018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

D5.3.12: 6 PhD and 18 MSc theses on the theme of this work package

Ansah, M. (2008) The use of natural systems for the treatment of greywater: A case study of Kpeshie lagoon. KNUST MSc thesis.

Due date of deliverable: M60
Actual submission date: M32

Start date of project: 1 February 2006 Duration: 60 months

Organisation name of lead contractor for this deliverable: KNUST

Revision [FINAL]

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

THE USE OF NATURAL SYSTEM FOR THE TREATMENT OF GREYWATER:

A CASE STUDY OF KPESHIE LAGOON

By
ANSAH, Martha

MSC THESIS

2008

THE USE OF NATURAL SYSTEM FOR THE TREATMENT OF GREYWATER:

A CASE STUDY OF KPESHIE LAGOON

By

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A thesis submitted to the Department of Civil Engineering

Kwame Nkrumah University of Science and Technology

In partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

In

WATER SUPPLY AND ENVIRONMENTAL SANITATION

Faculty of Civil and Geomatic Engineering,

College of Engineering

2008

CERTIFICATION

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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ABSTRACT

Handling of wastewater (greywater and blackwater) in urban areas is a big problem. This is not an exception for the La Sub Metro. Due to lack of wastewater treatment facilities, almost all the wastewater in the Sub Metro are discharged into the Kpeshie Lagoon without pretreatment.

The objective of this study was to determine the potential of natural system (Kpeshie Lagoon) for treating greywater through the characterization and determination of influent and effluent water quality of the Kpeshie Lagoon.

Characterization of greywater was carried out after four weeks of sampling process and the parameters analysed were as follows: colour, turbidity, pH, salinity, BOD, COD, conductivity, TSS, nutrients and trace metals.

The results indicated that the lagoon has a high potential of treating greywater if managed well.

The parameters that showed high removal efficiency were: 80% nitrates, 78% colour 74%BOD and 61% turbidity.

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Abbreviations

AAS: Atomic Absorption Spectrophotometer
Av Inf: Average Influent
BOD: Biochemical Oxygen Demand
BOD_5 : Biochemical Oxygen Demand at Fifth Day
Cd: Cadmium
CSIR: Council for Science and Industrial Research
Cu: Copper
DO: Dissolved Oxygen
EC: Electrical Conductivity
EPA: Environmental Protection Agency
FC: faecal coliforms
H^+: Hydrogen ion
H_2O: Water
K: Potassium
KNUST : Kwame Nkrumah University of Science and Technology
Loc: Location
Max: Maximum
Min: Minimum
Mn: Manganese
MnO_2: Manganous Oxide
Na: Sodium
NH_3-N: Ammonia Nitrogen
NO_3-N: Nitrite Nitrogen
N: Nitrogen
O/M: Organic Matter
O/C: Organic Carbon
Para: Parameter
P: Phosphorus
Pb: Lead
PO_4-P^- Phosphate Phosphorus
pH: Hydrogen Ion
SD: Standard Deviation
SE: Standard Error
TSS: Total Suspended Solid
US: United States

Acknowledgement

I am most grateful to the Lord Almighty for His divine favour and strength He granted me to go through this programme successfully. Honour is to His name forever.

I express my sincere gratitude to Prof. Mrs. Esi Awuah and Mr.S.O.Kwarteng, who whole heartedly supervised my work and directed the course of this research. God bless you richly for your help. I am grateful to EU-FP6 project SWITCH for their financial assistance.

Many thanks to the project manager, Dr. S. O. Odai for his encouragement during the research period. Mr. E.A. Donkor and the entire staff of Water Supply and Environmental Sanitation Project cannot be left out, thanks for their support.
My sincere thanks go to the head of Microbiology Department, Dr. Ampofo and all the laboratory technicians of CSIR. I also thank Kingsley, Mr. Bruce, Frederick Antwi and Emmanuel of environmental laboratory at KNUST for their assistance

Special thanks to S/Sgt Lawrence Bansah, my brother-in-law for the help and support he offered me throughout my research.

Again, I thank Overseer John Wayoe, Mr. Enoch Kumi and my fellow participants especially Ruby, Ebo Mawuli and Mike for their support. I wish to thank my many brethren who behind the scene kept praying for my success in this programme.

I am highly indebted my parents, Mr.T.B.K. Ansah and Madam Dorothy Antobam for their support and encouragement. May God bless and give them good health. To my siblings Mary, Elizabeth, Rebecca, Isaac and John, I say, the Lord bless you all for your enormous support and encouragement. May the good Lord bind us together in love.

CHAPTER ONE

1. INTRODUCTION

1.1 BACKGROUND

The water from kitchen, bath and laundry is known as greywater. Since greywater is not mixed with human excreta it reduces the problems with environmental impact but still the greywater has to be handled carefully to avoid waterlogging, smell and the uncontrolled release of chemicals and anthropogenic elements including micro-organisms into the environment (Ridderstolpe, 2004).

Nowadays, wastewater treatment technologies have become complex with the requirement of relatively sophisticated and expensive plants. In addition to capital cost, operation and maintenance expenses is high.

Natural treatment systems are a viable alternative that can produce effluents of high quality at a fraction of the capital cost and without requiring skilled operation. Their main limitation for application in industry is the fact that they take up lots of space.
Natural wastewater treatment systems are simple and low cost methods that utilize the physical, chemical and biological processes that occur in the natural environment between water, soil, plants, microorganisms and the atmosphere (Kadlec and Knight, 1996).

Coastal lagoons are a component of interface water systems in coastal areas between oceans and rivers which serves as pollution sinks for upstream and local activities including industrial discharges, urban storm water collection, domestic discharges and

agricultural drainage. As a result of these, lagoons bear the imprints of human activity demonstrated by increased sedimentation, toxic chemical contamination and eutrophication. This has serious influence on the ecological health of the lagoon (Annang, 2000).

