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Research Article

Sewage Treatment by Waste Stabilization Pond Systems

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Abstract
Sewage generated in Ghana is commonly discharged into the environment without any form of treatment to reduce the degree of contamination and mitigate potential public health and environmental issues. Although some attempts have been made in some parts of Ghana to utilize the waste stabilization pond (WSP) system to treat domestic sewage, the ponds often fail to achieve their purpose due to lack of basic maintenance and supervision. To assess the utility of the WSP system for treating sewage, wastewater samples were collected from the raw sewage, anaerobic, facultative and maturation ponds of WSPs at Obuasi in Ghana, and analyzed for physicochemical and microbiological contaminants. The results show that the final pond effluent meets recommended microbiological and chemical quality guidelines. The waste stabilization pond system demonstrates high removal efficiencies of wastewater contaminants. The biochemical oxygen demand, total suspended solids, nitrate and faecal coliforms reduction efficiencies of 97.3%, 97.6%, 83.3% and 99.94% respectively are highly significant, and compare well with reported removal efficiencies in the literature. Additionally, the ponds have high reduction efficiencies for heavy metals and pathogenic microorganisms. The wastewater treatment system complies with standard wastewater management practices, and provides a useful method for treating and disposing wastewater in Ghana.

Keywords
Wastewater—Pathogens—Waste Stabilization Ponds—Faecal Coliform—Sewage

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1. Introduction

Waste stabilization ponds (WSPs) utilize shallow basins for wastewater treatment through natural disinfection mechanisms by integrating the activity of phototrophic, autotrophic and heterotrophic microorganisms [1]. Effectively treating wastewater effluents can efficiently contribute to water conservation, expansion of irrigated agriculture, environmental and public health protection [2].

Although WSPs are most commonly used for treating domestic wastewaters, they have been recommended by the World Health Organization (WHO) for the treatment of agro-industrial wastes for reuse in agriculture and aquaculture due to their effective removal of excreted pathogens and helminth eggs [3]. Stabilizing sewage by utilizing WSP is considered an appropriate technique for the treatment and removal of pathogenic microorganisms from wastewater in tropical and subtropical regions of the world.

The ponds require little energy (only sunlight) and no disinfectants [4], while playing an important role in the removal of contaminants such as crude oil and heavy metals. These low energy consuming ecosystems that use natural processes in contrast with complex high maintenance treatment systems (such as trickling filters, activated sludge treatment, rotary biological contactors, etc.) have become well established as methods for wastewater treatment in tropical climates [5]. The treatment technique uses minimal operational and maintenance input to produce an effluent that meets the recommended microbiological and physicochemical quality guidelines [6]. Additionally, it requires daily minimum supervision for its operation, by simply cleaning the outlets and inlet channels.

WSP system generally consists of a series of ponds involving anaerobic, facultative and maturation ponds [5, 7, 8]. Anaerobic and facultative ponds are respectively used for primary treatment and secondary treatment. They are both for the removal of biochemical oxygen demand (BOD), Vibrio cholerae and helminth eggs. The maturation ponds are used for tertiary treatment of wastewater effluents and responsible for the removal of faecal viruses (e.g. rotavirus, astrovirus and norovirus), faecal bacteria (e.g. *Salmonella spp., Shigella spp.*, pathogenic strains of Escherichia coli) and, nitrogen and phosphorus nutrients [9].

The relative advantages of WSPs compared to other conventional wastewater treatment systems (such as rotary biological contactors, activated sludge treatment, trickling filters, aerated lagoons, biological filters and reed-bed systems) in relation to effluent standards with respect to algae removal, input of external energy, nutrient removal and relative costs include simplicity, low cost, low maintenance, low energy consumption, robustness, and environmental sustainability [10].

WSPs are particularly well suited for tropical and subtropical countries such as Ghana. Stabilization ponds are widely used for treatment of municipal wastewater in many countries with ample sunshine such as Colombia, El Salvador, Guatemala, Honduras, Israel, Jordan, Morocco, Nicaragua, Tunisia and Uganda [11]. They are typically used in smaller towns where land availability and cost is less of a constraint. In some cities (e.g. Amman in Jordan and Adelaide in Australia), larger stabilization ponds have been replaced in the early 2000s by activated sludge wastewater treatment plants. Due to the temperature and lengthy duration of sunlight which are key factors that enhance the performance process and effectiveness of the treatment system, tropical and subtropical countries offer excellent opportunity for high efficiency and satisfactory performance [12].

