Unlike sulphide, the anaerobic pond did not produce the highest amount of ammonia as shown in Figure 3. The level of ammonia decreased from pond1 to pond 4.The algae pond recorded the highest average ammonia (0.008-0.403 mgm^{-3}) than the macrophyte ponds (0.001-0.14 mgm^{-3}). Pistia pond had a lower level of ammonia than the duckweed pond. There was no significant difference among the ponds ($p>0.05$).

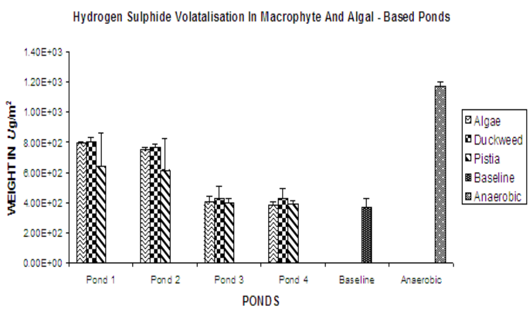

Figure 2. Average Sulphide in the ponds

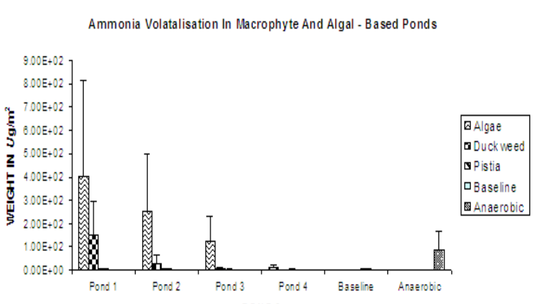

Figure 3. Average Ammonia released from the ponds in 24 hrs

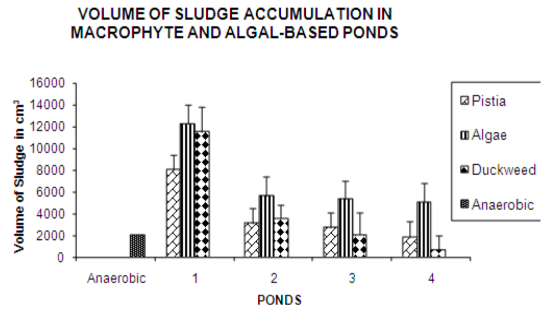

Figure 4. Volume of sludge accumulation in macrophyte and algal – based ponds

2.2 Sludge accumulation

The mass and composition of the bottom sludge formed in the waste stabilization pond were evaluated after the pilot scale pond had been in operation for 451days and about 13.53m^3 of digested wastewater had been treated. The rate of sludge accumulation in all the ponds calculated in Table 1, stands as a model for the design for stabilization ponds. Results of the study showed that, critical values occurred in the first algae with a value of 10.64cm^3 per day each. Sludge accumulation was highest in the algae pond, as shown in Figure 3 measuring 12.30 cm^3 representing 17.58% of the pond or 0.28% per unit volume discharged through the pond. This was followed by duckweed measuring 11.52 cm^3 representing 16.46% in the pond or 0.26% per unit volume discharged through the pond. The pistia pond measured 8.04 cm^3 representing 11.48% of the pond or 0.22% per unit volume discharged through the pond. Sludge accumulation in the ponds decreased in series from pond 1 through to pond 4. The pistia pond had 3.17cm^3, 2.76 cm^3, and 1.90 cm^3 in ponds 2, 3 and 4 respectively making up 4.52%, 3.94% and 2.71% of the pond or 0.07%, 0.06% and 0.04% of every unit volume of sewage discharged. The algal pond had 5.65 cm^3, 5.32 cm^3, and 5.1 cm^3 in ponds 2, 3, 4 respectively making up 8.07%, 7.61% and 7.29% of pond or 0.13%, 0.12% and 0.12% of every unit volume of sewage discharged.