1.2 PROBLEM STATEMENT

In urban areas the handling of waste water (greywater) is a big problem. Due to lack of waste water treatment facilities in the La Sub Metro, almost all the waste waters are discharged into the Kpeshie Lagoon without receiving any kind of treatment. Greywater volumes are large and their content of environmentally hazardous or infectious substances is high as farmers upstream of the Lagoon use them on their farms. Inhabitants of the area also fish in the Lagoon, thereby increasing the risk of environmental problems and human contact with the non-healthy water conditions (Ridderstolpe, 2004).

1.3 JUSTIFICATION

In determining the potential of the natural system and the quality of the water, using the lagoon as a case study:

- Relevant information will be provided to contribute to the development of guidelines of waste water discharges known to significantly pollute lagoons.
- Relevant information will provide early warning signal for agencies that monitor pollution of water bodies and the environment.
- Baseline information will be provided that will serve as corrective measures to restore the quality of the lagoon.

1.4 OBJECTIVE

To determine the potential of natural system for treating greywater.

1.5 SPECIFIC OBJECTIVES

- To characterize the greywater and determine the water quality of the Kpeshie lagoon.
- To characterize the soil receiving grey water at the study site.
- To determine dominant plant species in the study area.

1.6 SCOPE OF STUDY

Due to the limited time frame for the study, high cost of analysis and scarce resources, the study was restricted to collecting limited water samples from the study area for the following measurements: Physico-chemical analysis included; pH, Temperature, Turbidity, Colour, Conductivity, Total Suspended Solids, Salinity, Nitrates, nitrites, Ammonia, Phosphates, DO, BOD_5, COD, Cadmium, Lead, Manganese and Copper

Bacteriological analysis of faecal pollution (Faecal Coliform Count) was also carried out.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 LAGOONS

Lagoons are essentially bodies of saline water partially separated from the adjacent sea. They may be natural or artificial. Lagoons retain a proportion of their seawater at low tide and may develop as brackish, fully saline or hyper-saline water bodies. In addition, lagoons contain invertebrates rarely found elsewhere. They also provide important habitat for waterfowl, marshland birds and seabirds.

Lagoons are classified into 3 main types: leaky lagoons, choked lagoons, and restricted lagoons. Leaky lagoons have wide tidal channels, fast currents and unimpaired exchange of water with the ocean. The lagoon under study can be described as a leaky lagoon, since there is unimpaired exchange of water with the ocean.

Choked lagoons occur along high energy coastlines and have one or more long narrow channels which restrict water exchange with the ocean. Circulation within this type of lagoon is dominated by wind patterns.

Restricted lagoons have multiple channels, well defined exchange with the ocean, and tend to show a net seaward transport of water. Wind patterns in restricted lagoons can also cause surface currents to develop, thus helping to transport large volumes of water downwind (Hill 2001). Sea water exchange in lagoons occurs through a natural or man-modified channel or by percolation through, or overtopping of the barrier.

The salinity of the systems is determined by various levels of freshwater input from ground or surface waters.

2.2 GREYWATER AND ITS SOURCES

Greywater, also known as sullage, is non-industrial wastewater generated from domestic processes such as washing dishes, laundry and bathing. Greywater comprises 50-80% of residential wastewater (Wikimediafoundation, 2007).

Greywater gets its name from its cloudy appearance and from its status as being neither fresh nor heavily polluted .Greywater is distinct from blackwater (urine and faeces) in the amount and composition of its chemical and biological contaminants.

2.3 WATER AMOUNT

The amount of greywater produced in a household can vary greatly. While the water consumption in poor areas is about 20- 30 liters per person per day, a person in a richer area may generate several hundreds of liters a day. In greywater systems where there is no need to flush toilets and transport faecal matter, a lot of water can be spared (Ridderstolpe, 2004).

2.4 WATER QUALITY

Water is often ranked by its quality. However, there are many different measures of water quality and the quality of the water often depends upon its use. Water quality, especially freshwater quality, is often classified by its uses: recreational, drinking, fishing, and recharge. It is important to understand how the water upstream and downstream is being used because the downstream use will often dictate the overall

water quality and that will affect the discharge criteria for water discharge (Russell, 2006).

2.5 CHARACTERISTICS OF GREYWATER

According to Metcalf and Eddy (2003), wastewater is characterized by physical, chemical and biological constituents.

2.5.1 Physical Characteristics

The physical constituents of wastewater include temperature, turbidity, colour, suspended solids, conductivity, settleable solids and total chemical solids, etc. These characteristics are used to assess the reuse potential of wastewater and to determine the most suitable type of operations and processes for its treatment.

2.5.2 Chemical Characteristics

The chemical constituents of wastewater include nutrients such as free ammonia, nitrates, nitrites, total phosphorus, etc. These parameters are used to measure the nutrients present and the degree of decomposition in the wastewater. Alkalinity, pH, chloride, sulfates, metals such as cadmium, copper, lead, arsenic etc are all chemical constituents of wastewater. To assess the suitability of wastewater reuse and for toxicity effects in treatment and also to measure the acidity or basicity of the wastewater, these characteristics are considered.

Chemical Oxygen Demand, Biochemical Oxygen Demand, Total Organic Carbon are also chemical parameters used to measure the amount of oxygen need to stabilize wastewater biologically and chemically.

2.5.3 Biological Characteristics

Biological constituents of wastewater include coliform organisms, specific microorganisms and toxicity. These characteristics are used to assess the presence of pathogenic bacteria, specific organisms present and to detect level of toxicity, whether acute toxic unit or chronic toxic unit.

2.5.4 Suspended Solids

All waste streams have some suspended solids. The suspended solids are a collection of organic and inorganic materials of various sizes and density. The size and density ranges are from 3-5mm to 0.001 mm, and from 0.8-2.65 gm/cm^3 and higher .Some waste streams, including paper plants, food wastes, and some petrochemical processes, have Total Suspended Solids loads in excess of 1000 mg/L.

The solids generally have a biodegradable component and may have active biomass. The particles could be large and others could be smaller and tend to be indistinguishable and invisible in the water (Russell, 2006). Total suspended solids test results are used routinely to assess the performance of conventional treatment processes and the need for effluent filtration in reuse applications (Metacalf and Eddy, 2003).

