PERFORMANCE OF THE AKOSOMBO WASTE STABILIZATION PONDS IN GHANA

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Abstract
A study was conducted to determine the treatment performance of the Akosombo waste stabilization ponds and the effect of seasonal changes on the final effluent quality. The waste water quality parameters adopted to determine the treatment performance were suspended solids (SS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia, faecal coliform and trace metals. The ponds achieve SS, BOD and COD removals of about 84, 77 and 71 per cent, respectively. The ammonia removal was as high as 93 per cent whilst the faecal coliform removal was 99.99 per cent. The trace metal levels (Pb, Zn, Cd and Cr) of the final effluent were all low and insignificant (below the detection limit of < 0.01 mg l

Résumé
HODGSON, I. O. A.: Résultats de bassins de stabilisation du déchet d’ Akosombo du Ghana. Une étude était entreprise pour déterminer le résultat de traitement de bassins de stabilisation du déchet d’ Akosombo et l’ effet de changement saisonnier sur la qualité d’ effluent final. Les paramètres de la qualité des eaux usées adoptés pour déterminer les résultats de traitement étaient les flottants (SF), la demande pour l’oxygène biochimique (DOB), la demande pour l’oxygène chimique (DOC) l’ ammoniac, le coliforme fécal, et les oligoéléments. Les bassins atteignent les enlèvements de SF, DOB et DOC respectivement d’ environ 84, 77 et 71%. L’ enlèvement d’ ammoniac était aussi élevé qu’environ 93% alors que l’enlèvement de coliforme fécal était 99.99 %. Les niveaux d’ oligoéléments (Pb, Zn, Cd et Cr) de l’effluent final étaient tous faibles et non significatif (au-dessous de la limite et recherche de < 0.01 mg l

The study revealed that the seasonal changes influenced the quality of the final effluent. The final effluents in the rainy season were less polluted than those of the dry season which may be due to the dilution of the effluent by rain water. The study showed that the quality of the final effluent would not have any adverse effect on the lower Volta river that it is discharged into. The large volume of water available in the lower Volta river is adequate to dilute the final effluent entering it from Akosombo waste stabilization ponds. The mosquito nuisance usually associated with pond systems was absent because of the high fish proliferation in the ponds. A statistical model developed to predict the BOD of the raw sewage was significant at both confidence intervals of 95 and 99 per cent. Under Ghanaian conditions, the waste stabilization ponds system has been found to be more reliable than the other conventional systems, i.e., activated sludge and trickling filter system. The trend now is to adopt the waste stabilization ponds system as an appropriate sewage treatment system in areas where land is available in the country.

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A statistical model developed to predict the BOD of the raw sewage was significant at both confidence intervals of 95 and 99 per cent (R² = 0.8428, F calculé = 37.5, p (F > 3.74) = 0.05 et p (F > 6.51) = 0.01) and thus the model developed is not by chance. Under Ghanaian conditions the waste stabilization ponds system has been found to be more reliable than the other conventional systems, i.e., activated sludge and trickling filter system. The trend now is to adopt the waste stabilization ponds system as an appropriate sewage treatment system in areas where land is available in the country.
**Introduction**

Highly polluted waste water negatively impact on receiving water bodies. Some of the possible adverse effects of wastewater on receiving water bodies include loss of fish life, high levels of sludge deposition, creation of septic conditions and odours produced from anaerobic reactions that may occur at the bottom of the receiving water body, increased water treatment cost, eutrophication and eventual loss of water resources (Mara, 1981). Wastewaters with high levels of faecal coliforms have the potential of causing health problems to the people who come in direct contact with the receiving water body.

In developing countries, the most preferred wastewater treatment system is that which is able to treat the wastewater to meet the recommended physical, chemical and microbiological guidelines at a low cost with minimum operational and maintenance requirements. Waste stabilization ponds are becoming popular for treating wastewater in tropical and subtropical regions because of the abundant sunlight and high ambient temperatures. In Europe waste stabilization ponds are very widely used for small communities (Boutin et al., 1987; Bucksteeg, 1987). In the United States one third of all wastewater treatment plants that usually serve populations up to 5000 are waste stabilization ponds (EPA, 1983).