The duckweed ponds had 3.6 cm^3, 2.11 cm^3, and 0.6 cm^3 in ponds 2, 3, 4 respectively that represents 5.14%, 3.02% and 0.90% of ponds or 0.08%, 0.06% and 0.01% of every unit volume of sewage discharged. Sludge accumulated in the pistia ponds was comparatively smaller than the algae and duckweed ponds. Sludge accumulation decreased in series in all treatment systems.

Table 1. Percentage of Sludge Accumulation

	PISTIA	ALGAE	DUCKWEED	ANAEROBIC
POND 1	11.48	17.58	16.46	2.98
POND 2	4.52	8.07	5.14	-
POND 3	3.94	7.61	3.02	-
POND 4	2.71	7.29	0.9	-

3. Discussions

The highest average sulphide concentration in the anaerobic pond was (1.23mg m^{-3}, 24h). The maximum sulphide concentration obtained in an anaerobic pond by Genschow et al. [13] in a tannery wastewater was 1.6mgm^3, 24h. This is because in the anaerobic pond, sulphate is converted to sulphide at the bottom of the pond. The concentration of sulphide obtained in all the ponds facultative and maturation ponds for both the algae and macrophyte ponds ranged from 0.687-0.838mgm^{-3}, 24hrs, which were also high. The values recorded in the aerobic ponds were generally lower than those in the facultative and maturation ponds due to the decrease in organic load. The lowest concentration of 0.285mgm^{-3}, 24hrs observed in the surroundings (baseline) was twice as much as the WHO [14] ambient hydrogen sulphide concentration of 0.15mgm^{-3}, 24hrs.The average baseline value was high because the samples were taken close to the treatment site which usually gave off odour.

The duckweed ponds recorded the highest sulphide level because of the coverage of the surface of the pond by the fronds thus reducing oxygen dissolution in the pond. This was observed in the amount of dissolved oxygen (DO) levels which were present in the ponds profiles. The algae ponds had high amount of dissolved oxygen in the pond but sludge accumulations could cause sulphur-reducing bacteria to convert sulphate to sulphide. The Pistia ponds recorded the lowest sulphide level but this cannot be properly explained. In the algal ponds, ammonia transformation occurs through stripping to the atmosphere or assimilation into bacterial plant nitrification. Algae use ammonia and so eliminate an oxygen demand normally inherent in the bacteria nitrification of ammonia to nitrite and nitrate [15]. The algae pond gave the highest ammonia volatilization due to increased pH in the ponds. As dissolved oxygen and pH increases due to diurnal changes, there is a conversion of ammonium into ammonia, which is released into the atmosphere. The macrophyte ponds showed lower ammonia volatilization because of the plant cover which results in lower pH in the pond and thus enhanced the conversion of ammonia into ammonium.

The sludge accumulation was highest in the algae ponds followed by the duckweed and pistia ponds. This is due to algal cells which periodically fall to the bottom of the ponds either because of attachment or agglomeration and death of the algal cells. The hydrogen sulphide in the algae pond was due to this sludge accumulation. Large amounts of algae contributed to the total suspended solids and thus sludge accumulation. The macrophyte ponds showed lower sludge accumulation because the roots provide sites for attachment for micro-organisms and other suspended materials and are frequently removed through harvesting. In a related study it was observed that the macrophyte ponds had lower sludge accumulation than the algal ponds [3].

4. Conclusion

All the three ponds systems did not show any significant differences in terms of the hydrogen sulphide produced. There was no significant difference among the ponds in terms of ammonia production as well. The macrophyte ponds had lower sludge accumulation than the algae pond. The pistia pond provided the lowest sludge accumulation due to the high attachment on surface provided. It can thus be concluded from this research that the duckweed pond presents a better treatment option than the others. Duckweed especially Spirodela polyrrhiza should be considered in the treatment of domestic wastewater in Ghana since it has other agricultural uses which can be beneficial to the nation.

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