2.5.5 Turbidity

Turbidity is a measure of light transmitting properties of water. It is another test used to indicate water quality of waste discharges and natural waters with respect to colloidal and residual suspended matter. The measurement of turbidity is based on comparison of intensity of light scattered by a reference suspension under the same

conditions (Standard Methods, 2005). Turbidity measurements are reported as nephelometric turbidity units (NTU). Colloidal matter would scatter or absorb light and thus prevent its transmission (Metacalf and Eddy, 2003).

Suspended solids that cause turbidity are natural materials resulting from the erosive activity of water as it flows over surfaces. Domestic and industrial effluents contribute large amounts of suspended solids. Soaps, detergents, emulsifying agents also produce stable colloids that results in turbidity (Annang, 2000).

2.5.6 Colour

The colour of water is the result of the different wavelengths that is not absorbed by the water itself or the result of particulate and dissolved substances present (Chapman and Kimstach, 1992). Fresh water is usually a light brownish grey colour. However, as the travel time in the collection system increases and more anaerobic conditions develop, the colour of the wastewater changes sequentially from grey to dark grey and ultimately to black (Metacalf and Eddy, 2003).

Colour is partly due to suspended solids (apparent colour) and partly due to dissolved solids (true colour). Hence natural minerals such as ferric hydroxide and manganese oxide impact colour to water (Annang, 2000).

In most cases the grey, dark grey and black colour of the wastewater is due to the formation of metallic sulfides, which form as the sulfides produced under anaerobic conditions react with the metals in the greywater. Colour is measured by the Lovibond Nesslerizer disc.

2.5.7 Temperature

The temperature of water is a most important parameter because of its effect on chemical reactions and reaction rates, aquatic life and the suitability of the water for beneficial uses. Temperature varies with climatic fluctuations and responds to factors such as season, time of day, air circulation, cloud cover and depth and flow of water in the natural system (Annang, 2000). Wastewater temperatures, as high as 30 to 35^{o}C have been reported for countries in Africa and Middle East (Metacalf and Eddy, 2003).

Increased temperature, for example, could cause a change in the species of fish that could exist in the receiving water body. In addition, oxygen is less soluble in warm water than in cold water and this could result in serious depletion of dissolved oxygen concentration in the dry season or summer months. It should be realized that a sudden change in temperature could result in high rate of mortality of aquatic life and the abnormal growth of undesirable water plant and wastewater fungus. Temperature is measured using thermometer or read from a portable pH – meter.

Temperature affects physical, chemical and biological processes in water bodies and wastewater treatment. Hence the concentrations of many parameters including biological species present and their activities are affected.

2.5.8 pH

pH, also a potential of hydrogen is defined as the negative logarithm of hydrogen-ion concentration (Pankratz, 2000). The hydrogen-ion concentration is an important quality parameter of both natural waters and wastewaters. The usual means of expressing the hydrogen-ion concentration is pH. On the 0 to 14 pH scale, a value of 7 at 25°C represents a neutral condition. Decreasing values indicate increasing hydrogen ion concentration (acidity) and increasing values indicate decreasing hydrogen ion concentration (alkalinity).

Metacalf and Eddy (2003) observed that the concentration range suitable for the existence of most biological life is quite narrow and critical, it is from 6 to 9. Wastewater with an extreme concentration of hydrogen-ion is difficult to treat by biological means. If the concentration is not altered before discharge, the wastewater effluent may alter the concentration in the natural waters. pH is measured using a portable pH meter in the field.

Most organisms have adapted to life in water of a specific pH and may die if it changes even slightly. The toxicity level of ammonia to fish, for example, varies tremendously within a small range of pH values.

Acid rain containing nitric and sulfuric acids can sharply lower the pH of a stream as the rain runs quickly off streets and roofs into creeks. Acidic water can cause heavy metals such as copper and aluminum to be released into the water (www.fivecreeks.org).

2.5.9 Conductivity and Salinity

Conductivity is the ability of water to conduct electrical current. Since the electrical current is transported by ions in solution, the conductivity increases as the concentration of ions increases. Abrupt changes in conductivity might indicate that water or wastes are being diverted into the stream from a new source.

Conductivity could be used as a measure of total dissolved solids. Conductivity is also a good measure of salinity in water. The measurement detects chloride ions from the salt. Salinity affects the potential dissolved oxygen levels in the water. The greater the salinity level, the lower the saturation point (www.fivecreeks.org).

Salinity is the total amount in grams of inorganic materials dissolved in 1kg water when all the carbonate has been converted to oxide, all the bromide and iodine have been replaced by chlorine and all organic matter has been completely oxidized (Annang, 2000). Salinity of water is determined by measuring its electrical conductivity and this parameter helps to determine the suitability of greywater for irrigation.

The presence of salt affects plant growth in three ways: osmotic effects, caused by the total dissolved salts concentration in the soil water, specific ion toxicity, caused by concentration of individual ions and soil particle dispersion, caused by high sodium and low salinity. With increasing soil salinity in the root zone, plants expend more of their available energy on adjusting the soil concentration within the tissue (osmotic adjustment) to obtain the needed water from soil (Metacalf and Eddy, 2003).

2.5.10 Dissolved Oxygen (DO)

Oxygen is very essential to all aquatic life. The oxygen concentration of natural water bodies varies with temperature, atmospheric pressure, salinity turbulence and photosynthetic activity of algae and plants. The solubility of oxygen decreases as temperature and salinity increases and as pressure decreases (Annang, 2000).

Waste discharges high organic matter and nutrients, and this could cause a decrease in DO due to respiration during breakdown of organic matter. Determination of DO is very important in water quality assessment as it influences most chemical and biological processes in aquatic environment. Concentrations below 5mg/L may affect the functioning and survival of biological communities and below 2mg/L may lead to death of most fishes (Chapman and Kimstach, 1992).