Waste stabilization ponds are basically shallow man-made basins comprising a single or several series of anaerobic, facultative or maturation ponds. The primary treatment usually takes place in the anaerobic pond which is mainly designed for removal of suspended solids, and some of the soluble organic matter. Most of the remaining BOD is removed through the coordinated activity of algae and heterotrophic bacteria in the facultative ponds. The main function of the maturation pond is the removal of pathogens and nutrients (especially nitrogen). Since the waste stabilization ponds are exposed to the atmosphere all year round, the changes in the seasons or weather conditions could influence the quality of the treated effluent and as such the performance. The diurnal variation has been shown to influence the quality of the final effluent (Hodgson, 2003). The objective of the study was to determine the treatment performance of the Akosombo waste stabilization ponds, the effect of seasonal changes on the quality of the final effluent and develop a statistical model for prediction of the raw sewage BOD levels.

**Experimental**

*Study area*

Akosombo is located in the Eastern Region of Ghana. It has a population of about 16,000 people. The mean ambient temperature rainfall and humidity for March were 29.4 °C, 90.2 mm and 72.4 per cent, respectively, whilst for June they were 26.8 °C, 188.3 mm and 83.8 % respectively. The months of March and June, during which the samples for seasonal changes were taken, fell within the dry and rainy season, respectively. The dry seasons at Akosombo are usually sharp and pronounced.

The Volta River Authority (VRA) was established under the Volta River Development Act (Act 46 of 1961) as a corporate body, and it constructed the Akosombo township to provide accommodation for its employees working on the Hydro-electric dam plants at Akosombo and Kpong. The waste stabilization ponds were constructed to help in the storage, treatment and disposal of liquid waste generated in the township and to ensure good environmental health. The ponds were constructed and commissioned in April, 1993 to replace a trickling filter plant.

*Akosombo waste stabilization ponds*

Akosombo waste stabilization ponds consist of two ponds, namely primary facultative and maturation ponds as shown in Fig.1. The ponds consist of two serially connected basins with concrete embankments (WRRI, 1994). There are three inlet points to the first pond. These represent
influents from three different parts of the township. The sewage enters a retention chamber and then flows by gravity into the pond at two of the inlet points. The third flows by gravity. The rags, tissues, etc. are removed from the raw sewage by a screen in the retention chamber before it enters the ponds. The dimensions of the ponds are given in Table 1. The discharge rate of the treated effluent is about 1000 m³/day.

For the evaluation of the treatment performance of the waste stabilization ponds, grab samples of raw sewage, facultative pond effluent and maturation pond effluent (final effluent) were taken on a weekly basis for a period of 6 weeks before 10:00 a.m. For the effect of seasonal changes on the final effluent, grab samples of both the raw sewage and the final sewage were taken on a 2-hourly basis for a period of 8 h, between 0800 and 1700 h on a particular day in March (dry season) and a particular day in June (rainy season), respectively.

The temperature, pH and conductivity were

![Fig. 1. Akosombo waste stabilization ponds.](image)

| Pond                          | Area (ha) | Depth (m) | Retention (day) |
|-------------------------------|-----------|-----------|-----------------|
| Primary facultative pond      | 9.6       | 1.7       | 24              |
| Maturation pond               | 2.5       | 0.8       | 3               |

TABLE 1
Dimensions of the waste stabilization ponds
measured in-situ. Standard methods for the examination of water and wastewater (APHA, 1998) were adopted for the laboratory analyses. All the equipment for the bacteriological sampling was sterilized. The samples were immediately stored in an ice-chest and transported to the CSIR-WRI laboratories for analysis. Table 2 shows the wastewater quality parameters and the various analytical methods employed for the analysis.

**Results and discussion**

**Evaluation of the treatment performance of the sewage ponds**

The treatment performance of the ponds was assessed based on the following wastewater quality parameters:

- suspended solids (SS) removal
- organic matter removal (BOD, COD)
- ammonia removal
- micro-organisms removal; and
- metal ion removal

**SS removal**

The discharging of effluents with high levels of SS can cause sludge deposition and create anaerobic conditions in the receiving water body. The SS concentration of the raw sewage ranged from 46.0 to 204.0 mg l$^{-1}$ with a mean value of 86.3 mg l$^{-1}$ (Table 3). The SS of the treated effluent ranged from 12.0 to 16.0 mg l$^{-1}$ with a mean value of 14.2 mg l$^{-1}$. The mean overall SS removal efficiency of the pond system was 83.5 per cent which is significantly high. All the SS concentrations of the final effluent were satisfactory compared to the Ghana Environmental Protection Agency (EPA) guideline value of 50 mg l$^{-1}$. About 80 per cent of the SS present in the raw sewage was removed in the primary facultative pond, and the rest in the maturation pond.