According to [13], the commonest secondary treatment technologies adopted for domestic sewage treatment in Ghana are trickling filters, activated sludge and waste stabilization ponds. WSPs installed in some towns and communities such as Akuse, Akosombo and Kumasi are reported to perform remarkably well [13, 14]. However, the management of domestic wastewater in Ghana still remains a major problem to the local and national governments.

To complement the efforts by government in solving the challenges posed by sewage, six WSPs have been built by AngloGold Ashanti (Obuasi) mine for the collection and treatment of sewage to reduce the effect of certain water contaminants on the environment and protect public health. The wastewater in these ponds is treated to ensure that the levels of certain contaminants are brought below acceptable limits before discharging the effluents into the natural environment. To avoid polluting soils, receiving waters and endangering human health, flora, fauna and aquatic lives downstream from the points of discharge, it is necessary to monitor some water quality parameters in the treated domestic wastewater before it is discharged. This also provides a means for evaluating the performance of the treatment mechanism and makes data available for trend analysis and regulation evaluation.

2. Location, Relief and Climate of Obuasi

Obuasi is located in the Obuasi Municipal Assembly of the Ashanti Region of Ghana. The town is located 64 km south-east of Kumasi, the regional capital and 175 km north-west of Accra, the capital of Ghana. It has easy access to most parts of the country both by road and by railway. By railway, it is 72 km south of Kumasi, 192 km north of Takoradi habour and 330 km north-west of Accra.

Obuasi is situated in the tropical rainforest zone of Ghana. It has a long rainy season, which spans from March to December, followed by a brief dry season with sporadic rainfall from December to February. The highest rainfall occurs between May and July averaging 77.3 mm while the least occurs in December with an annual average rainfall of 39.1 mm. The annual average temperature is 28^{o}C. The area has thick vegetation and, where the relief is very high, there are usually shrubs [15]. Fig. 1 shows the location of the study area.

3. Waste Stabilization System

Waste stabilization systems comprise a single series of anaerobic, facultative and maturation ponds, or several such series in parallel. Anaerobic and facultative ponds are designed for removal of biochemical oxygen demand (BOD) and maturation ponds for pathogen removal. However, some BOD removal also occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds [7]. Anaerobic and facultative ponds only are required when the treated wastewater is to be used for restricted crop irrigation and fish pond fertilization, and a relatively weak wastewater (up to 150 mg BOD/l) is to be treated prior to surface water discharge. Maturation ponds are required only when the treated wastewater is to be used for unrestricted irrigation and when stronger wastewaters (BOD $>$ 150 mg/l) are to be treated prior to surface water discharge [4, 12].

Usage of waste stabilization ponds for treatment of sewage wastewaters can be found in over 50 countries with very different climatic conditions. A great number of these ponds can be found in Asia, Latin America and Africa [16]. The common treatment technologies adopted for domestic sewage treatments are trickling filters, activated sludge and waste stabilization ponds. [17] describes the advantages of the WSP system over other treatment systems including package plant, activated sludge, extended aeration activated sludge, biological ditch and aerated lagoon. The WSP system outperforms the other systems by its ability to remove BOD, faecal coliform, helminth, and virus, the mode and cost of construction, mode of operation, cost of maintenance, energy demand and cost of sludge removal. The main limitations of WSPs are that they require large areas of operation and are very inefficient in the removal of suspended solids.

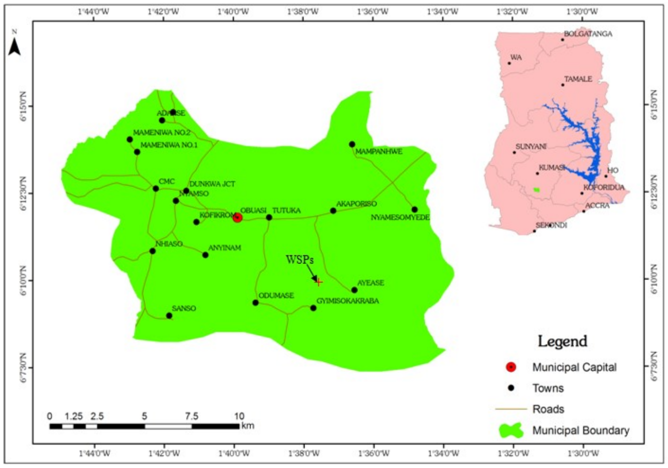

Figure 1. Study Area

Under the tropical conditions in Ghana, the Waste Stabilization Ponds (WSPs) have been found to be more suitable and appropriate compared to conventional treatment systems because of the ease of operation and maintenance and the high level of treatment efficiencies they are able to achieve [14]. Fig. 2 illustrates a typical scheme of WSP.