2.5.11 Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

BOD_5 is a measure of the quantity of dissolved oxygen used by microorganisms in the oxidation of organic matter. Micro-organisms utilize dissolved oxygen in water to oxidize polluting biodegradable organic matter, thereby giving an indication of the pollution load present. By measuring the initial concentration of a sample and the concentration after five days of incubation at 20^oC, the BOD can be determined (Standard Methods, 1998). The most serious limitation is that the five day period may or may not correspond to the point where the soluble organic matter that is present has been used.

COD measures biodegradable and non biodegradable organic matter of wastewaters. Some organic substances are resistant to biological degradation (eg tannic, cellulose,

benzene). COD test is used to measure the oxygen equivalent of the organic material in wastewater that can be oxidized chemically using dichromate in acid solution. COD is attractive as the test yield results within two hours.

2.5.12 Ammonia, Nitrites and Nitrates

Nitrogen occurs in natural waters as nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and organically bound nitrogen. As aquatic plants and animals die, bacteria break down large protein molecules containing nitrogen into ammonia. Sewage is the main source of nitrates added by humans to water bodies. Another important source is fertilizers, which could be carried into natural waters by storm water runoff (www.fivecreeks.org). Excessive nitrates stimulate growth of algae and other plants, which later decay and increase biochemical oxygen demand as they decompose. When ammonia oxidizes to nitrate, it requires substantial amounts of oxygen. The first oxidation is to nitrite by *Nitrosomonas* bacteria. The second group of bacteria take the nitrite and oxidize it to nitrate.

Nitrite concentrations in a viable bacterial population are seldom above 0.1 mg/l in surface water or 1mg/l in wastewater (Metacalf and Eddy, 2003). Nitrite is extremely toxic to most fishes and other aquatic species so usually present in low concentrations. Nitrate concentration in wastewater effluent is from 15 to 20mg/L as N. Ammonia, nitrite and nitrate concentration is determined by colorimetric methods (Metacalf and Eddy, 2003).

2.5.13 Phosphorus

Phosphorus is usually present in natural water as phosphates. In aqueous solution, phosphorus exists as orthophosphate, polyphosphate and organic phosphate. The orthophosphates, H_2PO^{4-}, H_3PO_4, HPO_4^{2-} are available for biological metabolism without further breakdown. Phosphorus is a plant nutrient needed for growth and a fundamental element in the metabolic reactions of plants and animals (hence its use in fertilizers).

Sources of phosphorus include human and animal wastes (i.e., sewage), industrial wastes, soil erosion, and fertilizers. Excess phosphorus causes extensive algal growth called "blooms," which are a classic symptom of cultural eutrophication and lead to decreased oxygen levels in natural water.

2.5.14 Faecal Coliforms

The most common risk of human health associated to wastewater comes from the presence of pathogenic microorganisms. Metacalf and Eddy (2003) reported that each person discharges from 100 to 400 billion coliform bacteria per day, in addition to other kinds of bacteria. Coliform bacteria in environmental samples, is an indication that pathogenic organisms associated with fecal contamination may be present (Polz, 2007).

Poorly treated greywater, leachate from sanitary landfills and urban solid waste disposal sites, which contain human faecal matter are potential sources of pathogens.

Detection of all possible pathogens is rather complex, costly and time consuming, hence *Escherichia coli* is used as indicator organism for detecting the presence of

pathogens. Methods commonly used are multiple tube fermentation and membrane filtration techniques.

2.6 TRACE METALS

Heavy metals are important because they are often toxic and they impede or interfere with the biological treatment process when in excessive quantities. Depending upon the metal and the species, all the reactions are pH dependent (Russell, 2006).

2.6.1 Cadmium

In Ghana cadmium is introduced into the aquatic environment through waste streams from mining activities, refuse and sewage sludge disposal in urban areas and manufacturing industries such as steel and iron. Cadmium is a contaminant in many chemical fertilizers (Moore et al, 1995). Phosphate fertilizers contain 5-100 mg Cd kg^{-1} (O'Neil, 1994). Storm water run offs carry these fertilizers in receiving water bodies.

Maximum cadmium concentrations recommended for irrigation is 0.01mg/L. Concentrations as low as 0.1mg/L is potential for accumulation in plants and soils to concentrations that may be harmful to humans (Metacalf and Eddy, 2003).

2.6.2 Copper

Copper is an essential micro nutrient, but at high doses has been shown to cause stomach and intestinal distress, liver and kidney damage, and anemia.

Copper is a reddish-brown metal, often used in plumbing of residential and commercial structures that are connected to water distribution systems. Copper

contaminating water occurs as the result of the corrosion of copper pipes that remain in contact with water for a prolonged period (Shelton et al, 2005).

Copper is toxic to a number of plants at 0.1 to 1.0mg/l in nutrient solutions. Recommended maximum concentration for irrigation is 0.2mg/l (Metacalf and Eddy, 2003).

2.6.3 Lead

Lead is one of the commonest metals that are used in industry for a wide variety of purposes, including pipes, paint pigment, alkyl compounds for gasoline, lead acid accumulators, brass and bronze fixtures and cable sheathing. Lead is a heavy metal that can cause a variety of adverse health effects in humans. At relatively low levels of exposure, these effects may include interference in red blood cell chemistry, delays in normal physical and mental development in babies and young children, deficits in the attention span, hearing, and learning abilities of children, and increases in blood pressure of some adults (Shelton et al, 2005). Plants growing near high ways often absorb this lead as do some grasses that grow near abandoned lead mines (Moore et al, 1995). Concentration of water above 5mg/l lead can inhibit plant growth. Materials that contain lead have frequently been used in the construction of water supply distribution systems and plumbing systems in private homes and other buildings. Lead in these materials can contaminate water and natural water as a result of the corrosion that takes place when water comes into contact with those materials.

2.6.4 Manganese

Manganese is an essential nutrient and toxicity is not expected from levels that would be encountered in wastewater. Manganese may form a coating on pipes and these may slough off, causing brown or black particles in the water (Shelton et al, 2005). Manganese is toxic to a number of crops at a few tenths mg/L, but only in acid soils (Metacalf and Eddy, 2003).

