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DEPARTMENT OF ENVIRONMENTAL SCIENCE

ASSESSING THE EFFICIENCY OF THE AKOSOMBO WASTEWATER STABILIZATION POND

BY

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ASSESSING THE EFFICIENCY OF THE AKOSOMBO WASTEWATER STABILIZATION POND

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DECLARATION

It is hereby declared that this thesis is the outcome of research work undertaken by the author. Any assistance obtained has been duly acknowledged. It is neither in part nor whole been presented for another degree elsewhere.

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DEDICATION

This research is dedicated to the Lord Jesus Christ and His Bride.

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I express my deep sense of gratitude and respect to my invaluable supervisor, Professor K. Obiri-Danso for his keen interest and valuable guidance, strong motivation and constant encouragement during the course of the work. I thank him for his great patience, constructive criticism and myriad useful suggestions apart from invaluable guidance to me. To my supervisor I say, God bless you.

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Finally, yet importantly, I owe a debt at Calvary but my redeemer the Lord Jesus paid it all. I will never forget Calvary.

ABSTRACT

The efficiency of the Akosombo wastewater stabilization pond in Ghana was assessed over a three month period. Bimonthly samples were collected from four points (raw sewage, facultative pond, maturation and final effluent) and the pH, temperature, total dissolved solid, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, ammonia-nitrogen, nitrate, phosphorus, total suspended solids, total coliform and faecal coliform were determined using standard methods. The study revealed that the ponds achieved mean overall TSS, BOD and COD removals of about 75.2%, 78.9%, and 64.2%, respectively. The mean overall removal efficiency of ammonia-nitrogen, nitrate and phosphorus were 95.5% 64.9% and 25.4% respectively. Total and faecal coliforms removal was as high as 100%. Most of the ammonia (80.1%), total coliform (96.9%) and faecal coliform (99.0%) present in the raw sewage were removed in the primary facultative pond whereas biodegradables in the raw sewage were reduced in the maturation pond attaining efficiency of BOD (70.3%) and COD (42.8%) respectively. An average overall effective reduction was 86.5% for the stabilization pond. The levels of compliance of effluents with the physicochemical and microbial parameters were all below the EPA permissible levels except faecal coliforms.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Surface waters play a significant role in the transmission of water-related infections as most are grossly polluted with untreated sewage (Oakley *et al.*, 2000). However, they are used extensively in bathing, washing, water contact sports and crop irrigation.

Water resources are becoming rapidly scarce all over the world. Water supply and safe disposal of excreta are the most important problems that developing countries face especially with the increasing technological advancement, urbanization and the increasing global population (Khan,1999). Environmental pollution do not only create ecological imbalance but also poses great risk to human health.

In sub Saharan Africa, almost two thirds of the population (64%) lack adequate access to excreta disposal facilities (World Bank, 2002). In global terms, the continent contains 13% of the world's population without access to improved sanitation, with only Asia having a lower access. Nonetheless, in many African countries, no access to improved sanitation means no access to any sanitation facility at all, with sanitation coverage varying from 84% in urban areas to 45% in rural areas (WHO, 2002). Sanitation includes solid waste disposal, wastewater disposal, wastewater reuse, human excreta disposal, and drainage of rainwater. However, the management of municipal wastewater and human excreta in peri-urban and rural areas by means of improved and sustainable sanitation remains a mirage. Improved sanitation refers to excreta disposal facilities that can effectively prevent human, animal and insect contact with excreta.

Ghana has one of the highest sanitation coverage in West Africa with 58% compared to 34, 32, 38, and 26%, respectively for Togo, Benin, Nigeria and Liberia (WHO, 2002).

Accra and Kumasi are partly sewered with only Tema and Akosombo being the only towns with a state of the art central sewerage system. Wastewater treatment is hardly ever accorded any resources. Service delivery is also not keeping pace with population growth and demand (Keraita and Dreschel, 2004).

Domestic wastewater usually contains greywater, (which is wastewater from washrooms, laundries, kitchens etc) and can also contain blackwater, (which is generated in toilets). Shuval *et al.* (1986) reported that waste stabilization ponds are the most suitable wastewater treatment option that could eventually be useful in agriculture. Waste stabilization ponds have proved to be a low-cost, sustainable method of wastewater treatment, particularly suited to the socioeconomic and climatic conditions prevailing in many developing countries. No input of external energy or disinfectants is needed (WHO, 2006).

In Ghana, the commonest secondary treatment technologies adopted for domestic sewage treatment are trickling filters, activated sludge and waste stabilization ponds. The waste stabilization ponds installed in some of the towns and communities in Ghana have performed remarkably well. Some of the places where the waste stabilization ponds can be found include Akuse, Akosombo and Kumasi (Hodgson, 2000)

The Akosombo township sewerage system is linked to waste stabilization ponds used to treat the sewage. These waste stabilization ponds are managed by the Environmental Section of Volta River Authority (VRA). The Waste stabilization ponds are in two parts, a facultative and maturation ponds. There are three inlet points to the first pond with each representing influent from three different parts of the township. The sewage enters a retention chamber and is then pumped into the pond at two inlet points. The third flow by gravity. A screen is provided for solid removal before entering the ponds. The final effluent is discharged into the lower Volta Lake. The ponds have a high fish population which could explain the minimal mosquito or insect nuisance usually common with waste stabilization ponds.

1.2 JUSTIFICATION

In the near future, the use of small-scale treatment plants such as the stabilization pond may gradually increase and demand for information on appropriate procedures and technologies will be needed. The technical and biological knowledge of this simple low rate system have to be evaluated according to the treatment processes in removing major constituents in domestic wastewater that will cause health risk.

The most appropriate wastewater treatment is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirements (Arar, 1988).
Apart from natural factors influencing water quality, human activities such as domestic wastewater discharge and agricultural practices impact negatively on river water quality. It is, therefore, important to carry out water quality assessments for sustainable management of water bodies.

In order to ensure good environmental health, Volta River Authority (VRA) has constructed wastewater stabilization pond at Akosombo. The ponds were constructed and commissioned in April, 1993 to replace a trickling filter plant. This is to help in the storage, treatment and disposal of wastewater generated in the township. The Volta Lake is the major source of potable water to the people living along the Lake. The Lake is also the main source of water for treatment by the Ghana Water and sewage Company. In order to protect aquatic life and the people living along the Lake, an assessment of the efficiency of the stabilization pond is necessary. This will help to ensure that the value and importance of freshwater resources are well managed ecologically to meet water quality standards.

In view of the fact that, there are many users of the Lake downstream, it is necessary to ensure that what is discharged into the Lake meet recommended standard set by Environmental Protection agency (EPA) Ghana.

Hence, the study provides the physicochemical and bacteriological characteristics of the stabilization pond in order to ascertain the efficiency of the Akosombo wastewater stabilization pond.

1.3 GENEAL OBJECTIVE

The objective of the study is to assess the efficiency of the Akosombo wastewater stabilization pond.

1.4 SPECIFIC OBJECTIVES:

- To determine the number of total and faecal coliforms in the influent and effluent.
- To measure physicochemical parameter; BOD, COD, total suspended solids, total dissolved solids, pH, temperature, ammonia, nitrate and phosphate in the influent and effluent.

CHAPTER TWO

LITERATURE REVIEW

2.1 DEFINITION OF WASTEWATER

Raschid-Sally and Jayakody (2008) defined wastewater as “a combination of one or more of: domestic effluent consisting of blackwater (excreta, urine and faecal sludge) and greywater (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban run-off; agricultural, horticultural and aquaculture effluent, either dissolved or as suspended matter”

Domestic wastewater can be regarded as the water borne from waste products of humans and their activities. It contains about 99.94% water by weight and about 0.06% dissolved and suspended materials. It is estimated that under acceptable quantity of water supply each individual contributes approximately 100litres of wastewater per day to a city’s sewage flow (Arthur, 1983).

2.2 SOURCES OF WASTEWATER

Wastewater is the water which is disposed from homes, offices and industry. It comes from toilets, sinks, showers, washing machines and industrial processes and was historically called sewage. The wastewater that comes from office building and business areas is regarded as commercial wastewater while the one generated during industrial operations is regarded as industrial wastewater (Samwel, 2005).

Figure 2.1: Sources of domestic wastewater (Samwel, 2005)

2.3 CHARACTERISTICS OF DOMESTIC WASTEWATER

Wastewater can be contaminated with a myriad of different components: pathogens, organic compounds, synthetic chemicals, nutrients, organic matter and heavy metals. They are either in solution or as particulate matter and are carried along in the water from different sources and affect water quality. These components can have biocumulative, persistent and synergistic characteristics affecting ecosystem, health and function, food production, human health and wellbeing, and undermining human security (Appelgren, 2004; Pimentel and Pimentel, 2008).

2.3.1 Physical Characteristics

Domestic wastewater is usually characterised by a grey colour, musty odour and has solids content of about 0.1%. The solid material is a mixture of faeces, food particles, toilet paper, grease, oil, soap, salts, metals, detergents, sand and grit. The solids can be suspended (about 30%) as well as dissolved (about 70%). Dissolved solids can be precipitated by chemical and biological processes. The suspended solids can lead to the development of sludge deposits and anaerobic conditions when discharged into the receiving environment (Henze and Ledin, 2001)

2.3.2 Chemical Characteristics

Domestic wastewater contains a variety of chemical substances of inorganic and organic nature.

a. Inorganic Contents

The inorganic content includes dissolved mineral salt, sulphates, phosphates, biocarbonates of Ca and Mg etc. It forms about 30% of the wastewater *(*Henze and Ledin, 2001*)*.

b. Organic Contents

Henze and Ledin (2001) reported that wastewater is composed of 70% organic matter. Protein, fats and carbohydrates are the principal groups of organic substances present. Out of this, protein constitutes about 40-60%, carbohydrates 20-25% and fats and oils 5-10% (Aurthur, 1983)

2.3.3 Biological Characteristics

Biologically, wastewater contains various organisms but the ones that are of concern are those classified as protista, plants, and animals. The category of protista includes bacteria, fungi, protozoa, and algae. Plants include ferns, mosses, seed plants and liverworts. Invertebrates and vertebrates are included in the animal category. Also, wastewater contains many pathogenic organisms which generally originate from humans who are infected with disease or who are carriers of a particular disease. Typically, the concentration of faecal coliforms found in raw wastewater is about several hundred thousand to tens of millions per 100 ml of sample (Henze and Ledin, 2001).

2.4 COMPONENT OF WASTEWATER

Table 2.1: Components of Wastewater

Component	Special interest	Environmental effect
Microorganisms	Pathogenic bacteria, virus and worms eggs	Risk when bathing and eating shellfish
Biodegradable organic materials	Oxygen depletion in rivers and lakes	Fish death, odours
Other organic Materials	Detergents, pesticides, fat, and grease colouring, solvents, phenols, cyanide	Toxic effect, aesthetic inconveniences, bioaccumulation in the food chain
Nutrients	Nitrogen, phosphorus,ammonium	Eutrophication, oxygen depletion, toxic effect
Metals	Hg, Pb, Cd, Cr, Cu, Ni	Toxic effect, bioaccumulation
Other inorganic Materials	Acids, for example hydrogen sulphide, bases	Corrosion, toxic effect
Thermal effects	Hot water	Changing living conditions for flora and fauna
Odour (and taste)	Hydrogen sulphide	Aesthetic inconveniences, toxic effect
Radioactivity		Toxic effect, accumulation

(Henze and Ledin, 2001)

2.5 WASTEWATER COLLECTION

Domestic wastewaters are collected in underground pipes which are called ‘sewers’. The flow in sewers is normally by gravity, with pumped mains only being used when unavoidable. The design of conventional sewerage (the sewer system used in industrialized countries and in the central areas of many cities in developing countries) is described in several texts (Metcalf and Eddy, 1991). However, it is extremely expensive. A much lower cost alternative, which is suitable for use in both poor and rich areas alike, is ‘simplified’ sewerage, sometimes called ‘condominial’ sewerage (Khan, 1999).