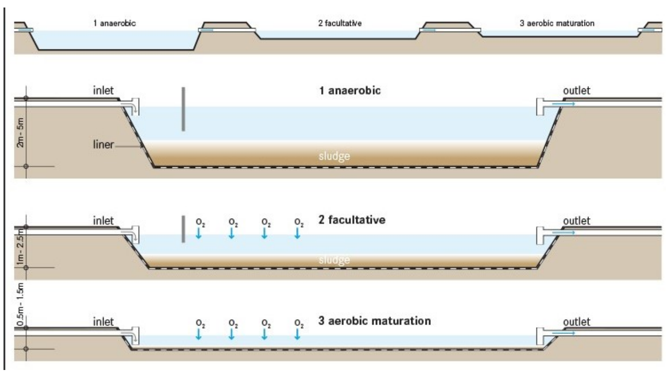

Figure 2. Typical Scheme of a Waste Stabilization System: Anaerobic, Facultative and Maturation Ponds in Series (source: [18])

Fig. 3 is a schematic diagram of the WSP at Obuasi [19]. These ponds consist of two anaerobic, four secondary facultative, and two maturation ponds. The raw sewage with high organic loading (compared to the other ponds) is discharged into a small receptacle lined with sieves to prevent large solids from entering the anaerobic ponds.

The anaerobic ponds are about 4 to 5 m deep. Their primary function is BOD removal. In anaerobic ponds sludge is deposited on the bottom and anaerobic bacteria break down the organic matter by anaerobic digestion, releasing methane and carbon dioxide. Viruses, bacteria, helminth, Ascaris eggs and other pathogens can also be inactivated by sedimentation when associated with solids.

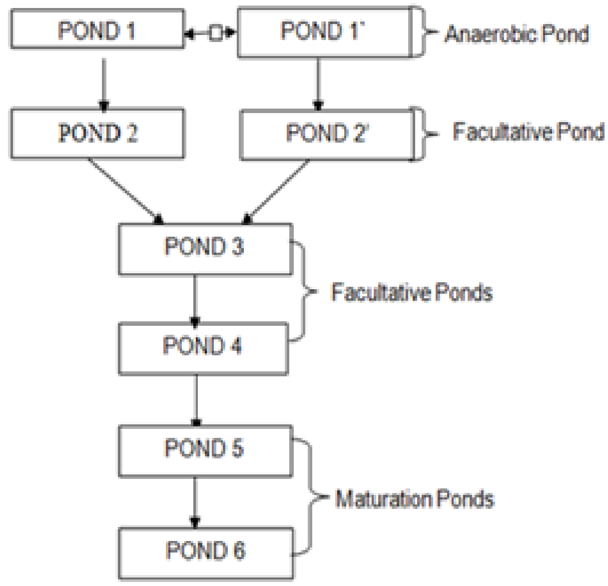

Figure 3. Schematic Diagram of the Waste Stabilization Ponds at Obuasi

Nitrogen, phosphorus and potassium can also be reduced by sludge formation and the release of ammonia into the air [20]. Anaerobic ponds help to settle undigested material and non-degradable solids as bottom sludge, dissolve organic material and break down biodegradable organic material.

The facultative ponds, which are 1 to 2 m deep, receive settled wastewater from the anaerobic ponds. They are also designed for BOD removal on the basis of a relatively low surface loading (100 to 400 kg BOD/ha day) to permit the development of a healthy algal population as the oxygen for BOD removal by the pond bacteria is mostly generated by algal photosynthesis [5]. The algae grow using sunlight and produce oxygen in excess to their own requirements. The excess oxygen is used by bacteria to further break down organic matter via aerobic digestion transforming the organic pollutants into carbon dioxide. In addition to the aerobic and anaerobic digestion of BOD in the facultative ponds "sewage BOD" is converted into "algal BOD" [5]. As a complete process, the facultative pond serves to further treat wastewater through sedimentation and aerobic oxidation of organic material, reduce odor, reduce some disease-causing microorganisms if pH rises and store residues as bottom sludge [20].