2.7 FACTORS INFLUENCING WATER QUALITY

The quality of water is influenced directly or indirectly by three major factors (Myebeck et al, 1992). These include:

- The geographical features of the catchment: including topography, relief, lithology, pedology, climate, land use, hydrology, hydro-geology, etc
- Water use: including dams, canals, water withdrawals for cities and industries, agriculture, navigation, recreation, fisheries etc.
- Pollution source (present and expected): including domestic, industrial and agriculture.

Gray (2003) established the influence of a catchment on the water quality, taking into account the different rock geology and the soil type within the catchment. For instance, water arising from hard water catchments has high concentrations of Ca, Mg and carbonate. Coastal surface waters are affected by wind–blown sea spray resulting in high concentrations of sodium, sulfate and chloride. Surface waters have a unique chemistry reflecting primarily the nature of the geology and soil type of the catchment.

2.8 WATER QUALITY PROCESSES IN SURFACE WATER

There are about three processes that affect the quality of surface water bodies.

One of the most important water quality processes is dispersion. Dispersion is the spreading of a substance despite the normal flow (Waals, 1992). A limited discharge of a substance at a certain time of travel will give a certain increase of the concentration in the water body. Further downstream, the increase of concentration will be less pronounced, but the time interval in which the substance passes the measuring point will be longer.

Another important process is the sedimentation and resuspension of suspended solids. In the very turbulent upper part of the water body, all kinds of materials will come into suspension. Further downstream as the velocity reduces and turbulence diminishes, gravels and coarse sand will settle. At the estuary, thus further downstream, fine sand and clay particles will settle due to very low velocity.

On the other hand, during a high flow, sediment particles can be scoured out again and become resuspended which brings about a sharp increase in the turbidity, thereby deteriorating the water quality (Waals, 1992).

The third part of the process is self purification. Under this process, all kinds of physical, chemical and biological processes are generally put together to improve the water quality. One of these processes is degradation of organic matter. This process consumes oxygen in the water, resulting in more or less severe oxygen depletion, impacting on the ecosystem of the water body (Waals, 1992).

2.9 POTENTIAL OF NATURAL SYSTEM FOR GREYWATER TREATMENT

All forms of household wastewater are infectious, pollutant and a risk to human health and the environment. When managed properly and carefully through sewage treatment processes wastewater can be converted into a valuable resource that can be reused under certain circumstances (NSW Health, 2005).

Greywater production and its degree of pollution are mainly determined by the habits of the consumers and is a result of products of personal hygiene, detergents, body dirt as well as soiled clothes. These pollutants are classified as easily biodegradable. Greywater is continuously available due to daily personal hygiene requirements and its production is independent from the weather conditions (Russell, 2006).

Natural systems that are receiving bodies for wastewater produced from households include wetlands, lakes, streams, lagoon and rivers.

"Wetlands" is the collective term for marshes, swamps and areas found in generally flat vegetated areas, in depressions in the landscape, and between dry land and water along the edges of streams, rivers, lakes and coastlines.

Coastal wetlands are closely linked to estuaries, where sea water mixes with fresh water to form an environment of varying salinities. Hence, coastal lagoons are considered as wetlands.

Wetlands help regulate water levels within watersheds, improve water quality, reduce flood and storm damages, provide important fishes and wildlife habitat and other recreational activities (www.EPA USA).

Mitsch and Gosselink (1993), described wetland as the ‘kidneys of the landscape and biological supermarkets’. The former refers to the nutrient and pollution filtration fuctions of wetlands. This nutrient retention function of wetlands is considered to be one of its significant roles on landscape, making them valuable habitat for some species of fish, shrimps and mollusc (Annang, 2000).

Wetlands play an integral role in the ecology of the watershed. The combination of shallow water, high levels of nutrients and primary productivity is ideal for the development of organisms that form the base of the food web and feed many species of fish, amphibians, shellfishes and insects. Wetlands store carbon within their plant communities and soil instead of releasing it to the atmosphere as carbon dioxide. Thus wetlands help to moderate global climate conditions.

Wetlands provide values that no other ecosystem can, including natural water quality improvement, flood protection, shoreline control, opportunities for recreation and aesthetic appreciation and natural products for our use at no cost. Wetlands can provide one or more of these functions. (www.EPA USA).

Wetlands have important filtering capabilities for intercepting surface water runoff from higher dry lands before the runoff reaches open water. As the runoff water passes through, the wetland retains excess nutrients and some pollutants and also reduces sediments. In performing this filtering function, wetlands save us a great deal of money. For example, a 1990 study showed that, without the Congaree Bottomland Hardwood Swamp in South Carolina USA, the area would need a $ 5 million wastewater treatment plant (www.coe.edu).

In addition to improving water quality through filtering, some wetlands maintain stream flow during dry periods, and many replenish groundwater.Wetlands within and downstream of urban areas are particularly valuable, counteracting the greatly increased rate and volume of surface water runoff from pavement and buildings (www.EPA USA).

2.10 PERFORMANCE OF NATURAL TREATMENT SYSTEM

Natural treatment system refers to any unit process which involves water, soil, plants, microorganisms and interactions with the atmosphere (Muzola, 2007).