2.6 WASTEWATER TREATMENT SYSTEMS

Wastewater treatment is a combination of physical, chemical and biological processes. The Physical process involves the removal of coarse and suspended matter whereas in biological process, microorganisms play a vital role in decomposing biodegradable organic matter. The chemical process further enhances the treatment quality (Kashiwaya and Annaka, 1980; McCarty *et al.*, 1984; Kuribayashi, 1992).

2.7 CLASSIFICATION OF WASTEWATER TREATMENT SYSTEM

Broadly, wastewater treatment systems are divided into two main treatment operations: preliminary treatment /primary treatment and secondary treatment. However, Advanced Wastewater Treatment (AWT) operation is also adopted where the aim is to reuse/recycle treated wastewater for different purposes.

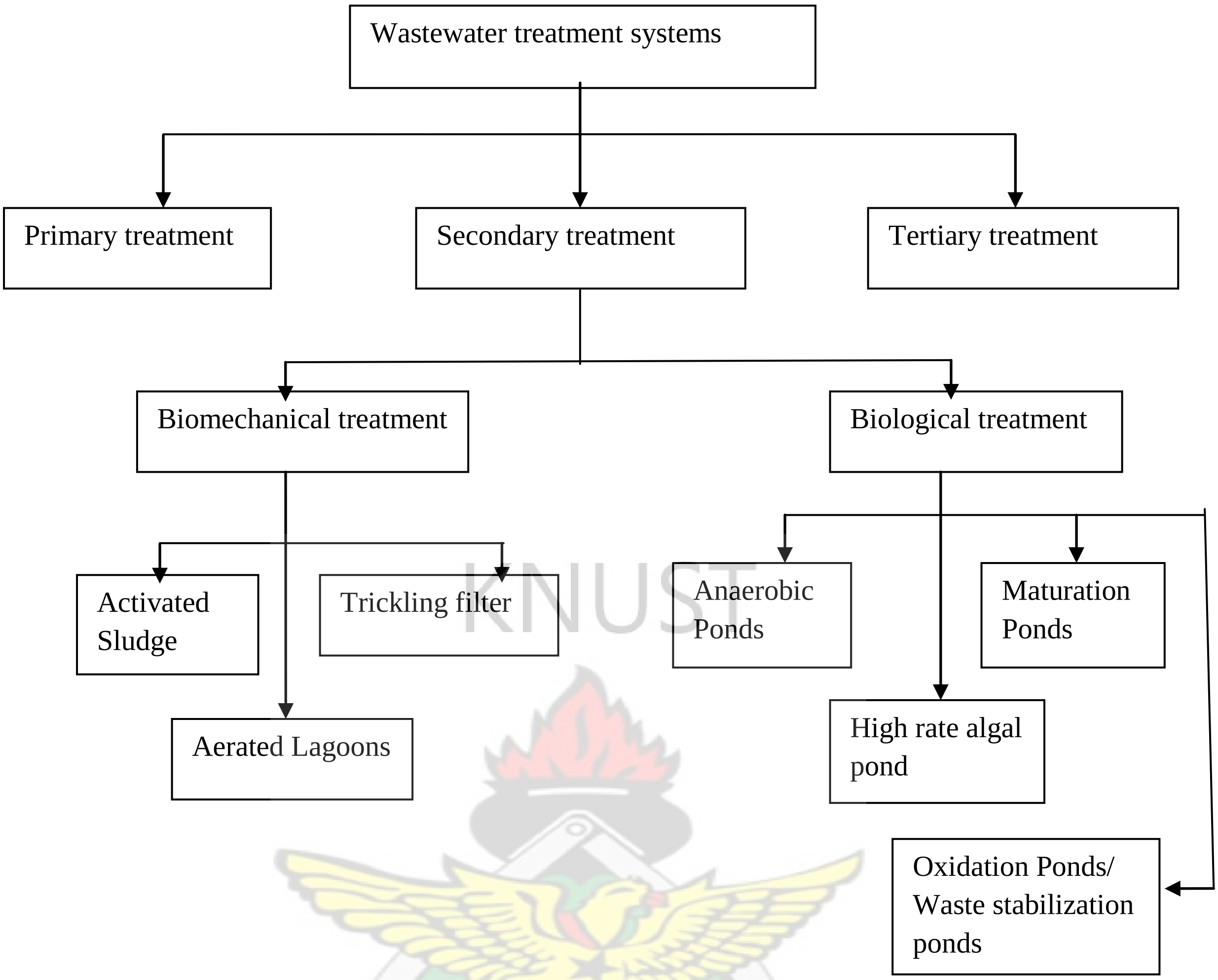


Figure 2.2: Generalized flow diagram for municipal wastewater treatment (Source: Khan, 1999).

2.7.1 Primary Treatment of Wastewater

Primary treatment involves the use of screening devices for the removal of mostly floating objects, comminutor for cutting solids coming with the wastewater and sedimentation tanks for removal of settleable solids. The design of the primary sedimentation tanks may be such as to remove grit, sand, and pieces of glass and metals separately from settleable organic matter (Graff *et al.*, 1989)

Primary treatment removes about 60 percent of suspended solids from wastewater. This treatment also involves aerating (stirring up) the wastewater, to put oxygen back into the system (http://ga.water.usgs.gov/edu/wuww.html).

2.7.2 Secondary Treatment of Wastewater

The secondary wastewater treatment system depends upon the availability and supply of oxygen. The oxygen may be generated mechanically (through air compressors) or biologically (through algal cells) (Khan, 1999). Secondary treatment removes more than 90 percent of suspended solids (http://ga.water.usgs.gov/edu/wuww.html).

2.8 TYPES OF CONVENTIONAL WASTEWATER TREATMENT SYSTEMS

2.8.1 Activated Sludge Treatment

This system is mechanical in that raw wastewater is introduced into an aeration tank where oxygen is supplied by mechanical means. The aeration of mixed settled wastewater produces microorganically active sludge. After settlement, the effluent is removed and flesh wastewater is added and the process of aeration continues. Oxidation and nitrification occurs due to aeration of wastewater for several weeks and a dark brown flocculent sludge is produced. This is repeated many times with flocculating sludge being retained. As a result, putrification occurs progressively with shorter aeration periods and the sludge becomes more active. Finally, a type of sludge is obtained containing more actively growing microbial cells which can treat wastewater in a shorter period of time (Lumbers, 1984a). Filamentous microorganisms affect the sludge settling.

Severin (1980) reported that at high filamentous length concentration, zone settling velocity reaches maximum value and then decreases with increasing suspended solids concentration. The sludge age together with mixed liquor and suspended solids in the aeration tank generate the dynamic ability of the over all process. An under loaded and over loaded system can lead the whole process dynamically unstable (Cakici and Bayramoglu, 1995).

Barker and Dold (1995) observed good COD and nitrogen balance on different types of laboratory scale activated sludge system. It is reported that Gram-positive bacteria are able to accumulate high concentration of phosphorus (Li and Ganczarczyk, 1990; Appeldoorn *et al.*, 1992; Cote *et al.*, 1995). But, Li and Ganczarczyk (1990) observed mainly Gram negative bacteria in sludge exhibiting enhanced biological removal. The activated sludge has a BOD and suspended solid concenstration of 15-30 mg/l which would hardly meet the strict discharge standard introduced by different countries. It is not commonly used in developing countries because it is difficult to operate due to mechanical complexities (Matin and Matin, 1991). Uiga and Crites (1980) reported 90-99% removal of total coliform and faecal coliform in activated sludge system.

2.8.2 Trickling Filters

This system comprises the bed of ground rock and formed plastic. The wastewater when sprayed slowly trickles down in the form of liquid film. During this process, a zoogleal slimy layer (collection of microorganisms) develops over the bed. The wastewater containing the organic and inorganic material passes through the bed comes in contact with bacteria and slime. These substances upon coming in contact

with bacteria are broken down to simpler forms. Microorganisms are very active in this phase. The oxygen needed for the aerobic treatment is transferred from the gaseous phase into the liquid phase (Schroeder, 1977).

Another type of this system is the rotating biological contractor (RBC). In this type light weight material such as Styrofoam is used to support the slime layer and operate by moving the slime through wastewater (Schroeder, 1977).

2.8.3 Aerated Lagoons

Aerated lagoons were actually developed from the oxidation ponds in temperate regions, in which oxygen is supplied by means of mechanical aeration (surface of diffused aeration). Aerated lagoons are now usually designed as completely mixed non return activated sludge units. These lagoons are medium depth basins designed for biological treatment of wastewater on continuous basis. Because aerated lagoons are normally designed to achieve partial mixing, only aerobic/anaerobic stratification may occur and a large fraction of biological solids produced from waste conversion settle at the bottom of the lagoon (Schroeder, 1977). Long retention time of 2-6 days is required for removal of >90% $BOD_{5,}$ 60-90% COD and 70-90% TSS when the effluent concentration of these parameters ranges from 200-500mg/l (Matin and Matin, 1991).

2.8.4 Rotating Biological Contactors

Rotating biological contactors (RBCs) are fixed-film reactors similar to biofilters in that organisms are attached to support media. In the case of the RBC, the support media are slowly rotating discs that are partially submerged in flowing wastewater in the reactor. Oxygen is supplied to the attached biofilm from the air when the film is out of the water and from the liquid when submerged, since oxygen is transferred to the wastewater by surface turbulence created by the discs' rotation. Sloughed pieces of biofilm are removed in the same manner described for biofilters (FAO, 1992).

When coupled with a disinfection step, these processes can provide substantial but not complete removal of bacteria and virus. However, they remove very little phosphorus, nitrogen, non-biodegradable organics, or dissolved minerals (FAO, 1992).

2.9 BIOLOGICAL SYSTEM OF WASTEWATER TREATMENT

The biological system is largely depended upon the microbial activity taking place in raw wastewater. In most of the cases, the wastewater is kept in shallow ponds where the microorganisms stabilize organic matter.

2.10 CLASSIFICATION OF PONDS

2.10.1 Anaerobic Pond

Anaerobic ponds are deep treatment ponds that exclude oxygen and encourage the growth of bacteria, which break down the organic matter. Commonly, they are 2-5 m deep and receive high organic loads equivalent to100 g BOD_5/m^3 day. These high organic loads produce strict anaerobic conditions (no dissolved oxygen) throughout the pond. In general terms, anaerobic ponds functions much like open septic tank and work extremely well in warm climates. Ponds may receive volumetric organic loadings in the acid of 100 to 350 g BOD_5/m^3 day, depending on the design temperature (Mara et al., 1992; Peña, 2002).

There are two groups of bacteria that take part in the degradation process. Initially, facultative organisms convert complex organic materials (carbohydrates, protein, fats etc.) into aldehydes, alcohols and fatty acids. These organisms are regarded as formers and the process is represented as:

$$C_x H_yO_zN_uS_v + H_2O \longrightarrow \text{acid formers} \longrightarrow CH_3COOH + CO_2 + NH_3 + H_2S + H$$

In the second stage, the organic acids are then converted into methane and carbon dioxide by strict anaerobic methane forming bacteria. The process is represented as:

$$CH_3\,COOH + H_2O \longrightarrow CH_4 + CO_2 + H_2$$

These processes take place simultaneously and are temperature depended. The rate of break down sharply decreases with the reduction in temperature and fermentation is almost negligible at temperature below 15^{o}C. Therefore, 15^{o}C and 19^{o}C have been reported as the minimum temperature for visible changes (Ellis, 1983). Austermann-Haun and Seyfried (1992) reported that anaerobic pre-treatment is useful as it provides high rate nitrogen removal and at the same time a high rate of energy recovery from biogas, at about 50% of the whole energy need of the treatment plant. Ahmed *et al.* (1988) found that BOD, COD and SS removal increased with retention time from 1-3 days in anaerobic ponds. Beyond 3 days, no significant reductions were observed in BOD, COD and SS.