The maturation ponds (which are 1 to 1.5 m deep) receive the effluent from the facultative ponds. The size and the number of maturation ponds depend mainly on the required bacteriological quality of the final effluent. The primary function of maturation ponds is the removal of excreted pathogens. Pathogens die off due to the high temperature, high pH or radiation of the sun leading to solar disinfection. Virus removal occurs by adsorption onto settleable solids and consequent sedimentation [20]. Maturation ponds achieve only a small removal of BOD, but their contribution to nutrient (nitrogen and phosphorus) removal can also be significant [5].

4. Methods

Samples were taken from the raw sewage and from the effluents of Ponds 1 to 6. The American Public Health Association standard methods for the examination of water and wastewater [21] were followed. The physicochemical and microbiological parameters of WSP samples were analyzed. Wastewater quality parameters analyzed included total suspended solids (TSS), total dissolved solids (TDS), pH, biological oxygen demand (BOD), nitrate, total coliforms, faecal coliforms, Escherichia coli (E. coli), oil and grease, dissolved oxygen, conductivity, colour, lead (Pb), iron (Fe), copper (Cu), arsenic (As), zinc (Zn) and chloride (Cl^-). The quality of the final pond effluent was compared with recommended microbiological and physicochemical quality guidelines (typically adapted from the World Health Organization, U. S. Environmental Protection Agency, and the World Bank Group) by the Environmental Protection Agency of Ghana (EPA) to determine conformance. Additionally, the reduction efficiencies of the various parameters were calculated by using equation 1.

$$\eta = \frac{C_r - C_f}{C_r} \times 100 \tag{1}$$

Where: η is removal or reduction efficiency in %, C_r is the concentration in the raw sewage, C_f is the concentration in the final pond effluent.

5. Results and Discussion

The discharge of effluents with high TSS concentrations can cause sludge depositions and anaerobic conditions in the receiving water body. The TSS concentration of the raw sewage is 1260 mg/l and that of the final effluent is 30 mg/l, giving a reduction efficiency of 97.6%. Fig. 4 shows the TSS content of the effluents from the pond system. The final effluent of the WSP system compares well with recommended guidelines. The high TSS concentrations of the effluents from the anaerobic and facultative ponds can be attributed to the high TSS levels of the raw sewage. The TSS removals in Ponds 1 to 5 support the findings of Arthur [17], that the ability of WSP systems to remove TSS is poor. However, it must be noted that the TSS concentrations of the pond effluents decrease along the treatment series as expected, and that the overall high reduction efficiency achieved is in contrast with Arthur [17]. The high TSS reduction efficiency demonstrates that the WSP systems at Obuasi are efficient in reducing TSS.

Effluents with high concentrations of nitrates can cause unwanted phytoplankton growth in the receiving water bodies. According to Metcalf and Eddy [22], nitrate is typically absent in domestic sewage. The nitrate concentration of the raw sewage is 2.39 mg/l while that of the final effluent is 0.4 mg/l. The nitrate concentration of the final effluent is acceptable as it is far less than the guideline value of 50 mg/l. The nitrate removal efficiency of 83.3% achieved by the treatment ponds can be described as appreciable. Fig. 5 shows the nitrate concentrations of the effluents. The results show that the nitrate levels in all the ponds are far lower than the recommended guideline value.

When effluents with high concentrations of BOD are discharged into the natural drains, they can cause depletion of natural oxygen resources which may lead to septic conditions. The BOD of the raw sewage is 280 mg/l and that of the final pond effluent is 7.6 mg/l. The average BOD removal efficiency of the ponds is calculated to be 97.3%. Fig. 6 shows the BOD levels in the effluents. A study by Gloyna [23] indicates that it is uncommon to obtain better than 90% BOD removal in waste stabilization. The findings in this research suggest that the WSP systems at Obuasi are very effective in the removal of BOD.

The faecal coliforms level of the raw sewage is 65000 counts/100 ml while that of the final pond effluent is 40 counts/100 ml. The average faecal coliforms removal efficiency is determined to be 99.94% which is significant. Waste stabilization ponds usually give such high micro-organism removal efficiency. Effluents with high concentrations of faecal coliforms have high potential of endangering public health. The concentration of the faecal coliforms of the final effluent is very low compared to the recommended guideline value of 1000 counts/100 ml (see Fig. 7). This indicates that the final pond effluent can be discharged into the natural environment without posing threat to humans and the ecosystem in general.