**Organic matter removal**

**BOD removal.** Effluents with high concentration of BOD can cause depletion of natural oxygen resources which may lead to the development of septic conditions in the receiving water body. The BOD removal and the consequent quality of the effluent depend on the amount of oxygen present, retention time and temperature of the ponds. The BOD levels of the raw sewage ranged from 40.0 and 90.0 mg l$^{-1}$ with a mean value of 55.8 mg l$^{-1}$

### Table 2

Wastewater parameters and the analytical methods employed for determination

| Parameter                  | Method employed and detection limit                                                |
|----------------------------|----------------------------------------------------------------------------------|
| Temperature                | Mercury in glass thermometer, > 0.5 °C                                            |
| pH                         | Gallenkamp pH meter, >1 unit                                                      |
| Conductivity               | Jenway model 4020 conductivity meter, >1 µS/cm                                     |
| Suspended solids           | Gravimetric method, > 1 mg l$^{-1}$                                               |
| Ammonia-Nitrogen           | Ion Chromatograph, > 0.005 mg l$^{-1}$                                           |
| Nitrate- Nitrogen          | Ion Chromatograph, > 0.005 mg l$^{-1}$                                           |
| Phosphate – Phosphorus     | Ion Chromatograph, > 0.005 mg l$^{-1}$                                           |
| BOD                        | Dilution/dissolved oxygen after 5 days incubation at 20 °C, > 0.1 mg l$^{-1}$     |
| COD                        | Potassium dichromate reflux method, >5 mg l$^{-1}$                               |
| Total coliform             | Membrane filtration method, > 0 counts/100 ml                                    |
| Faecal coliform            | Membrane filtration method, > 0 counts/100 ml                                    |
| Heavy metals (Cu, Cd, Ni, Zn, Cr) | Atomic absorption spectrophotometry, Cu > 0.020 mg l$^{-1}$, Cd > 0.002 mg l$^{-1}$, Ni > 0.010 mg l$^{-1}$, Zn > 0.005 mg l$^{-1}$, Cr > 0.010 mg l$^{-1}$ |
whilst that of the treated effluent ranged from 8.0 to 14.5 mg l\(^{-1}\) with a mean value of 12.8 mg l\(^{-1}\). The strength of the raw sewage could be considered as weak (Mara, 1976). The mean overall BOD removal efficiency was 77 per cent which is high and comparable to other waste stabilization ponds which give BOD removal efficiencies greater than 70 per cent (Arceivala, 1981). The mean overall BOD removal included the algal BOD. About 64\% of the BOD is removed in the primary facultative pond.

Abis (2002) reported BOD removal range between 67.5 and 98.6 per cent with a mean of 91 per cent for pilot scale facultative ponds in the United Kingdom. Generally, high proportion of the BOD that does not leave the facultative pond as methane ends up as algal cells. With the removal of algal and other solids from the effluent, the BOD removal range was found to be 89.7 to 99.7 per cent with a mean of 97.3 per cent (Abis, 2002). All the measured BOD levels were low and acceptable compared to the EPA guideline values of 50 mg l\(^{-1}\). The mean BOD to ammonia to phosphate ratio, for the raw sewage, was 150:24:1. The suitable ratio of BOD to ammonia to phosphate for microbial growth is about 100:3:1 (Hammer & Hammer Jnr, 2001) indicating that the ammonia concentration required by the organisms for the biological breakdown of the sewage was about five times in excess.

**COD removal.** The COD levels for the raw sewage were between 91.0 and 317 mg l\(^{-1}\) with a mean of 176 mg l\(^{-1}\), whilst the final effluent COD level ranged from 32.6 to 79.0 mg l\(^{-1}\) with a mean of 51.9 mg l\(^{-1}\). The mean overall COD removal was calculated to be 70.6 per cent which is appreciable. The primary facultative pond achieved a mean COD removal of 69 per cent. The ratio of the mean BOD to COD for the raw sewage was 0.32, which indicates a medium level of biodegradability. All the measured COD levels for the final effluent satisfied the EPA guideline values.