The pH is one of the criteria for the activity of methanogenic bacterial. The optimal pH for these bacteria is 7-8 (Ellis, 1984a; Toprak, 1995). Romli *et al.* (1994) suggested that recycling in a two phase anaerobic system reduces the consumption of alkali. The increase in gas production under recycling is caused mainly by the stripping of dissolved CO_2 from liquid phase to gaseous phase thereby developing methane concentration of biogas. A small amount of sulphide is beneficial as it reacts with heavy metals to form insoluble metal sulphides, which precipitate out. In the case of typical municipal sewage, it is generally accepted that a maximum anaerobic pond loading of 300 g BOD_5 / m^3 d at 20^0C will prevent odor nuisance (Mara *et al.*, 1992). Furthermore, Mara and Pearson (1986) propose a maximum sulphate volumetric loading rate of 500 g SO_4 / m^3d (equivalent to 170 g S/ m^3d) in reported order to avoid odor nuisance.

Knörr and Torrella (1995) a higher removal efficiency of total coliforms in anaerobic ponds when compared to the facultative lagoons (the latter units were however more efficient at removing faecal coliforms). Some figures from this research carried out at a WSP system in the Mediterranean coast of Spain showed removals of one log unit for total coliforms in the anaerobic pond. Meanwhile, the viral removal efficiency was very poor in the anaerobic pond.

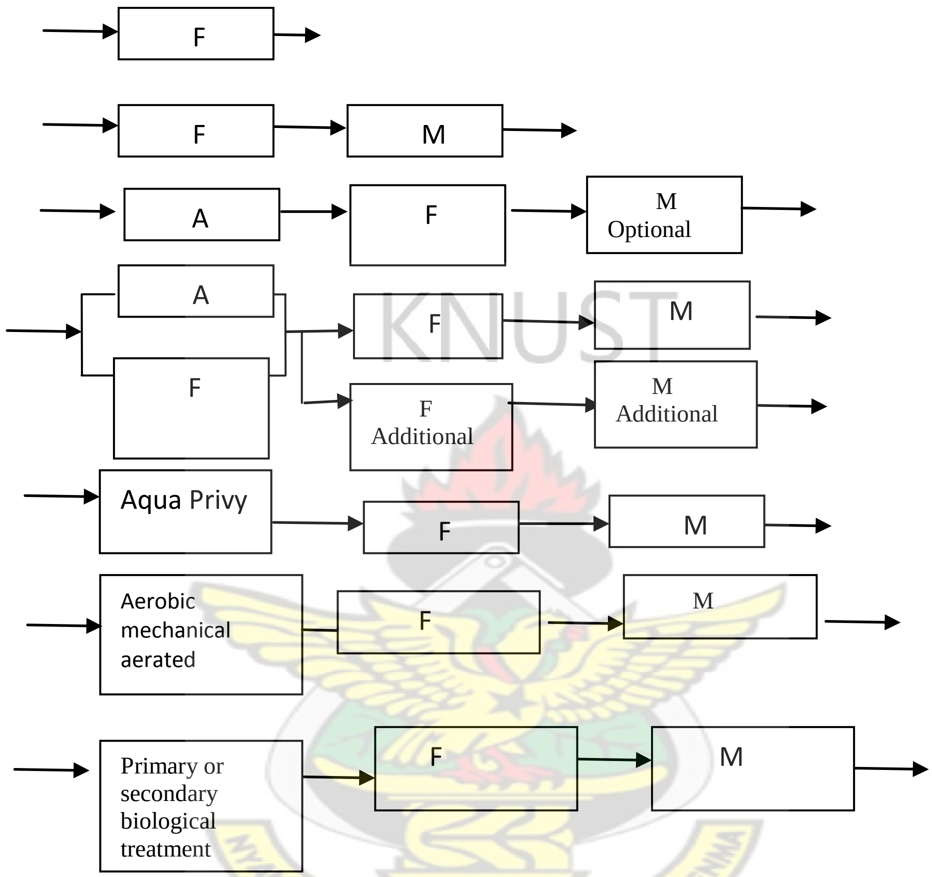
2.10.2 High Rate Algal Ponds (HRAP)

This was originally developed by Oswald at the University of California in the sixties, high-rate algal ponds have continued to be developed and implemented particularly in the United States. These systems are shallower than a facultative pond and operate at shorter hydraulic retention times. A paddlewheel is normally incorporated to drive the water around a "race-track" shaped pond. The oxygen production is reported to be significantly higher than typical facultative pond designs. The micro algae produced in these systems are also reported to have good settling properties (Green *et al*., 1996).

2.10.3 Waste Stabilization Ponds

Wastewater stabilization Ponds (WSPs) are one of the main natural methods for wastewater treatment. They are man-made earthen basins, located at any one point, and comprise of one or more series of anaerobic, facultative and, depending on the effluent quality required, maturation ponds. A typical stabilization system consists of several constructed ponds operating in series; larger systems often have two or more series of ponds operating in parallel. Treatment of the wastewater occurs as constituents are removed by sedimentation or transformed by biological and chemical processes. In the bottom of the ponds, a sludge layer forms due to the sedimentation of influent suspended solids as well as algae and bacteria that grow in the pond (Pena *et al.*, 2000).

Waste stabilization pond technology is the most cost-effective wastewater treatment for the removal of pathogenic microorganisms. The treatment is achieved through natural disinfection mechanisms. It is particularly well suited for tropical and subtropical countries because the intensity of the sunlight and temperature are key factors for the efficiency of the removal processes (Mara *et al.*, 1992). Wastewater stabilization pond systems are designed to achieve different forms of treatment in up to three stages in series, depending on the organic strength of the input waste and the effluent quality objectives. Effluent from first-stage anaerobic ponds will overflow into secondary facultative ponds, which comprise the second-stage of biological treatment. Following primary or secondary facultative ponds, if further pathogen reduction is necessary, maturation ponds will be introduced to provide tertiary treatment (Pescod and Mara, 1988).



F- Facultative pond
M- Maturation pond
Figure 2.3: Typical pond layout of wastewater stabilization ponds.
(Source: Pescod and Mara, 1988).

2.11 TYPES OF WASTEWATER STABILIZATION PONDS

2.11.1 Anaerobic Ponds

These units are the smallest of the series. Commonly they are 2-5 m deep and receive high organic loads equivalent to 100 g BOD_5 / m^3. d. These high organic loads produce strict anaerobic conditions (no dissolved oxygen) throughout the pond. In general terms, anaerobic ponds function a lot like open septic tanks and work extremely well in warm climates (Mara, 1997).

A properly designed anaerobic pond can achieve around 60 % BOD_5 removal at 20° C. One-day hydraulic retention time is sufficient for wastewater with a BOD_5 of up to 300 mg/l and temperatures higher than 20° C. Designers have always been preoccupied by the possible odour they might cause. However, odour problems can be minimised in well designed ponds, if the SO_4^{2-} concentration in wastewater is less than 500 mg/l. The removal of organic matter in anaerobic ponds follows the same mechanisms that take place in any anaerobic reactor (Pena, 2002).

According to Van Haandel and Lettinga (1994), BOD elimination rates for anaerobic wastewater ponds range from 50 to 85%. The biochemical reactions that take place in anaerobic ponds are the same as those occurring in anaerobic digesters, with a first phase of acidogenesis and a second slower-rate of methanogenesis. Gambrill *et al.* (1986) have suggested conservative removals of BOD_5 in anaerobic ponds as 40% below 10°C, at a design loading of 100 g/m^3d, and 60% above 20°C, at a design loading of 300 g/m^3d, with linear interpolation for operating temperature between 10°C and 20°C. Higher removal rates are possible with industrial wastes, particularly those containing significant quantities of organic settleable solids. Of course, other environmental conditions in the ponds, particularly pH, must be suitable for the anaerobic microorganisms bringing about the breakdown of BOD.

Knörr and Torrella (1995) reported a higher removal efficiency of total coliforms in anaerobic ponds when compared to the facultative lagoons (the latter units were however more efficient at removing faecal coliforms). Some figures from this research carried out at a WSP system in the Mediterranean coast of Spain showed removals of one log unit for total coliforms in the anaerobic pond. Meanwhile, the viral removal efficiency was very poor in the anaerobic pond. Arridge *et al*. (1995) working on an experimental WSP complex in Northeast Brazil found one log unit removal in the anaerobic pond for each of the following indicators: faecal coliforms, faecal streptococci and *Clostridium perfringens*. Salmonellae were reduced from 130 to 70 MPN/100 ml and *Vibrio cholerae* was reduced from 40 to 10 MPN/100ml respectively. Anaerobic ponds appear to be essential for high levels of *V. cholerae* removal. Oragui et al. (1995) reported the removal of one log unit for rotaviruses in the anaerobic pond of the experimental WSP complex located in Campina Grande in Northeast Brazil. A study by Grimason *et al*. (1993) found out that, occurrence and removal of *Cryptosporidium spp*. oocysts and *Giardia* spp. cysts in eleven WSP systems located in towns across Kenya. The results from this study showed that a significantly higher concentration of *Giardia* cysts was detected in raw sewage compared to anaerobic pond effluent.

2.11.2 Facultative Pond

The most common type of waste stabilization pond in current use, the facultative pond is designed to remove organic contaminants by natural biodegradation. The upper portion of the pond is aerobic, while the bottom layer is anaerobic which promotes nitrogen removal. Algae supply most of the oxygen to the upper portion (WHO, 2006).

According to Peña, (2002), facultative ponds are of two types: primary facultative ponds receive raw wastewater, and secondary facultative ponds receive the settled wastewater from the first stage (usually the effluent from anaerobic ponds).While primary facultative ponds are designed and used for the removal of both suspended solids and BOD/COD, secondary facultative ponds are designed and used for the removal of only BOD/COD. However, even nutrient and pathogen removal occurs coincidentally in the facultative ponds (Knorr and Torella, 1995).

Facultative ponds are typically designed with a depth of up to 2.5 m (Metcalf and Eddy, 2003). However, effluent 'reservoirs' with depths exceeding 6m are used to store sewage effluent in several countries, and a loading rate of 50 kg BOD $ha^{-1}.day^{-1}$ is typically considered to be the maximum allowable loading if odour control is the goal (Shilton, 2005). Therefore, facultative ponds may be deeper than 2.5 m to achieve the storage requirement if these loading rates are adopted (Reed *et al.*, 1995).

Facultative ponds are designed for BOD removal on the basis of a low organic surface load to permit the development of an active algal population. In this way algae generate the oxygen needed to remove soluble BOD. Healthy algae populations give water a dark green colour but occasionally they can turn red or pink due to the presence of purple sulphide-oxidising photosynthetic activity (Mara and Pearson, 1986). Facultative ponds should remove 80% of incoming BOD (Mason, 1997). However, Sukias *et al.* (2001) found that facultative ponds in New Zealand typically removed only 40% to 50% of the BOD remaining in effluent after treatment in an anaerobic pond. Removal efficiencies of up to 30 – 70 % N and 20 – 40 % P have been reported in facultative lagoons, (Shilton, 2005).

2.11.3 Maturation Pond

FAO (1992) reported that effluent from facultative ponds treating municipal sewage or equivalent input wastewater will normally contain at least 50 mg/l BOD_5 and if an effluent with lower BOD_5 concentration is required it will be necessary to use maturation ponds. For sewage treatment, two maturation ponds in series, each with a retention time of 7 days, have been found necessary to produce a final effluent with $BOD_5 < 25$ mg/l when the facultative pond effluent had a $BOD_5 < 75$ mg/l.

The main function of the tertiary treatment in the maturation pond is the removal of pathogens and nutrients (especially nitrogen). The treatment is achieved through natural disinfection mechanisms. It is particularly well suited for tropical and subtropical countries because the intensity of the sunlight and temperature are key factors for the efficiency of the removal processes (Mara *et al.*, 1992).

Maturation ponds are very shallow (usually around 1m depth), although Mara (1997) believes that at this reduced depth emergent plant growth and mosquito breeding problems can result. The size and number of maturation ponds needed in series is determined by the required retention time to achieve a specified effluent pathogen concentration. In the absence of effluent limits for pathogens, maturation ponds act as a buffer for facultative pond failure and are useful for nutrient removal (Mara and Pearson, 1998).

2.12 CLIMATIC FACTORS AFFECTING STABILIZATION PONDS PERFORMANCE

Physical and chemical factors affect the habitat of microorganisms and consequently the anaerobic sewage treatment process. The most important environmental factors to take into consideration are: temperature, pH, and degree of mixing, nutrient requirements, ammonia and sulphide control and the presence of toxic compounds in the influent (Van Haandel and Lettinga, 1994).