Other wastewater parameters (pH, conductivity, TDS, oil and grease, As, Fe, Cu, Pb, Zn, Cl^-, total coliforms, E. coli, colour and DO) of the final pond effluent compare well with their respective recommended levels. The raw sewage contains small concentrations of metals which can be attributed to the relatively "normal" pH level. While the metal concentrations of the final pond effluent remain low and meet regulatory requirements, the pH of the maturation ponds are higher than that of the anaerobic and facultative ponds. It is common to find variations in pH in WSP systems. Maturation ponds usually have high pH which aid in the pathogen die-off mechanism. Kayombo et al [24] also report diurnal pH changes in WSP, and indicate that increase in pH up to 11 is common in WSPs, with highest pH levels usually reached during the late afternoon.

It is also demonstrated that the ponds can be effective in reducing oil and grease, which otherwise can affect aquatic activities, and contaminate soils and plants. The high oil and grease reduction efficiency is corroborated by the findings of Shpiner et al [25]. They concluded that waste stabilization ponds can treat synthetic produced water (PW) and achieve high oil and grease removal levels (>90%). Although the chloride concentration of the final pond effluent meets regulatory requirements, there are observed variations in the chloride concentration along the pond series. These changes in the chloride concentrations as the sewage passes through the ponds are also reported by [26]. The ponds also achieved high total coliform and E. coli reduction efficiencies. The progressive removal of pathogens along the series of ponds is consistent with the findings of Mara et al [12]. Stabilization ponds are generally reported to demonstrate high pathogen removal efficiencies [27, 28, 29]. Table1 shows results of the wastewater parameters analyzed for the pond series.

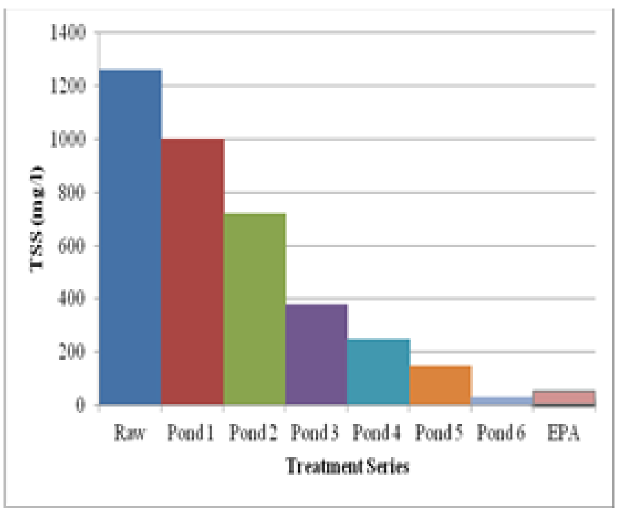

Figure 4. TSS Concentration of Pond Effluents

Table 1. Physicochemical and Microbiological Parameters of WSP Samples

Parameter	Raw Sewage	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6	EPA
pH	7.6	7.6	7.4	7.8	8	9.5	8.9	9-Jun
Conductivity	11860	11480	10800	6360	4620	3119	1410	1500
TDS	6103	5800	5500	3200	2400	1560	854	1000
TSS	1260	1002	720	380	250	150	30	50
Oil & Grease	12.98	12.33	7.24	3.18	1.02	0.11	0.01	100
As	0.89	0.81	0.79	1.48	1.21	1.04	1.3	1.5
Fe	0.71	0.69	2.05	0.99	0.24	0.05	0.14	2
Cu	0.02	0.01	0.05	0.01	<0.01	<0.01	<0.01	2.5
Pb	0.09	0.06	0.02	0.02	0.01	<0.01	<0.01	0.1
Zn	0.08	0.08	0.35	0.012	0.05	0.01	0.02	5
Cl-	261	248	274	212	323	263	177	250
NO3-	2.39	2.08	2.01	0.02	5.19	1.66	0.4	50
Total Coliforms	183744	161600	144000	55200	33200	1256	380	1000
Faecal Coliforms	65000	61000	5200	4000	3100	280	40	1000
E. Coli	298	255	94	53	30	13	3	10
Colour	1198	1120	560	270	140	40	20	200
BOD5	280	103	73	51.4	45.7	15.1	7.6	50
DO	6	6.3	6.4	6	6	6.7	6.8	-