**Nutrient removal**

Wastewaters with high nutrient levels can cause undesirable phytoplankton growth in the receiving water body. The ammonia concentration of the raw sewage ranged from 4.8 to 18.3 mg –l\(^{-1}\)
with a mean value of 9.0 mg l\(^{-1}\). The ammonia concentrations of the final effluent were between 0.15 and 1.51 mg l\(^{-1}\) with a mean value of 0.61 mg l\(^{-1}\). The mean ammonia removal efficiency was 93.1 per cent which is appreciably high (Hodgson, 2000). Total nitrogen removal in waste stabilization system could be as high as 95 per cent. The facultative pond achieved a mean ammonia removal of about 74 per cent. The mean ammonia concentration of the final effluent was found to be satisfactory compared to the EP\(_A\) guideline value of 1 mg l\(^{-1}\).

**Micro-organism removal**

The factors that influence coliform removal in both primary facultative and maturation ponds include retention time, temperature, pH and light intensity. The total coliform levels of the raw sewage were between 229,000 to 38,000,000 counts/100ml with a mean of 7,700,000 counts/100 ml. The total coliform levels of the final effluent ranged from 290 to 179,000 counts/100 ml with a mean value of 44,000. The total coliform removal efficiency was 99.43 per cent. The faecal coliform level of the raw sewage ranged from 19,000 to 17,400,000 counts/100 ml with a mean of 3,450,000 counts/100 ml, whilst the faecal coliform level of the final effluent ranged from 40 to 900 counts/100 ml with a mean value of 350 count/100 ml.

The mean faecal coliform removal efficiency was 99.99 per cent which is significantly high. Most of the total coliform (98.8%) and faecal coliform (98.4%) were removed in the primary facultative pond. Waste stabilization ponds usually give such high micro-organism removal efficiencies. Arciivala (1981) reported that the die-off rate of the micro-organisms was accelerated when the pH of the pond water was greater than 9.3 units. Hodgson & Larmee (1998) showed that there was no coliforms present in final effluent from a maturation pond with pH above 10.7 units. Compared to the EPA guideline value of 0 counts/100 ml, the faecal coliform levels of the final effluent were unsatisfactory.

**Metal ion removal**

Moshe (1972) reported that high concentrations of metal ions (Cd, Cu, Ni, Zn and Cr) adversely affect pond efficiency. However, pH levels higher than 8 cause metal ions to precipitate and allow pond purification process to occur normally. The pH range for the final effluent was between 7.7 and 9.1 units. Polprasert & Champratheep (1989) showed that adsorption of metals was increased in attached growth stabilization pond as compared to stabilization ponds without attached growth. The metal ion concentration of the raw sewage for Cd (< 0.002-0.008 mg l\(^{-1}\)), Zn (0.010-0.021 mg l\(^{-1}\)), Pb (< 0.005 mg l\(^{-1}\)) and Cr (< 0.01 mg l\(^{-1}\)) were generally low. Also, the Cd (< 0.002 mg l\(^{-1}\)), Zn (< 0.005 mg l\(^{-1}\)), Pb (< 0.005 mg l\(^{-1}\)) and Cr (< 0.01 mg l\(^{-1}\)) concentrations in the final effluent were below the detection limit and, thus, satisfactory when compared to the EPA guideline values.

**Effect of seasonal changes on the final effluent**

The temperature of the final effluent for March ranged from 29.9 °C to 31.7 °C with a mean of 30.9 °C (Table 4), whilst the range for the rainy season (June) ranged from 28.4 to 30.3 °C with a mean of 29.6 °C, indicating a slightly higher mean temperature for March compared to that of June. This was expected since the ambient mean air temperature for March (29.4 °C) was higher than that of June (26.8 °C). However, the temperatures of the final effluent were both higher than their corresponding ambient temperatures.