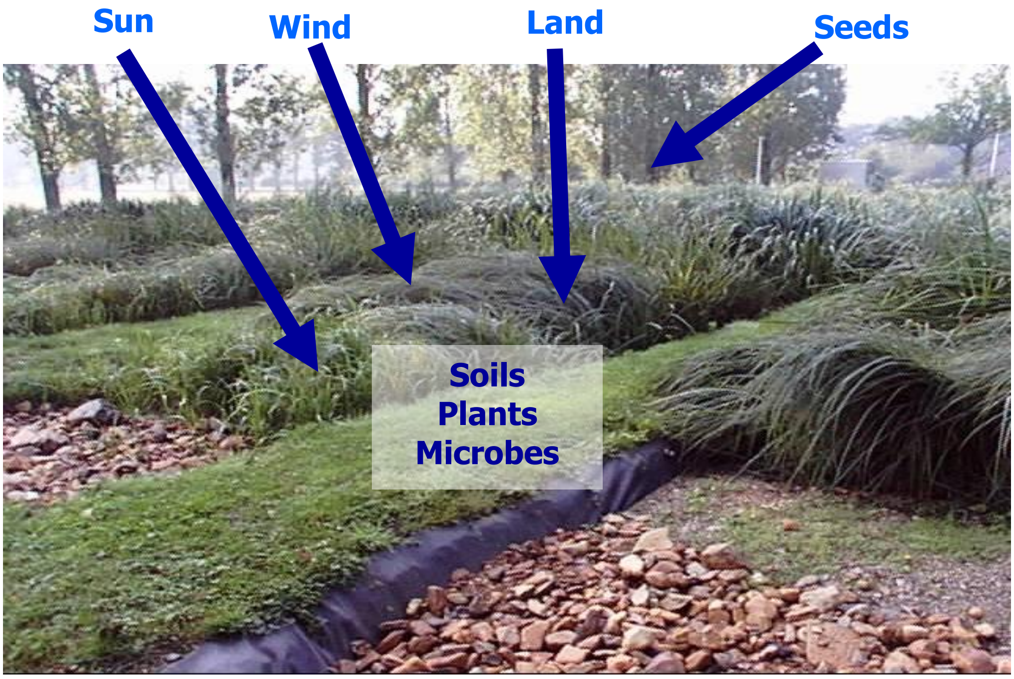

Plate 1: Natural Treatment System

If the plants are removed (plate 1), then it becomes like a conventional biological treatment system. The presence of plants differentiates it from other systems.

Natural treatment systems provide a good and robust solution to the rising wastewater problem.

A study conducted at KNUST campus by Muzola 2007, showed that natural wetland is able to treat greywater to meet the EPA Ghana guideline values. He established that the best performance was obtained at suspended solid removal efficiency of 98.8%. Turbidity, Suspended Solids, COD, BOD and Total Coliforms removal ranged between 85-99%. Phosphate and Nitrite-Nitrogen ranged between 70-85%, Conductivity and Nitrate-Nitrogen, heavy metals (Mn and Pb) were less than 50%, while Cu, Fe and Zn were between 50-79%.

CHAPTER THREE

3. METHODOLOGY

3.1 DESCRIPTION OF STUDY AREA

The La Sub Metro has a population of 81,684 with about 5543 homes according to Statistical services with an annual population growth of 3.1% (Kpanja, 2006).

The water bodies in this sub metro are the Africa Lake and the Kpeshie Lagoon. The Kpeshie lagoon is less than 1km^2 in surface area and it is located at the outskirt of La township. The Sub Metro share boundaries with the following Sub Metros: Osu Clottey towards the east, Ayawaso towards the north and Teshie to the west. There are a number of hotels in this sub metro. The La pleasure beach transports its grey and blackwater to an activated sludge system which is located around the junction of the lagoon. Kpeshie Lagoon is the receiving water body to the various drains in the Kpeshie catchment as shown in Fig1.

Greywater that enters the lagoon has it sources from Burma Camp Community, La Community, Tebibiano Community, Teshie Camp2 Community, Africa Lake and from the mangrove swamp surrounding the lagoon.

The Africa lake, which receives storm water from its environs opens into the lagoon. The black water from Burma camp is channalised through sewers into a waste stabilization pond. La, Tebibiano and Teshie Camp2 township mostly use pit latrines (30%), ventilated improved pits (46%), bucket latrines(2%), septic tanks systems(20%) and (2%) open defeacation. The lagoon opens into the sea, though it is

sometimes closed with sand barriers by the traditional rulers in the Sub Metro. Almost all the greywater in the catchment finally end up in the Kpeshie lagoon (Kpanja, 2006).

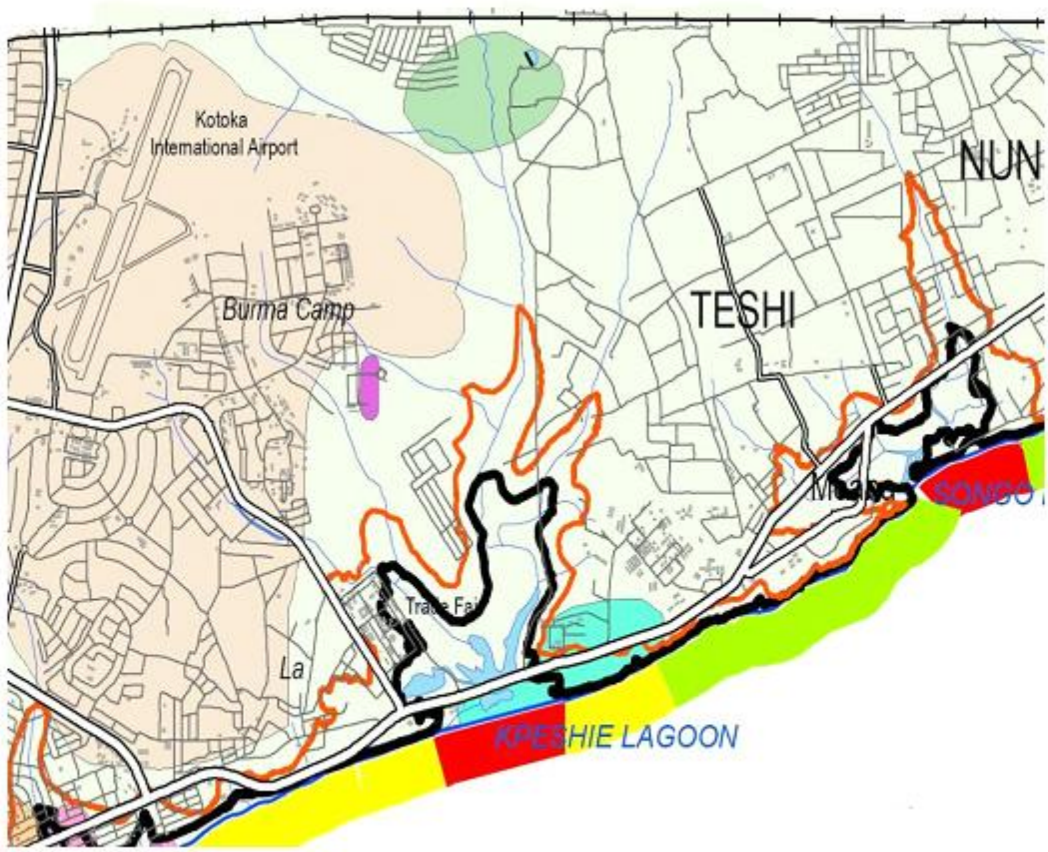

Fig 1. Study Site

3.2 SAMPLING POINTS

Sampling points were selected to capture the major activities carried out along the stretch of the lagoon which would affect the water quality. The following locations as shown in figure 2 were sampled for analysis.