2.12.1 Light

The microbial population in ponds is greatly affected by the intensity and spectral composition of penetrating light. In ponds, photosynthetic oxygen production has been shown to be relatively constant within the range of 5280 to 53800 luman m^2 (US-EPA, 1983).

The presence of dissolved and particulate matter as well as organisms themselves influences the quantity and quality of light penetration in the ponds. These restrictions confine the photosynthetic activity only in the upper layer that is called euphotic zone of net photosynthetic activity. Light intensity from solar radiations varies with time and latitude. In cold climate, light penetration is reduced drastically because of snow cover. In tropical and subtropical regions, the stabilization pond system is the treatment choice due to increased total sunshine hours (US-EPA, 1983).

Hot climate is therefore ideal for pond operation as intense sunshine enables algal photosynthesis to occur for extended period and provide reserve dissolved oxygen for use during the night (Mara, 1978).

2.12.2 Temperature

As temperature rises, the rate of reaction also increases. In order to have a reasonable methane production rate, the temperature should be maintained above 20°C. Methane production rates are doubled for each 10°C temperature increase in the mesophilic range (Droste, 1997).

Temperature influences the photosynthetic oxygen production and biological degradation. Algae can survive at a temperature of 5 to 40^{o}C. Green algae show most efficient growth and activity at a temperature near 30 to 35^oC. Aerobic bacteria remain viable at a temperature range of 10 to 40^oC. For anaerobic bacteria present at bottom, the optimum temperature range is 15 to 65^oC. But in the ponds, they are exposed to lowest temperatures thus greatly reducing their activity (US-EPA, 1983)

Llorens *et al*. (1993) observed the highest primary productivity values in deep sewage stabilization lagoon during spring summer period which was characterized by high temperatures and an increased degree of solar radiation.

2.12.3 Wind

Wind is responsible for aeration and mixing but may also contribute to short-circuiting. Middlebrooks *et al*. (1982) studied the principle of wind mixing and suggested that wind mixing enhances the stabilization ponds performance and stressed that alignment of the lagoon inlet-outlet axisperpendicular to the prevailing wind direction is essential in reducing the effect of wind induced short- circuiting.

2.13 SOME IMPORTANT PARAMETERS RELATED TO STABILIZATION PONDS PERFORMANCE

2.13.1 Total suspended solids (TSS)

Approximately 75% of the municipal Suspended Solids (SS) are organic in nature and half of the organic solids are settleable. The distribution of these solids is not uniform throughout the system and the treatment stages preceding biological treatment exert a considerable influence on SS (Defrain and Schmidt, 1992).

The SS removal in stabilization ponds is a function of retention time. Ahmed *et al*. (1988) reported that SS removal increased with retention time from 1-3 days in anaerobic ponds. They reported that after 3 days, no significant reduction in SS was observed. Wolverton and McDonald (1979) and Xu *et al*. (1992) reported 90-95% removal efficiency of SS in macrohydrophyte ponds.

Tanner *et al*. (1995) observed 75-85% mean annual SS removal at nominal retention time of two to seven days in constructed wetlands. They suggested that high and often variable levels of SS are largely composed of phytoplankton biomass and detritus which commonly are discharge from stabilization ponds.

2.13.2 Dissolved Oxygen

Two major processes affect oxygen levels in the stabilization ponds: oxygen consumption by microbial respiration and rate of oxygen input via algal photosynthesis. Therefore, the maintenance of a permanently oxygenated environment in stabilization ponds depends on a positively balance equilibrium between respiration and photosynthesis (Abeliovich and Vonshak, 1993). Dissolved oxygen concentration of 0.5-2mg/l is sufficient to prevent the system from oxygen limitation (Lumbers, 1984b).

Beccari *et al.* (1992) observed marked decrease in the ratio of substrate removal rate and intrinsic ammonia oxidation rate when the dissolved oxygen concentration was <2mg/l. Shugui *et al.* (1994) reported that dissolved oxygen plays a significant role in the removal of primary organic pollutants such as alkyl benzene, chloro benzene and naphthalene in stabilization ponds. These compounds are degraded in the presences of oxygen. Kulin *et al*. (1983) used both Winkler method and portable dissolved oxygen meter for the determination of dissolved oxygen and suggested the use of portable dissolved oxygen meter.

2.13.3 pH

According to Zehnder *et al.* (1982), the optimum pH range for all methanogenic bacteria is between 6 and 8, but the optimum value is close to 7. Van Haandel and Lettinga (1994) reported the same observation and also pointed out that, since acidogenic populations are notably less sensitive to pH variations, acid fermentation will predominate over methanogenic fermentation. Thus, the system must contain adequate buffering capacity to neutralize the production of volatile acids and carbon dioxide, which dissolves at the operating pressure (Droste, 1997). Mara (2004) reported that as the pH increases, the proportion of total ammonia present as NH_3 also increases, thus ammonia toxicity increases with increasing pH. As ammonia toxicity increases with pH, it can be self-correcting at sub lethal concentrations. This is because rapid photosynthesis leads to a high pond pH (often 9–10), ammonia toxicity thus increases and therefore photosynthesis decreases; the pH falls and the ammonia toxicity decreases – this leads to increased photosynthesis, an increase in pH and therefore in ammonia toxicity, and so the cycle repeats itself.

2.13.4 Biochemical Oxygen Demand (BOD_5)

(BOD) indicates the amount of oxygen required by aerobic microorganisms to decompose the organic matter in a sample of water in a defined time period.

In stabilization ponds, Dissolved Oxygen (DO) has a very close relationship with BOD removal efficiency. The quantitative relationship between DO and BOD concentration after 20 month test by Bian and Li (1992) reported that DO of 4.9 mg/l was equivalent to BOD_5 of 30 mg/l which offered a good treatment effect in the normal operation of pond system. Gearheart (1992) worked on the stabilization ponds effluent and proved that lower hydraulic rates produced higher BOD_5 removal.

Panicker and Krishnamoorthi (1981) reported that 3 days retention time, the average BOD_5 removal in the lagoon was 81.4%. Retention period of 200-300 hours produced BOD_5 Of 10mg/l or less. Moreno *et al.* (1994) worked on lagoon treatment with 75kg BOD_5 / ha and reported 90% removal of BOD_5 at 20-60 days retention. Ahmed *et al.* (1988) reported that BOD_5 removal increase with retention time from 1-3 days in anaerobic ponds. Beyond 3 days no further significant reduction was observed.
Khan and Ahmad (1992) reported that even at high organic loading of 507kg / ha of BOD_5 the stabilization ponds worked well in subtropical region. This was mainly due to favourable climatic conditions in this part of the world.

Haraguchi (1990) used individual sewage treatment tank for the treatment of domestic wastewater with statistic daily BOD_5 load of 40gm/day/person. After treatment, the BOD_5 load was 4gm of the BOD_5 and removal was 90%. El-Rehaili (1995) observed that effect of chlorination on BOD_5 diminishes with increasing the organic content of the wastewater when primary settled wastewater was chlorinated with less than 50 mg/L chlorine. Mason (1997) confirms that Facultative ponds should remove 80% of incoming BOD. However, Sukias *et al.* (2001) found that facultative ponds in New Zealand typically removed only 40% to 50% of the BOD remaining in effluent after treatment in an anaerobic pond. When combined with the reductions achieved by the anaerobic pond, the pairing of an anaerobic pond and facultative storage pond removes around 90% to 95% of BOD.

2.13.5 Nitrogen Removal

In waste stabilization pond systems the nitrogen cycle is at work, with the probable exception of nitrification and denitrification. In anaerobic ponds organic nitrogen is hydrolyzed to ammonia, so ammonia concentrations in anaerobic pond effluents are generally higher than in the raw wastewater (unless the time of travel in the sewer is so long that all the urea has been converted before reaching the WSP). Volatilization of ammonia seems to be the only likely nitrogen removal mechanism occurring to some extent in anaerobic ponds (Hamzeh and Ponce, 2008). Soares *et al.* (1996) found a very low removal of nitrogen in anaerobic ponds.

Nitrogen removal occurs in facultative and maturation ponds, mainly through the incorporation of ammonia into algal cells (Mara, 2003). At high pH values, ammonia leaves the pond through volatilization. There is little evidence for nitrification (and hence denitrification, unless the wastewater has a high nitrate content) (Mara, 1997). This is due to the fact that the population of the nitrifying bacteria is low because of the lack of physical attachment sites in the aerobic zone. Total nitrogen and ammonia removal from WSP can reach 80 and 95%, respectively (Mara, 1997).

In stabilization ponds, nitrogen is found as soluble ammonia and as particulate and dissolved organic nitrogen while nitrates and nitrite are usually present in small concentration (Khan, 1999). Pano and Middlebrooks (1982) derived their equations for ammonia removal in facultative ponds which were receiving BOD loads of only 10–40 kg/ha day, much less than those used in warm climates. Silva *et al.* (1987) investigated nitrogen removal in WSP in northeast Brazil: they found that the Pano and Middlebrooks model was satisfactory for ammonia removal in facultative and primary maturation ponds, but not for removal in secondary and tertiary maturation ponds. Results for all facultative and maturation ponds showed that ammonia removal at 25–27°C was very well predicted. Mara *et al.* (1992) reported a total nitrogen removal of 80% in all waste stabilization pond systems, which in this figure corresponds to 95% ammonia removal. It should be emphasized that most ammonia and nitrogen is removed in maturation ponds.

2.13.6 Phosphorus

The mechanisms of phosphorus removal most likely take place in maturation ponds (Mara et al. 1992). Phosphorus removal formal in stabilization ponds may result from physical processes such as adsorption, coagulation and precipitation. Phosphorus removal in stabilization ponds has been reported to be 30 to 95% (US-EPA, 1983) Phosphorus removal in facultative and maturation ponds occurs mainly through precipitation as calcium hydroxyapatite at pH >9 (Mara,2003). However, overall Phosphorus removal in a series of WSP is often only ~50 per cent, with effluent concentrations usually >3 mg P/l. If lower concentrations are required by the regulator, in-pond dosing with aluminium sulphate ('alum') or ferric chloride can be effective in reducing Phosphorus levels from up to 15 mg/l to ~1 mg/l, without causing significant sludge accumulation (Surampalli *et al.*, 1995). Mara (1997) suggested that the best way to remove much of the phosphorus in the wastewater by WSP is to increase the number of maturation ponds. Converti *et al.* (1995) studied the effect of temperature on phosphate removal from sludge. They suggested that a temperature increase from 20^{o}C- 50^{o}C brings about a net reduction of phosphorus concentration higher than 60% in only 70 hours. Lo *et al.* (1994) studied the enhanced nutrient removal by oxidation reduction potential (ORP). Excellent phosphorus removal of 99.5% was attained under an ORP set point of 70-180 mv.

2.14 MICROBIAL QUALITY OF WASTEWATER.

Although microorganism had been observed in the 17th century, the recognition of water as a source of pathogenic organism was in the late 1800's when Von Fritsch described *Klesbsiella pneumonia* and *K. rhinoscleromatis* as microorganism characteristically found in human faeces (Ashbolt *et al.*, 2001).

By 1914, the U.S Public Health Service (U.S.P.H.S.) had adopted the coliform group as an indicator of faecal contamination of drinking water (Bitton, 2005). A total coliform count in water bodies is an important parameter for checking possible sewage contamination (Elmund *et al.*, 1999). Feachem *et al.* (1983) found that enteric pathogens enter the environment in the faeces of infected hosts and can enter water directly through defecation into water, contamination with sewage effluent or runoff from soil and surface water. The process of purification in stabilization ponds depends upon the presence of bacteria, algae and protozoa. The bacteria important in stabilization ponds are chemoautotrophs and chemoheterotrophs that are rod shaped facultative anaerobes and mesophilic (Khan, 1999).