The temperature variation for both the rainy and dry seasons was minimal. The pH of the final effluent, for both the dry and rainy seasons, were between 7.25 and 9.01, and 7.69 and 9.06, respectively. The conductivity gives an indication of the amount of dissolved minerals present in the solution. The conductivity of the final effluent for March ranged from 157-290 μS cm\(^{-1}\) with a mean of 224 μS cm\(^{-1}\), indicating low amount of dissolved mineral salts in the raw sewage. The conductivity of the final effluent for June was...
between 195 to 210 $\mu$S cm$^{-1}$ with a mean of 204 $\mu$S cm$^{-1}$. The conductivity of the final effluent in March varied more than that of June. The suspended solids concentration for both March and June ranged from 13.0 to 20.0 mg l$^{-1}$ and from 6 to 38 mg l$^{-1}$, respectively. Their corresponding means were 15.8 and 22 mg l$^{-1}$. The means of the suspended solids for June were far higher than that of March. The increase in suspended solids may be due to erosion of soils nearby into the ponds caused by the rains.

**Organic matter**

The BOD levels in March ranged from 10.2 to 15.0 mg l$^{-1}$ with a mean of 11.9 mg l$^{-1}$, whilst the BOD levels in June ranged from 5.5 to 9.5 mg l$^{-1}$ with a mean of 7.7 mg l$^{-1}$. The BOD levels in June were lower than those in March which may be due to the diluting of the final effluent by the rains. The mean rainfall for June (188.3 mm) was higher than that of March (90.2 mm).

**Nutrients**

The ammonia, nitrate and phosphate levels provide an indication of the nutrient content of the final effluent. The ammonia level for March was between 0.63 and 1.11 mg l$^{-1}$ with a mean of 0.87 mg l$^{-1}$, whilst the ammonia level for June ranged from 0.4 to 0.8 mg l$^{-1}$ with a mean of 0.6 mg l$^{-1}$. The nitrate concentration for both March and June ranged from 0.41 to 0.99 mg l$^{-1}$ and 0.59 to 0.97 mg l$^{-1}$, respectively. Their respective means were 0.73 and 0.74 mg l$^{-1}$ which are close. The phosphate level for March ranged from 1.39 to 1.51 mg l$^{-1}$ with a mean of 1.43 mg l$^{-1}$, whilst the phosphate level in June ranged from 0.15 to 0.54 mg l$^{-1}$ with a mean of 0.26 mg l$^{-1}$.

**Micro-organisms**

The total coliform range in March (128,000-1,780,000 counts/100 ml) was higher than that in June (32,000-58,000 counts/100 ml). The mean total coliform for March (708,400 counts/100 ml) was also higher than that of June (42,000 counts/100 ml). The faecal coliform range for both March and June were 1,240-1,940 counts/100 ml and 180-800 counts/100 ml, respectively. Their respective means were 1,760 and 580 counts/100 ml, indicating

### Table 4

| Parameter          | Final effluent dry season (March) | Final effluent in rainy season (June) |
|--------------------|----------------------------------|--------------------------------------|
|                    | Range               | Mean         | Range               | Mean         |
| Temperature °C     | 29.9 – 31.7         | 30.9         | 28.4 – 30.3         | 29.6         |
| pH, units          | 7.25 – 9.01         | -            | 7.69 – 9.06         | -            |
| Cond. $\mu$S cm$^{-1}$ | 157 – 290       | 224         | 195 – 210           | 204         |
| SS                 | 13 – 20             | 15.8         | 6 – 38              | 22           |
| Ammonia            | 0.63 – 1.11         | 0.87         | 0.4 – 0.8           | 0.60         |
| Nitrate            | 0.41 – 0.99         | 0.73         | 0.59 – 0.97         | 0.74         |
| Phosphate          | 1.39 – 1.51         | 1.43         | 0.15 – 0.54         | 0.26         |
| BOD                | 10.2 – 15.0         | 11.9         | 5.5 – 9.5           | 7.7          |
| COD                | 57 – 73             | 66.9         | 24 – 49             | 38.6         |
| Total coliform counts/100ml | 128,000 – 1,780,000 | 708,400     | 32,000 – 58,000     | 42000        |
| Faecal coliform counts/100 ml | 1,240 – 1,940 | 1,760     | 180 – 800           | 580          |

All the units are in mg l$^{-1}$ except otherwise stated.
lower faecal coliform counts in the rainy season
compared to that in the dry season.