The locations for sampling include: S1, S2, S3, S4, S5, S6, S7, S9 and S10. These numbers are defined as:

Station	Location
S1	Tebibiano channel, north side of the lagoon
S2	Teshie Camp 2, east side of lagoon
S3	Burma Camp channel, west north side of the lagoon
S4	Mangrove swamp, upstream of the lagoon
S5	La drain, west side of the lagoon
S6	Africa Lake, west side of lagoon
S7	After Africa Lake
S8	Junction, where all the sources get into the lagoon
S9	Main body of Lagoon
S10	Effluent of lagoon into the sea

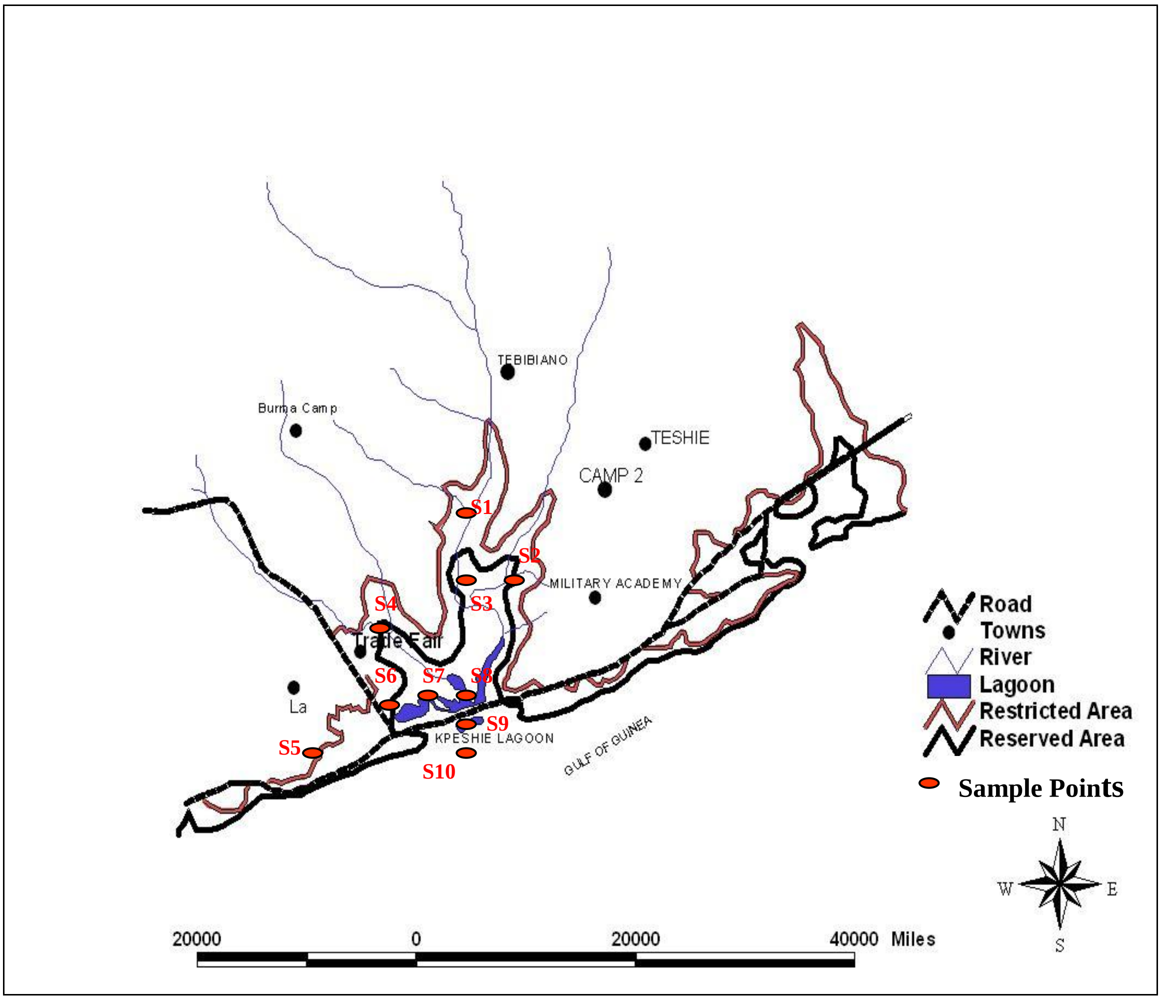

Fig 2. Sampling Point Locations

The following parameters were analysed: BOD, COD, Turbidity, Colour, pH, Temperature, Total Suspended Solids, Conductivity, Nutrients, Faecal Coliforms and Trace Metals.

3.3 SAMPLING PROCEDURES AND ANALYSIS

Sampling was done between October 10 and November 7, 2007. In all, four consecutive samples were made on weekly basis. Samples of water were collected with plastic bucket at stations S8 and S9 due to site conditions. At all other stations, water samples were collected by dipping sampling bottles directly into the water body against the direction of flow.

Table 1 below shows the method and type of instrument used for the analysis of the parameters mentioned above.