In natural treatment systems such as WSP, the pathogens are progressively removed along the ponds series with the highest removal efficiency taking place in the maturation ponds (Mara *et al.*, 1992). The faecal bacteria of interest are the pathogens which cause infectious intestinal disease, such as *Campylobacter*, diarrhoeagenic *Escherichia coli*, *Salmonella*, *Shigella* and *Vibrio cholerae* and *E coli* which is used as a bacterial and viral pathogen indicator organism (Mara,2003).

Gearheart (1992) reported 99% removal of faecal coliforms in 6days retention time. He also suggested that a combination of oxidation ponds and wetland could effectively meet secondary effluent and public health standard of coliform of less than 200CFU/100 ml.

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

The Akosombo stabilization pond is located in the Asuogyaman district of the Eastern Region of Ghana. Akosombo is approximately between latitudes 6^0 34^0 N and 6^0 10^0 N and longitudes 0^0 1 W and 0^0 14 E. It is about 120 m above Mean Sea Level (MSL) and it covers a total estimated surface area of 26 $km^{2.}$ (ADA, 2006).

3.1.2 Relief and Drainage

The topography of the town is generally undulating. It is mountainous, interspersed with low lying plains to the west and the east. The mountainous terrain is rugged and characterised by the configuration of several summit and steep slopes of hard sandstone and quartzite ridges many rock out crops and scarps. Rain water is drained by the Volta Lake created as a result of the construction of the Dams (ADA, 2006).

3.1.3 Climate

Akosombo lies within the dry equatorial climate zone, which experiences significant amount of precipitation. This is characterized by a double maxima rainfall seasons, which reaches its peak rainfall period from May to July. Annual rainfall usually starts in April with the peak month in June and ends in November. The annual rainfall is between 670 mm and 1130 mm. The dry season sets in November-December and ends in March. The temperature is warm throughout the year with maximum reaching 37.2^0 C and a minimum of 21.0^0 C. Relative humidity is generally high ranging from the highest of 98% in June to 31% in January (ADA, 2006).

3.1.4 Vegetation

The vegetation is predominantly dry semi-deciduous forest and savannah woodland. The natural bio-physical environment appears rather vulnerable to farming and other forms of environmental stress (ADA, 2006).

3.1.5 Geology & Soil

The main rock types of the area are quartzite acidic, gneiss and schist. These are coarse-grained muscovite and biotite schist and gneiss containing numerous quartz veins. Several out – crops of the rocks are in the area. Upland along the hill slopes, the soils consist mainly of forest littosol and laterites. In the low lying areas along the Volta Lake, the soil type falls within the Savannah Greisol and Aluviosols. There are hydro – morphine soils confined to the large depression and valley bottoms of the Volta river plains. The soil is greyish, dark red in colour. It is mainly impervious and moderately supplied with nutrients. Because of its structure, the soil is liable to temporary flooding in times of high water levels. Its nutrients status is moderate but to ensure sustained yield of crops it requires the use of fertilizers (ADA, 2006).

3.2 THE AKOSOMBO STABILIZATION POND

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. 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. The ponds are sited 200 m from the Volta River, below the Akosombo power generation station.

The design of the Akosombo stabization pond was carried out in accordance with the facultative pond criteria. The system was designed to consist of three ponds; facultative pond, first maturation and second maturation ponds in series. There are three inlet points to the first pond. These represent influent from three different parts of the township. The sewage enters retention chambers and then pumped into the pond at two of the inlet points. The third flows by gravity. A screen is provided for solids removal before entering the pond. There is also a flume for flow rate determination. However, only two ponds are in operation. The third pond will be constructed when the quality of effluent from the ponds does not meet GEPA guidelines. The final effluent is discharged through a 12 inch diameter asbestos pipe and falls into the main township drain from a height of 1.5 m. The mixture of wastewater from the drain and effluent is discharged into the Volta River.

The dimensions of the ponds in their final configuration are based on the data below.

Population	30,000
Sewage flow (50gal/cap days)	6.8m^3 / day
Biological Oxygen Demand (80g/cap day	2,400kg/day
Suspended solids (90g/cap day)	2700kg/day
Volumetric loading rate	250kg BOD/ha/day

Assumption

The criteria is based on the assumption that in a tropical climate such as that of Akosombo, a facultative pond can be loaded with as much as 250 kg/ha day of BOD and a further treatment of 4 to 6 days is advisable in full aerobic maturation ponds. The dimensions of the ponds are given in Table 3. 2

Table 3.1 The dimension of the ponds

POND	Area (ha)	Depth (m)	Retention (Days)
Facultative	9.6	1.7	24
First maturation	2.5	0.8	3

3.3 THE FACULTATIVE POND

This treatment area is a combination of aerobic-anaerobic system. The depth is approximately 1.7 m and the waste water is supposed to remain in it for a period of 24 days.

Plate 1: The facultative pond

3.4 THE MATURATION POND

The maturation pond is designed to be the aerobic type with depth of 0.8 m and retention time of 3 days.

Plate 2: The maturation pond

The two ponds are at different levels and therefore the treated water flows by gravity from one to the other and the final effluent is discharged through an asbestos pipe into the Volta Lake.

3.5 SAMPLING

Bimonthly water samples were collected from the system influent (Raw), effluents from the facultative Pond, maturation pond and the system effluent between February and April 2011. Samples were collected early in the morning between 7:00 and 9:00 am from all the four sampling sites into sterilized glass bottles using a hand held sampler. Samples were taken at 10 cm depth of the ponds. Samples were immediately transported in an ice-chest containing ice pack to the VRA and CSIRWRI laboratories for analysis.

3.6. TEMPERATURE, TOTAL DISSOLVED SOLIDS (TDS) AND pH

The water temperature, TDS and pH were measured with Cyberscan water meter (model CON 410). This composite meter allows reading to be taken fast and thereby eliminate errors due to time.

3.7 DISSOLVED OXYGEN (DO)

The dissolved oxygen was measured *in-situ* with Eutech international water meter (MODEL DO700) and the reading taken in mg/l DO

3.8 TOTAL SUSPENDED SOLIDS (TSS)

The Photometric method was used in TSS determination. Five hundred milliliters (500 ml) of the sample was blended at high speed for two minutes. The blended sample was poured into a 600 ml beaker and stirred. Ten milliliters (10 ml) of the blended sample was poured into a sample cell. A second sample cell (blank sample) was filled with deionized water to the 10 ml mark and swirled to remove gas bubbles. The blank sample was inserted into the cell holder with the fill line facing right. The reading was taken as 0 mg/l TSS. The prepared sample was swirled to remove any gas bubbles and uniformly suspend any residue. This was then inserted into the cell holder of the HACH spectrophotometer (Model DR2800) and the reading taken in mg/l TSS.

3.9 BIOCHEMICAL OXYGEN DEMAND (BOD_5)

Five-day biochemical oxygen demand (BOD_5) levels in water samples were determined using the Winkler's method (azide modification) and standard laboratory procedures (APHA, 1995)

3.10 CHEMICAL OXYGEN DEMAND (COD)

Chemical Oxygen Demand was determined by the closed reflux, titrimetric method as described in the standard method for the examination of water and wastewater (APHA, 1995).

3.11 AMMONIA-NITROGEN (NH_3-N)

Ammonia Nitrogen was determined by the Salicylate method. A square sample cell was filled to the 10 ml mark with the prepared sample. A second square sample cell was filled to the 10 ml mark with deionized water (blank). The content of one Ammonia Salicylate powder pillow was added to each cell, stopper and shaken to dissolve. A reaction period of three minute was allowed, after which the content of one Ammonia Cyanurate reagent powder pillow was added to each cell, stopper and shaken to dissolve. During a 15 minute reaction time, a green colour developed to indicate the presence of ammonia-nitrogen. When the 15minute reaction time expired, the blank was inserted into the cell holder of the Hach spectrophotometer (Model DR2800) and the reading was taken as 0.00 mg/L NH_3-N. After that the sample was inserted into the cell holder and the reading taken in mg/l NH_3-N.

3.12 NITRATES

The nitrate level in each sample was measured using the Cadmium Reduction Method by direct reading using the Hach spectrophotometer (model DR 2800). Fifteen milliliters (15 ml) of the sample was measured into a 25 ml graduated cylinder. The content of NitraVer 6 reagent powder pillow was added and vigorously shaken for three minutes. A two minute reaction time was allowed after which 10 ml of the solution was poured into a clean square sample cell making sure that no cadmium is transferred. The content of one NitriVer 3 Nitrite reagent powder pillow was added to the solution in the sample cell and shaken gently for 20 seconds. The solution was allowed to react for 15 minutes after which a second square sample cell was filled to a 10ml mark with the original sample (bank). After the 15 minute reaction period, the blank sample cell was placed into the cell holder of the spectrophotometer for calibration. The prepared sample was then placed into the cell holder to determine the nitrate concentration.

3.13 PHOSPHORUS

Phosphorus was determined using the PhosVer 3 (Ascortic Acid) Method. A square sample cell was filled to the 10 ml mark with the sample. The content of one PhosVer 3 phosphate Powder Pillow was added to the cell and vigorously shaken for 30 seconds. After 2 minutes of reaction time, the second sample cell is filled to the 10 ml mark with the original sample (blank). After the 2 minute reaction period, the blank sample cell was placed into the cell holder of the spectrophotometer for calibration. The prepared sample was then placed into the cell holder to determine the phosphorus concentration.

3.14 TOTAL AND FEACAL COLIFORM

The enumeration of feacal and total coliforms was done using the Membrane Filtration (MF) Method.

Serial dilutions were prepared in order to reduce the concentration of the water sample. A growth pad was dispensed into a sterile petri dish and saturated with Membrane Lauryl Sulphate Broth (MLSB). A sterilized forceps was used to pick the filter membrane (0.45 µm pore size) onto the bronze membrane support of the filtration unit. The water sample was poured into the filter funnel up to the 100 ml graduation and the hand vacuum pump was applied to pass the water through the membrane. For feacal coliform, the filter was placed on the top of the MLSB saturated pad in a seal petri dish, inverted, and submerged in a water bath and incubated at $44^{o}C$ for 18 hours. Colonies which appeared red with a metallic green sheen were counted and expressed in CFU/100 ml. For total coliform, the filter was placed on the top of the MLSB saturated pad in the petri dish and incubated at $37^{o}C$ for 18 hours. Visible colonies which appear yellow were counted and expressed in CFU/100 ml.

3.15 DATA HANDLING AND ANALYSIS

Raw data was captured in the computer using Microsoft Excel Spreadsheet 2003. The analyses were executed by SPSS (version 16 for Windows, year 2003). The data was presented in the form of tables and charts.

CHAPTER FOUR

RESULTS

4.1 PHYSICAL QUALITY OF SAMPLES FROM THE STABILIZATION PONDS

Results of the physical parameters of the water samples from the various ponds of the treatment plant are shown in Table 4.1. Generally there was an increase in pH levels from the various treatment ponds. However, these increases were not statistically significant ($p > 0.05$). The temperature levels in the ponds decreased along the treatment process line although these decreases were not statistically significant ($p > 0.05$). Significant reductions ($p<0.05$) were observed in Total suspended solids levels from the raw water sample through the facultative pond to the effluent point. However, Total Dissolved Solids decreased from an average of 142.83 mg/l in the raw water sample to 137.50 mg/l in the effluent. This decrease was however not significant.

Table 4.1: Physical quality of samples from the various treatment ponds

Parameter	Sampling Ponds of the Treatment Plant			
(units)	Raw	Facultative	Maturation	Effluent
pH	6.97 (±0.11)	6.97 (±0.04)	7.15 (±0.09)	7.32 (±0.12)
Temperature (^{0}C)	29.12 (±0.26)	29.08 (±0.29)	28.90 (±0.37)	28.93 (±0.30)
TSS (mg/l)	143.97 (±12.17)	105.00 (±7.96)	71.76 (±8.16)	35.67(±10.03)
TDS (mg/l)	142.83(±19.66)	108.17 (±1.74)	131.83 (±18.44)	137.50 (±17.85)

Figures in parenthesis are standard errors (n=24)

4.2 NUTRIENT LEVELS IN THE WATER SAMPLES FROM THE STABILIZATION PONDS

One major function of a stabilization pond is the removal of nutrients to prevent algal bloom. Recorded average ammonia levels in the raw wastewater was 8.53 mg/l but this was significantly ($p<0.05$) reduced to 0.07 mg/l in the effluent (Figure 4.1). Additionally, Nitrates were also significantly reduced ($p<0.05$) from a mean value of 1.68 mg/l in the raw wastewater to 0.56 mg/l in the effluent (Figure 4.2). Furthermore, phosphates were significantly reduced ($p<0.05$) from 1.77 mg/l to 1.32 mg/l in the effluent (Figure 4.3).