Regression model for predicting the BOD of the 
raw sewage

Regression analysis has been developed to 
predict the BOD of the raw sewage using the BOD, 
SS and conductivity data of the raw sewage 
obtained from the both the rainy and dry seasons
in 2004, and in March and December 1999 (Hodgson, 2003). The BOD, SS and conductivity 
measured values used are given in Table 5. 
Though, the data set used for this model is small 
(17 observations), it covers the range of values of 
BOD levels expected for raw sewage for the 
Akosombo waste stabilization ponds system. 
Since it takes about 5 days to obtain the results of 
the laboratory analysis for BOD measurements 
the model could assist in obtaining a fair idea of 
the raw BOD levels using simple measurable 
wastewater parameters like SS and conductivity

\[
\text{BOD} = -77.0831 + 0.4513 \times \text{TSS} + 0.3866 \times \text{conductivity}
\]

The regression model given above is 
significant at 95 and 99 per cent confidence 
interval (R square = 0.8438, F calculated = 40.1,
p(F > 3.74) = 0.05 and p(F > 6.51) = 0.01) and, thus, 
the regression model developed is not due to 
chance. The model could assist in getting a 'quick'
first hand information of a rough estimate of the 
BOD levels in the raw sewage and also the average 
amount of BOD that could be removed from the 
sewage by the waste stabilization pond, i.e. by 
multiplying the predicted BOD by the mean BOD 
percentage removal of 77 per cent. Fig. 2 shows 
the correlation between the measured BOD and 
the predicted BOD which gives a good fit.

Conclusion

The following conclusions were made from the 
study conducted to determine the performance 
of the Akosombo waste stabilization ponds 
system and the effect of seasonal changes on the 
quality of the final effluent:

- The ponds achieved mean overall SS, BOD 
  and COD removals of about 84, 77, and 71 
  per cent, respectively. The mean overall 
  ammonia reduction was as high as about 
  93 per cent whilst the faecal coliform 
  removal was 99.99 per cent. The trace metal 
  levels (Pb, Zn, Cd and Cr) of the final 
  effluent were all low and insignificant (< 
  0.01 mg l\(^{-1}\)). Most of the SS (80%), BOD 
  (64%), COD (69%), ammonia (74%) and 
  faecal coliform (98.4%) present in the raw 
  sewage were removed in the primary 
  facultative pond (pond 1). Further polishing 
  of the effluent from the facultative pond 
  was obtained in the maturation pond.

- The quality of the final effluent was found 
  to be satisfactory and would not have 
  serious potential health hazard and any

| BOD, mg l\(^{-1}\) | SS, mg l\(^{-1}\) | Conductivity µS cm\(^{-1}\) |
|-----------------|-----------------|-----------------------------|
| 160             | 116             | 427                         |
| 81              | 34              | 326                         |
| 78              | 134             | 283                         |
| 88              | 64              | 193                         |
| 20              | 20              | 190                         |
| 22              | 36              | 200                         |
| 32              | 56              | 220                         |
| 52              | 110             | 232                         |
| 34              | 76              | 174                         |
| 10              | 30              | 237                         |
| 16              | 31              | 284                         |
| 42              | 82              | 216                         |
| 50              | 80              | 226                         |
| 34              | 48              | 230                         |
| 26              | 38              | 243                         |
| 70              | 96              | 310                         |
| 74              | 92              | 250                         |
adverse effect on the lower Volta river into which effluent is discharged.

- The mosquito nuisance usually associated with ponds system was absent because of the high fish proliferation in the ponds.

- The results showed that seasonal changes influenced the quality of the final effluent. The final effluent in the rainy season was less polluted than that of the dry season which may be due to the dilution of the effluent by the rains. However, the final effluent met the required EPA guideline values with the exception of the total and faecal coliforms.

- The developed regression model for predicting BOD levels of the raw sewage is:

  \[
  \text{BOD} = -77.0831 + 0.4513 \times \text{SS} + 0.3866 \times \text{conductivity}
  \]

  The model is significant at both 95 and 99 per cent confidence intervals (R square = 0.8428, F calculated = 37.5, p(F > 3.74) = 0.05 and p(F > 6.51) = 0.01) and, thus, the model developed is not due to chance.

**Acknowledgement**

The study was undertaken as part of the project on development of appropriate technologies for domestic sewage treatment and disposal. The cooperation and efforts of the staff of CSIR-Water Research Institute, Environmental Chemistry Division, especially Mr William Doudu, Mrs Patience Atsakpo and Mr Emmanuel Adu-Ofori, are hereby acknowledged.

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Received 17 Feb 06; revised 6 Nov 06.