(All concentrations in $^{mg}/_{l}$ except pH, Conductivity ($^{\mu S}/_{cm}$), Colour (PCU) and the Coliforms($^{counts}/_{100ml}$)

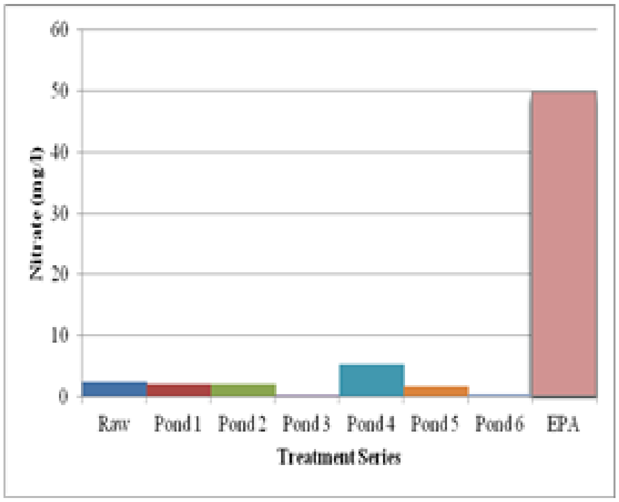

Figure 5. Nitrate Concentration of Pond Effluents

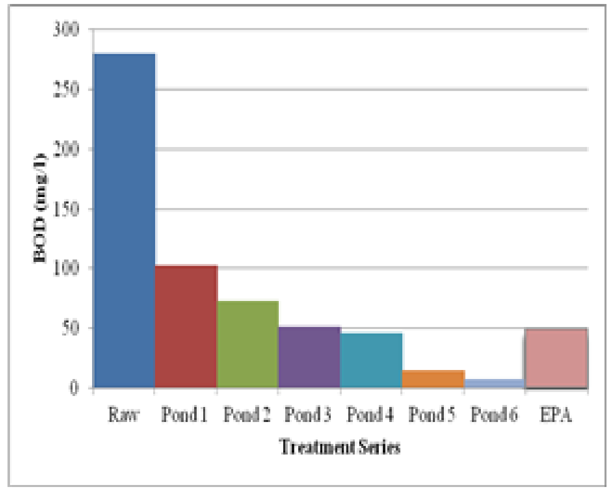

Figure 6. BOD Levels of Pond Effluents

6. Conclusions and Recommendation

The waste stabilization pond system at Obuasi is assessed to achieve high removal efficiencies of wastewater contaminants. The ponds demonstrate high reduction efficiencies in the physicochemical, microbiological and heavy metal contaminants levels of the wastewater. Given that the temperature in Obuasi ranges from 22 ^oC to 34 ^oC, with rainfall throughout the year, the contaminant removal efficiencies are not expected to vary significantly during the year. The waste stabilization pond system is appropriate for treating wastewater and produces effluents that meet the recommended microbiological and chemical quality guidelines at low cost and minimal operational and maintenance requirements. The wastewater treatment system is effective and complies with standard wastewater management practices. The quality of the final pond effluent is not anticipated to have adverse effects on the environment when discharged into nearby surface water sources. The waste stabilization pond system provides a useful method of wastewater treatment and disposal for growing communities, and therefore should be regarded as a method of choice for treating wastewater in Ghana.

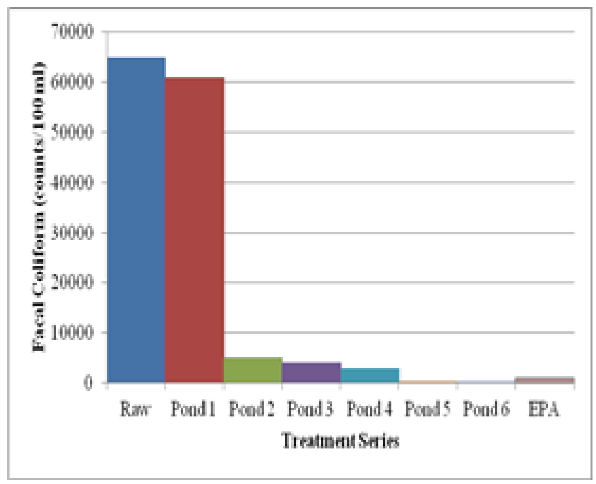

Figure 7. Faecal Coliform Levels of Pond Effluents

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