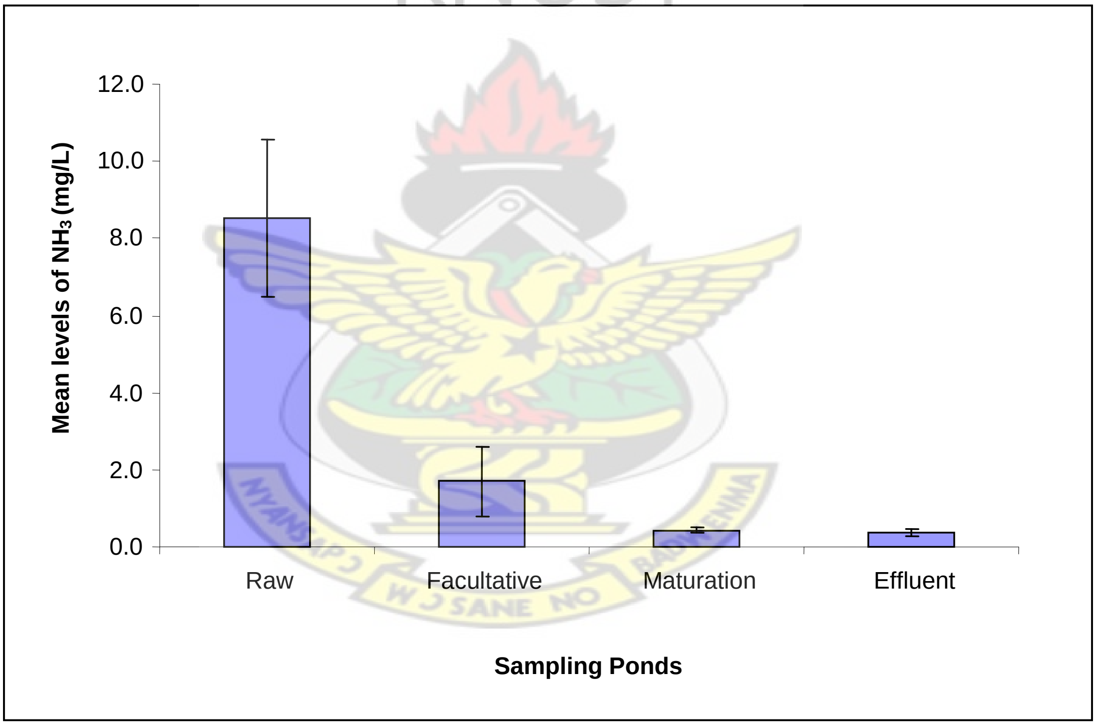


Figure 4.1: Ammonia levels in samples from the various treatment ponds

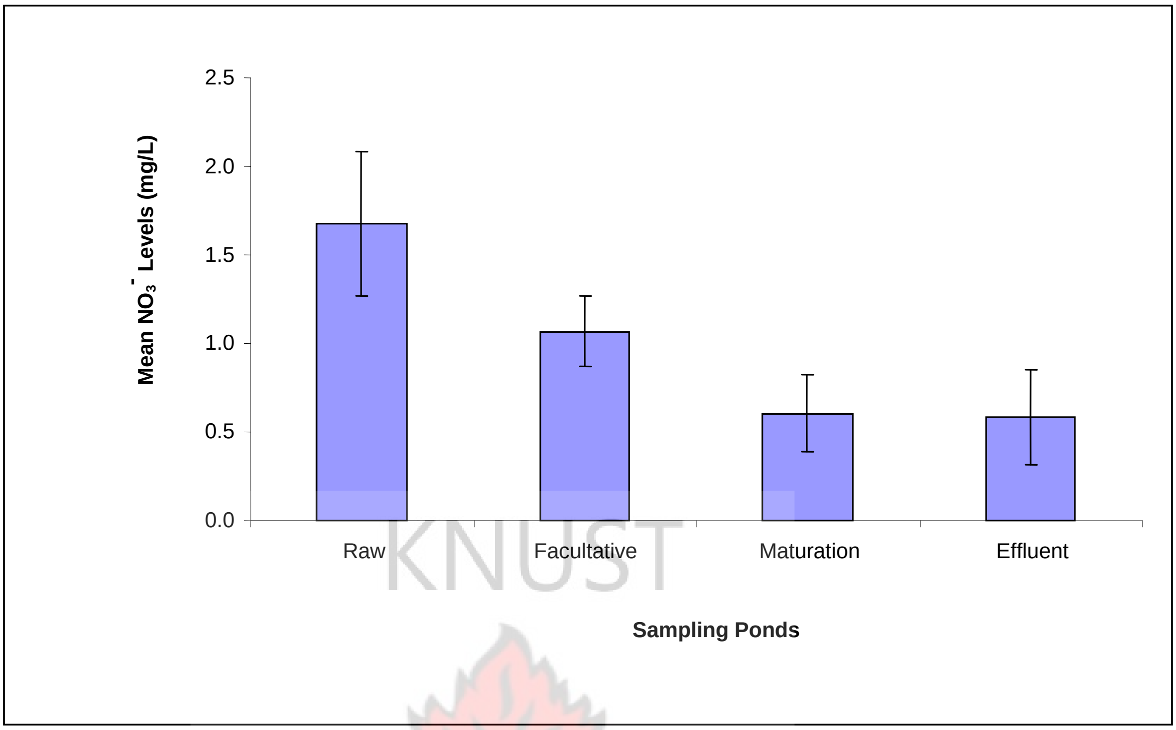


Figure 4.2: Nitrate levels in samples from the various treatment ponds

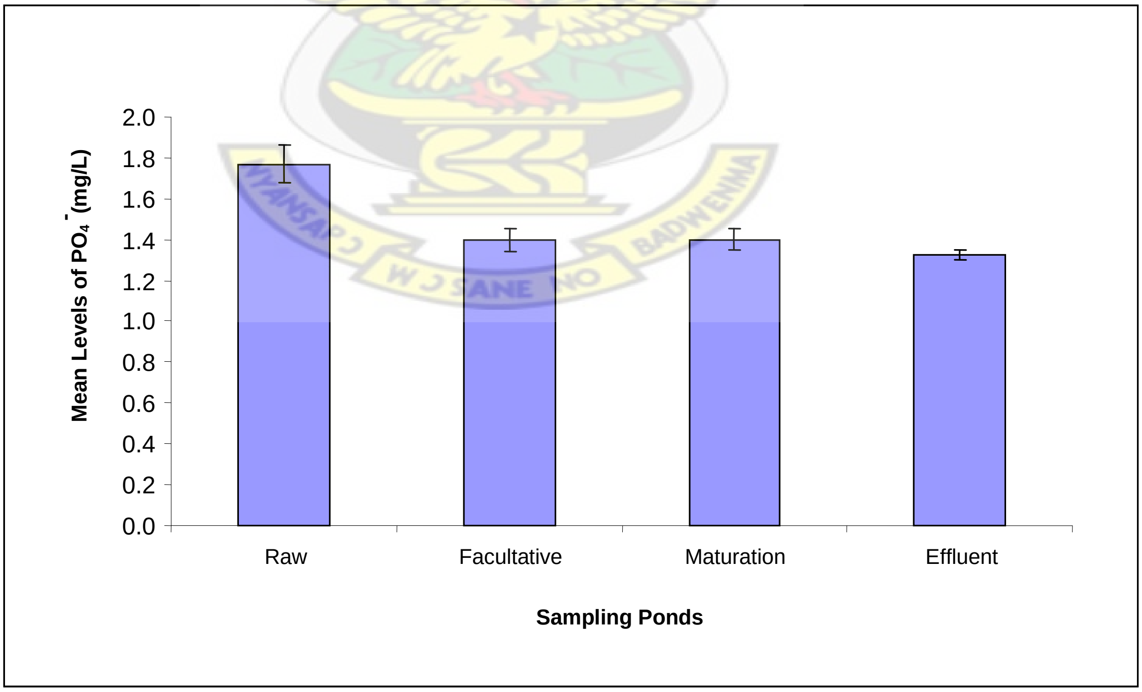


Figure 4.3: Phosphate levels in samples from the various treatment ponds

4.3 OXYGEN DEMAND OF THE WATER SAMPLES FROM THE STABILIZATION PONDS

The oxygen content of wastewater is low because of the pollutant concentration. The oxygen content of wastewater is determined by Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of the water. There was a significant ($p<0.05$) increase in the mean DO level in the raw wastewater (0.54 mg/l) to 2.94 mg/l in the effluent (Figure 4.4). The BOD level in the wastewater significantly ($p>0.05$) decreased from a mean of 42.21 mg/l in the raw wastewater to 8.91mg/l in the effluent (Figure 4.5). Similar trend were observed in the COD level; however the decrease was not significant ($p>0.05$) (Figure 4.6) as COD in the raw wastewater, 364.72 mg/l was reduced to 130.73 mg/l in the effluent.

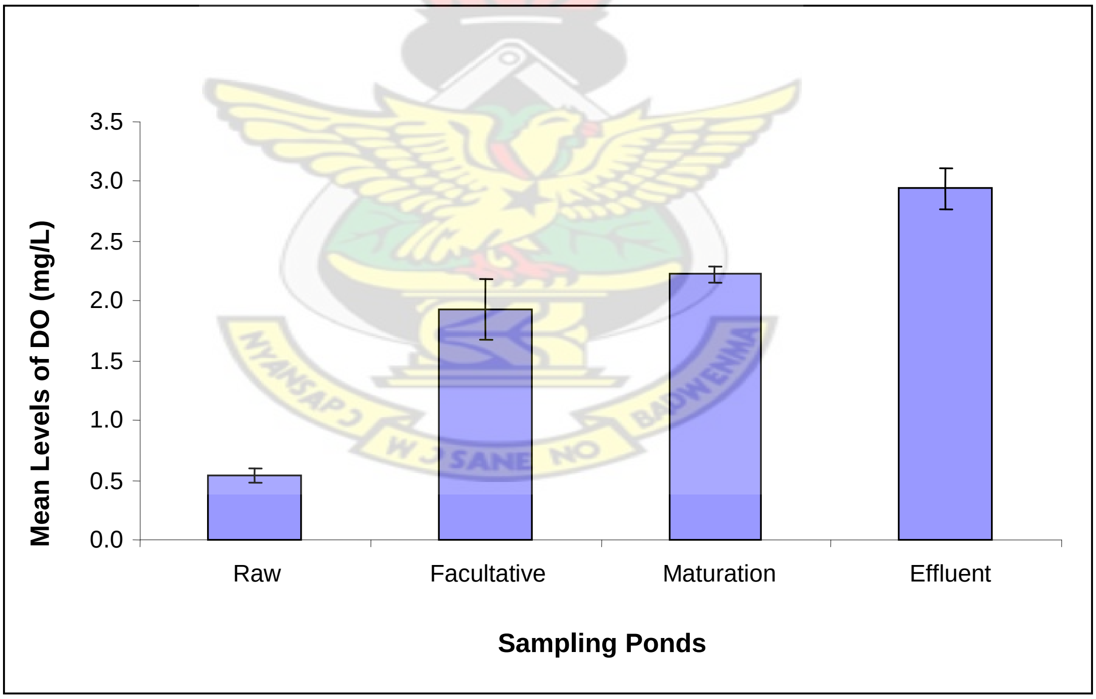


Figure 4.4: DO levels in samples from the various treatment ponds

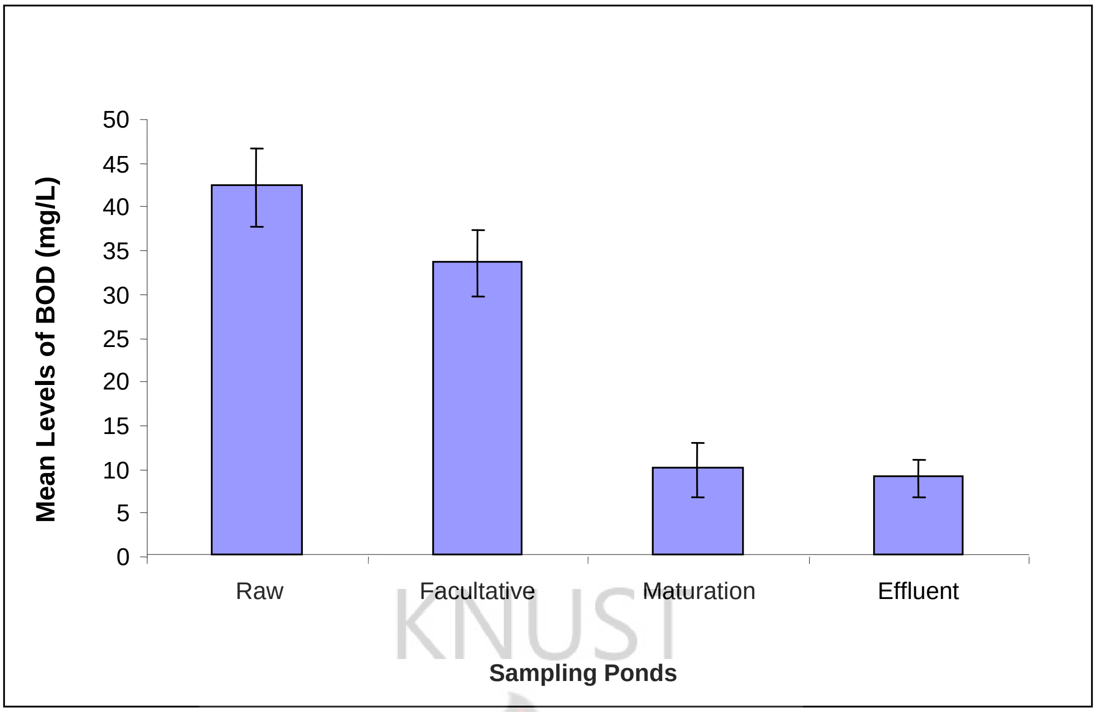


Figure 4.5: BOD levels in samples from the various treatment ponds

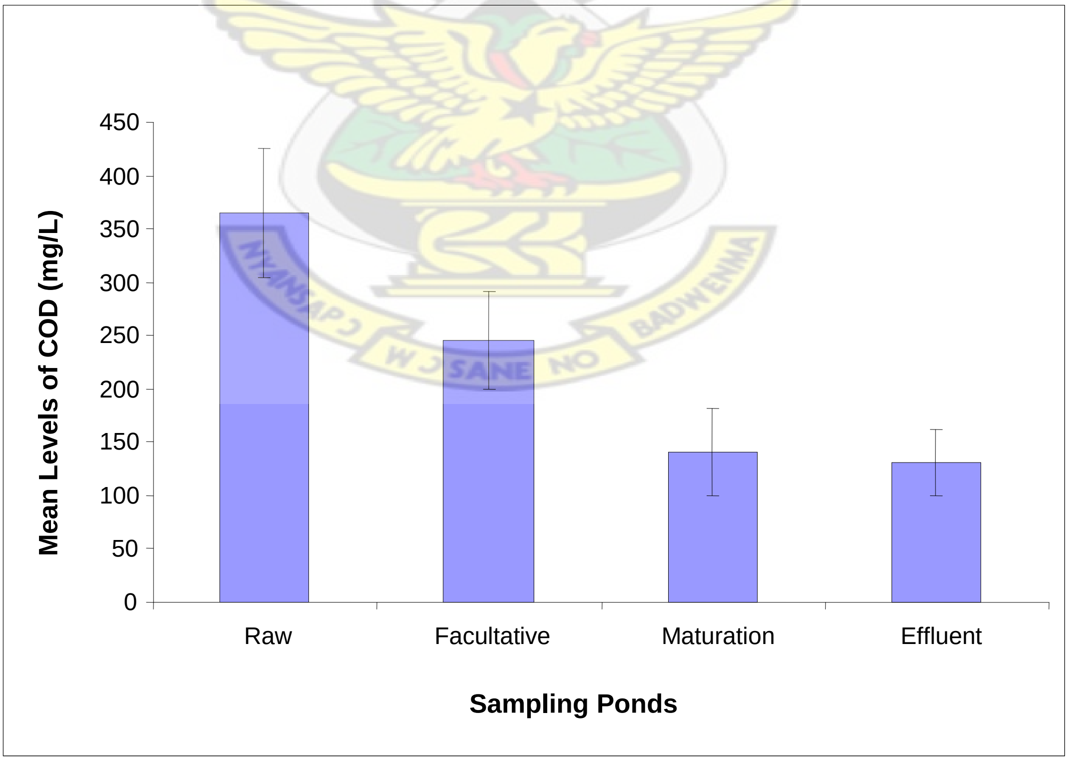


Figure 4.6: COD levels in samples from the various treatment ponds

4.4 MICROBIAL QUALITY OF WASTEWATER FROM THE STABILIZATION POND

The microbial load of the wastewater determines the extent of contamination of the water. There was a significant reduction ($p<0.05$) in both total and faecal coliforms in the raw wastewater compared to the effluent. The mean total coliform counts (100 ml) were $9.43x10^6$ in the raw wastewater which was reduced to $2.83x10^2$ in the effluent. However, faecal coliforms (100 ml) reduced from $5.97x10^6$ in the raw wastewater to $5.67x10^1$ (Figure 4.7).

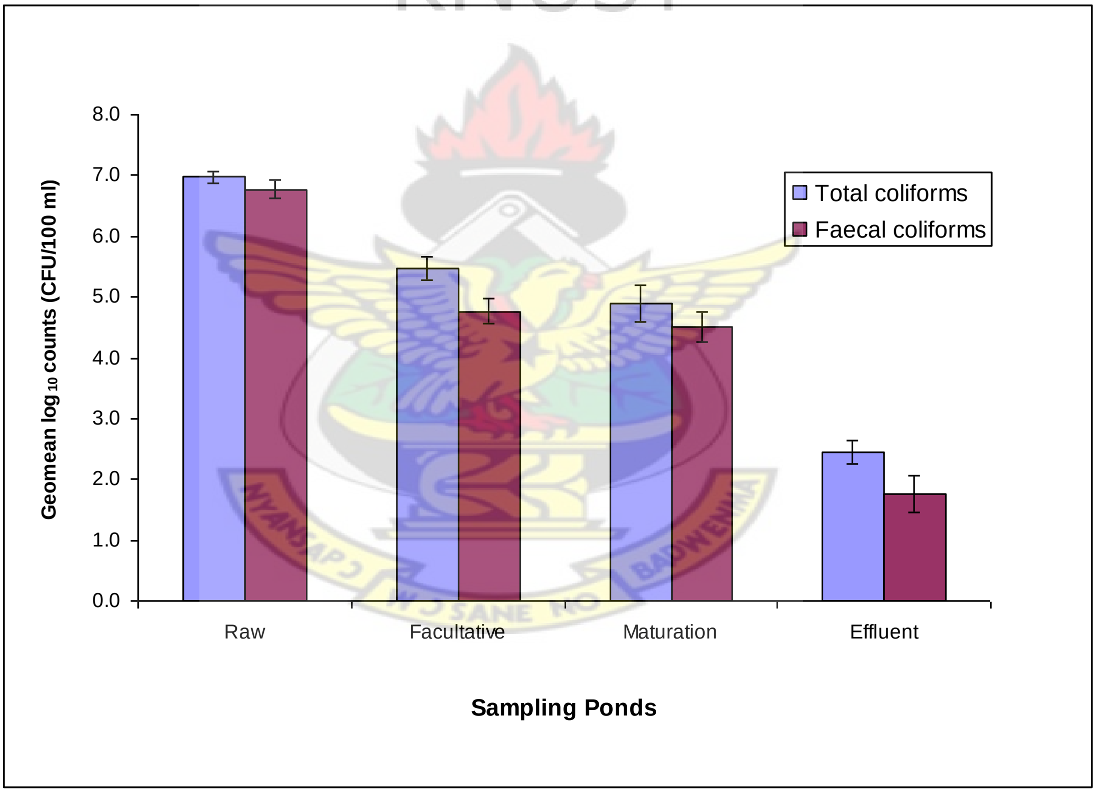


Figure 4.7: Microbial quality of samples from the various treatment ponds

4.5 EFFICIENCY OF THE WASTEWATER STABILIZATION POND

There was a slight increase in pond temperatures whilst pH decreased (Table 4.2). However, mean TDS of 142.83 mg/l in the raw wastewater was reduced by 24.3% and 7.7% after the facultative and maturation ponds. The overall removal was 3.7%. The effluent indicated an average DO value of 2.94 mg/l which had been increased from 0.54 mg/l in the raw wastewater. Effectively, this was an increase of 72.0% and 13.1% from the facultative pond to maturation pond with an overall increase of 81.6%. Removal efficiencies of BOD were 20.5% and 70.3% in the facultative and maturation ponds, respectively. The overall BOD removal efficiency was 78.9%. The average removal efficiencies of organic load in the wastewater stabilization pond measured as COD were 32.6% and 42.8% after facultative and maturation ponds respectively with an overall COD removal efficiency of 64.2%. The ammonia removals which serve as nutrient in the wastewater were 80.1% and 74.7% after the facultative and maturation pond respectively with an overall ammonia efficiency of 95.5%. Nitrate removal efficiencies were also 36.3% and 43.9% after facultative and maturation respectively. The overall nitrate removal was 64.9%. The results also indicated that phosphate was also reduced by 20.9% and 0.0% after facultative and maturation ponds respectively. The overall reduction was 25.4%. TSS removal efficiencies by the stabilization pond were 27.1% and 31.7% after facultative and maturation ponds respectively. The overall TSS removal efficiency was 75.2%. The average removal efficiencies of bacterial loads within the facultative pond were 1-2 $\log_{10}$ (96.9-99.6%) for total coliforms, and 100% for faecal coliforms.

Table 4.2: Mean removal efficiency of parameters in the stabilization pond

Parameters (units)	Sampling Ponds (Mean levels of parameters)			
	Raw	Facultative	Maturation	Effluent
pH	6.97	6.97	7.15	7.32
Temperature (^oC)	29.12	29.08	28.90	28.93
TDS (mg/l)	142.83	108.17	131.83	137.50
DO (mg/l)	0.54	1.93	2.22	2.94
BOD_5 (mg/l)	42.21	33.54	9.97	8.91
COD (mg/l)	364.72	245.73	140.52	130.73
NH_3^-N (mg/l)	8.53	1.70	0.43	0.38
NO_3^- (mg/l)	1.68	1.07	0.60	0.59
TSS (mg/l)	143.97	105.00	71.67	35.67
Total P (mg/l)	1.77	1.40	1.40	1.32
Total Coliforms (CFU/ 100ml)	$9.43x10^6$	$2.96x10^5$	$7.68x10^4$	$2.83x10^6$
Faecal Coliform (CFU/100ml)	$5.97x10^6$	$5.80x10^4$	$3.30x10^4$	$5.67x10^1$

Table 4.3: Percentage removal efficiency of parameters in the stabilization pond

Parameters (units)	Sampling Ponds (Percentage levels of parameters)		
	Facultative Pond	Maturation Pond	Overall Removal
TDS (mg/l)	24.3	7.7	3.7
DO (mg/l)	72.0	13.1	81.6
BOD_5 (mg/l)	20.5	70.3	78.9
COD (mg/l)	32.6	42.8	64.2
NH_3^- N (mg/l)	80.1	74.7	95.5
NO_3^- (mg/l)	36.3	43.9	64.9
TSS (mg/l)	27.1	31.7	75.2
Total P (mg/l)	20.9	0.0	25.4
Total Coliforms (CFU/ 100ml)	96.9	74.0	100.0
Faecal Coliform (CFU/100ml)	99.0	43.0	100.0

4.6 COMPARISON OF EFFLUENT LEVELS WITH EPA PERMISSIBLE LEVELS

The levels of compliance of effluents with the physicochemical and microbial parameters were all below the EPA permissible levels except faecal coliforms (Table 4.4). This confirms that the stabilization pond is effectively treating the wastewater to the acceptable EPA permissible guideline levels. An average overall effective reduction was 86.5% for the stabilization pond.

Table 4.4: Comparison of effluents with EPA Permissible levels

Parameters (Units)	Effluents Levels	EPA Permissive Levels
pH	7.31	6-9
Temperature (^oC)	28.93	<30˚C
TDS (mg/l)	137.50	1000
DO (mg/l)	2.94	>3.0
BOD_5 (mg/l)	8.91	50
COD (mg/l)	130.73	250
NH_3^- N (mg/l)	0.38	1.0
NO_3^- (mg/l)	0.59	50
TSS (mg/l)	35.67	50
Total P (mg/l)	1.32	2.0
Total Coliforms (CFU/ 100ml)	283.33	400
Faecal Coliform (CFU/100ml)	56.67	10

CHAPTER FIVE

DISCUSSION

5.1 PHYSICAL PARAMETERS AS A MARK OF EFFICIENCY OF THE STABILIZATION POND

Waste stabilization ponds are widely used for the treatment of wastewater in rural areas (Racault and Boutin, 2005). Changes in pH within the stabilization pond along the treatment process (i.e. Raw to final effluent) increased but remained neutral in all the ponds. The neutral range in pH in the ponds suggests that methanogenesis was taking place; otherwise a build-up of fatty acids, the products of acidogenesis, would eventually overcome the buffer capacity of the wastewater and cause the pH to drop (Nelson *et al.*, 2004). This condition is favorable for most bacteria, biological processes and biochemical reactions in ponds especially for aquatic plants and animals which require minimal range of pH for growth. The neutral pH values obtained in this study is similar to that reported by Hodgson (2007). In general, the mean pH of 7.31 was within the Ghana Environmental Protection Agency (GEPA) standard of 6-9 and World Health Organization standard of 7.0 to 8.5.

The study revealed that temperature changes within the stabilization ponds were not statistically significant ($p > 0.05$). Although some decreases were recorded this may have been as a result of the large surface area of the ponds and mixing due to wind velocity caused by trees planted at the embankment of the ponds. This may have effect in the efficiency of organic matter removal and photosynthesis by algae. The mean temperature of 28.93^{o}C in the final effluent was lower than the recommended limit for no risk according to the EPA, Ghana (<30^{o}C) water quality guidelines for domestic use. Based on this guideline, the temperature of the final effluent may not pose any threat to the homeostatic balance of the receiving water bodies (Jaji *et al.* 2007).

The TDS decreased from an average of 142.83 mg/l in the raw water sample to 137.50 mg/l in the effluent which was not high enough to influence the quality of the receiving water body. According to McCulloch *et al.* (1993), elevated TDS can be toxic to freshwater animals by causing osmotic stress and affecting the osmoregulatory capability of the organisms.

Total suspended solids (TSS) include all suspended particles in the water samples from the various sampling ponds. In this study, significant reductions ($p<0.05$) were observed in TSS levels from the raw sample to the effluent point. The concentration of TSS in the raw sewage decreased from the facultative pond towards the pond outlet. The higher TSS concentration near the inlet in the facultative ponds may result in greater thickness of the sludge layer, which causes more compression, but this may also be affected by a higher fraction of silts and sand that settle out near the inlet (Nelson *et al.*, 2004).

The effect of waste discharge on a surface water source is largely determined by the oxygen balance of the system and its presence is essential in maintaining biological life within a system (DFID, 1998). The DO in the facultative pond (72%) was high in the final effluent.

Dissolved oxygen concentrations in unpolluted water normally range between 8 and 10 mg/l and concentrations below 5mg/l adversely affect aquatic life (DFID, 1998; Rao, 2005). DO standards for drinking water purposes is 6*mg/l* whereas for sustaining fish and aquatic life is 4-5 mg/l (Rao,2005). The DO value from this study was within the recommended standard set by Ghana Environmental Protection Agency (GEPA).

5.2 PERFORMANCE OF THE FACULTATIVE POND

The strength of the raw sewage is determined by its organic loading. Sewage with BOD more than 500 mg/l is classified as strong whereas those with concentrations less than 200 mg/l are weak (Mara, 2003). Removal efficiencies observed for the facultative pond, for organic matter (BOD and COD) was lower, 42.2 mg/l than the design removals. Hence, the average BOD loading of the raw sewage will be classified as weak. This was reduced to 33.54 mg/l in the facultative pond. The BOD removal efficiencies observed were much lower than the expected efficiency at an average temperature of 29.08^{o}C, 20.5%. Studies by Sukias *et al.* (2001) showed that facultative ponds in New Zealand typically removed only 40% to 50% of the BOD in effluent after treatment in an anaerobic pond. This could be because of heavy sludge accumulation (not desludged for the last 10 years) and the consequent reduced HRT and hydraulic short circuiting. This is also apparent from the lower TSS removal efficiency observed, 27.1%. The results also suggest that algal activity was more intense in the facultative pond than the maturation pond. This is reflected in the high ammonia uptake, 80.1% (Table 4.3).

The nutrients studied in the facultative pond were ammonia-nitrogen, nitrate and phosphorus. The 80.1% ammonia-nitrogen removal is anticipated since the rate of ammonia uptake is proportional to the initial concentration, 8.53 mg/l (Table 3.2) and therefore higher removal efficiencies was achieved when initial concentration was high. Phosphorus and nitrate removal were very low in the facultative pond, 20.9% and 36.3% respectively compared to removal efficiencies of up to 30 - 70% N and 20-40% P in facultative lagoons (Shilton, 2005). This may mean phosphorus is either incorporated into new algal biomass or part settled to the bottom in the form of non-biodegradable death algae material. Phosphorus can also be removed by precipitation as inorganic P.

From the obtained results, it can be observed that the facultative pond was more efficient in the reduction of classical bacterial indicators, total and faecal coliforms. Most of the total coliform (96.9%) and faecal coliform (99.0%) were removed in the primary facultative pond. This may be due to the high temperature in the facultative pond (Table 4.2).

5.3 PERFORMANCE OF THE MATURATION POND

The average removal efficiencies of organic load in the maturation pond measured as COD and BOD were 70.3% and 42.8% respectively. The study revealed that the maturation pond removed more of the incoming BOD than the facultative pond. This condition was due to relatively high pH (7.15) which favours algal activities in degrading organic matter in the pond. The increase in pH value is due to CO_2 consumed during photosynthesis of the algae (Mahassen *et al.,* 2008).

The common practice in the design of the WSP is not based on nutrient removal; rather, it is based on BOD and faecal coliforms removal. The results of this study show that, the maturation pond removed more of the incoming ammonia nitrogen than nitrate and phosphorus. Mara *et al*. (1992) reported a total nitrogen removal of 80 % in all waste stabilization pond systems, which almost corresponds to 74.7 % ammonia removal in this study. The low removal of nitrate and 0.0% removal of phosphorus may be explained by the fact that extensive algal growth exhausts available nutrients. Yan and Jameson, (2004) reported that the amount of nitrogen and phosphorus removed from the maturation pond depends on algal biomass. Mara (1997) suggested that the best way to remove much of the phosphorus in the wastewater by WSP is to increase the number of maturation ponds. However, both nitrogen and phosphorus must be removed in order to prevent eutrophication in receiving water bodies.

Maturation ponds are designed for pathogen removal. In this study, coliform removal in the maturation pond decrease along the system reaching values of 74.0% and 43.0% for total and fecal coliforms respectively. The decrease in coliform levels may be due to the short retention time of the maturation pond (3 days). Similar trend was observed by Hodgson (2007). According to Hodgson (2007), retention time, temperature, pH and light intensity influence the coliform removal efficiency of facultative and maturation ponds. Also, the entrance of effluent from the facultative pond to the maturation pond was from one point. This may mean bad distribution of the wastewater and bad mixing with the microorganisms in the pond.

5.4 POTENTIAL IMPACT ON THE RECEIVING WATER QUALITY

The final effluent joins the town drainage water and flows into the lower Volta River. All the physicochemical and total coliform parameters observed were in compliance with the standard set by GEPA. With the exception of faecal coliform, which did not comply, the bacteriological quality of the sewage effluent cannot possibly cause any detrimental effect on the river quality. Dilution expected from the lower Volta river is adequate to absorb and assimilate the sewage effluent flowing into the river. According to Obiri-Danso and Jones (1999a), die-off and dilution significantly reduce the numbers downstream of the discharge point.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The Akosombo waste stabilization ponds are efficient as it was able to achieve an overall mean removal of 75.2%, 78.9%, and 64.2% of TSS, BOD and COD respectively. Similarly, removal efficiency for ammonia-nitrogen, nitrate and phosphorus were 95.5% 64.9% and 25.4% respectively. Faecal and total coliforms removal was 100%.

Most of the ammonia (80.1%), total coliform (96.9%) and faecal coliform (99.0%) 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 although the reductions were not significant. The study revealed that most of the biodegradables in the raw sewage were reduced in the maturation pond attaining efficiency of BOD (70.3%) and COD (42.8%). It was realized in the study that, the ponds performance in the reduction of phosphorus was poor. The levels of compliance of effluents with the physicochemical and microbial parameters were all below the EPA permissible levels except faecal coliforms. This confirms that the stabilization pond is effectively treating the wastewater to the acceptable EPA permissible guideline levels. An average overall effective reduction was 86.5% for the stabilization pond. Therefore, effluent discharged from the Akosombo wastewater stabilization pond will not cause pollution of the Volta Lake and the source of domestic water used by downstream users especially Abume people.

6.2 RECOMMENDATIONS

- A monitoring program should be designed to determine sludge accumulation, characteristics, and pathogen inactivation in the facultative pond.
- Further investigation should be conducted to determine the health implications associated with the fish in the ponds if it could be used for human consumption.
- The effluent from the pond could be put to alternative use such as agriculture and watering of lawns.

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APPENDIX A1: ANOVA OF CONTINUES VARIABLES AMONG PARAMETER

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.505	3	.168	3.029	.053
	Within Groups	1.111	20	.056		
	Total	1.616	23			
Temperature	Between Groups	.208	3	.069	.123	.945
	Within Groups	11.270	20	.564		
	Total	11.478	23			
TDS	Between Groups	4205.833	3	1401.944	.892	.463
	Within Groups	31446.000	20	1572.300		
	Total	35651.833	23			
DO	Between Groups	18.294	3	6.098	39.703	.000
	Within Groups	3.072	20	.154		
	Total	21.365	23			
BOD	Between Groups	5079.999	3	1693.333	3.294	.042
	Within Groups	10281.790	20	514.089		
	Total	15361.789	23			
COD	Between Groups	215343.2	3	71781.067	1.990	.148
	Within Groups	721491.1	20	36074.557		
	Total	936834.3	23			
NH3	Between Groups	273.148	3	91.049	12.146	.000
	Within Groups	149.930	20	7.496		
	Total	423.078	23			
NO3	Between Groups	4.724	3	1.575	3.242	.044
	Within Groups	9.715	20	.486		
	Total	14.440	23			
TSS	Between Groups	38533.205	3	12844.402	33.568	.000
	Within Groups	7652.800	20	382.640		
	Total	46186.005	23			
Phosphate	Between Groups	.723	3	.241	10.575	.000
	Within Groups	.456	20	.023		
	Total	1.179	23			
Total coliforms	Between Groups	55.186	3	18.395	25.348	.000
	Within Groups	14.514	20	.726		
	Total	69.700	23			
Faecal coliforms	Between Groups	108.434	3	36.145	24.929	.000
	Within Groups	28.999	20	1.450		
	Total	137.433	23			

APPENDIX 2: AN AERIAL VIEW OF AKOSOMBO WASTEWATER STABILIZATION POND

APPENDIX 3: THE INLET PIPE TO THE FACULTATIVE POND

APPENDIX 4: THE OUTLET OF THE POND