Table 1. Methods and Instruments used for Water Quality Analysis

Parameter	Method used	Instrument
BOD	Winkler Modification	Appendix 1
COD	Closed tube Method	Appendix 1
Turbidity	APHA Standard Method(USEPA)	HACH Model 2100P Turbimeter
Conductivity	Tetra Con 325,330i	Tetra Con 325,330i
Suspended Solid	Gravimetric Method	Appendix 1
Nitrate	Cadmium Reduction Method (Nitra Ver Powder Pillows)	HACH Type DREL/2010 Spectrophotometer
Nitrite	Diazotization Method (Powder Pillows)	HACH Type DREL/2010 Spectrophotometer
Ammonia	Nesslerization Method	HACH Type DREL/2010 Spectrophotometer
Phosphorus	Orthophosphate Phos Ver 3 (Ascorbic Acid) Method {Pillow Powder}	HACH Type DREL/2010 Spectrophotometer
Trace metals		Perkin Elmer 30303 A.A.S
Chemical and Physical of the Soil	USEPA Methods 3050, 7130.	Perkin Elmer 30303A.A.S
Faecal coliforms	Membrane filtration method	Membrane filter

Some part of the study area is used for the cultivation of vegetables, thus the upstream of Burma Camp channel. Again, the bank of Africa lake is also used for crop farming.

Faecal Coliforms- Samples for bacteriological analysis were collected in sterilized plain glass bottles and stored under ice. These were transported to the laboratory for analysis. The membrane filtration method was used, incubating at 45^{o}C for 18-24 hours and counting the yellow colonies developed.

For trace metals, about 75ml of samples were digested with 5ml concentrated nitric acid and the concentration of the metal measured directly with Atomic Absorption Spectrophotometer (Perkin Elmer 30303 AAS).

Soils samples as well as predominant plant species in the study were collected and identified. Soil sampling points were taken from locations S3, S4, S6 and S7. Soil samples were taken from the top layer, middle layer and bottom layer. They were then mixed together and analysed. Samples were taken between 0-45cm deep at each of these locations.

3.4 FLOW MEASUREMENT

Flow rate measurement was carried out over a 24 hour period for only station S5 for three consecutive times. Due to site limitations, the flow rate for the other stations which flow into the lagoon and the lagoon itself could not be taken. Appendix11, table 19 gives the values for the flow measurement.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 DATA ANALYSIS AND RESULTS

A summary of field and laboratory results on the study area is given in the appendix11, table22. The mean value of each parameter for the various sampling points were computed and tabulated. Plots of mean values at the various sampling points to show the trend or spatial variation of the parameters were also made.

4.2 CHARACTERISTICS OF GREYWATER

Greywater is continuously available due to daily personal hygiene requirements and this has been discharged into the environment (the lagoon) since those communities came into existence. Since the production of greywater is independent of the weather conditions, it is essential to control the pollution level so as to ensure efficient treatment by the natural system, even though the lagoon has its own maintenance system.

Greywater production and its degree of pollution are mainly determined by the habits of the consumers and it is a result of products of personal hygiene, detergents, as well as soiled clothes. Table 2 shows the characteristics of grey water. The table below shows the characteristics of average influent (S1, S2, S3, S4, S5, S6 and S7) and effluent (S10) quality of the greywater.

Greywater parameters of the average influent that were within the permissible limits of EPA Ghana guideline include turbidity, COD, pH, nitrates, phosphates, cadmium, lead and copper. The other parameters were above the permissible levels.

Table 2. Grey water Characteristics

Parameter	Average Influent	Standard Error ±	Effluent	Standard Error ±	EPA Ghana
Temp ^{o}C	29.11	0.34	30	0	<3 above amb
pH	7.84	0.09	7.55	0.20	6-9
Conductivity µS/cm	17102.79	3426.46	25315	8351.32	1500
Turbidity NTU	72.14	20.47	28.3	6.58	75
Salinity mg/l	13.06	2.93	15.58	4.80	
Colour TCU	74.64	13.73	16.25	5.45	20
TSS mg/l	92.39	26.48	52	31.36	50
BOD mg/l	63.79	26.49	16.45	5.51	50
COD mg/l	236.99	66.35	136.23	31.44	250
NH_3-N mg/l	2.88	0.48	2.04	0.05	1
NO_3-N mg/l	2.04	0.49	2.12	1.20	75
NO_2-N mg/l	0.10	0.03	0.02	0.01	
PO_4-P mg/l	1.24	0.26	2.78	2.23	2
Cadmium mg/l	0.003	0.002	0.002	0	0.1
Lead mg/l	0.01	0.0005	0.005	0	0.1
Manganese mg/l	0.61	0.13	0.187	0.061	0.1
Copper mg/l	0.01	0.00	0.008	0.003	2.5
F.Coliforms FC/100ml	1.64E+05	4.80E+05	2.80E+05	1.10 E+05	400

Though few parameters of the influent were below the EPA Ghana guidelines, the effluent quality of most of the parameters such as pH, turbidity, colour, TSS, BOD, COD, NH_3-N, NO_3-N, cadmium, lead and copper showed so much improvement in quality. The idea that natural system has a potential of treating greywater cannot be rejected considering the quality of the effluent.

4.2.1 Temperature

Mean temperature ranged from 27 to 31.5°C. The highest temperature was recorded at sample point S5 and the lowest recorded at sample point S4. The low temperature may be attributed to the shed from the mangrove swamp, while the high temperature may be due to the activities within the community and the washing bay along the sampling point. The lagoon and effluent values were 29.25°C and 30°C respectively. These values were above the EPA Ghana guidelines of 3°C above ambient of 25°C for discharge into water bodies. This could be due to high temperature of greywater from the sampling locations at the study site.

4.2.2 pH

All the waters that were analyzed were alkaline. The mean pH values ranged from 7.3 to 8.4 which were all within the EPA guideline range of 6 to 9. These values are quiet normal for costal waters.

4.2.3 Conductivity

Conductivity of water is determined to obtain the ability of the waters to conduct electrical current. The mean conductivity values ranged between 1233.75uS/cm and 42900 uS/cm. The lowest value was recorded at S1 and this is an indication that the greywater has less dissolved ions present. The highest value was recorded at S7; this might be due to the presence of other dissolved compounds as groundnut vegetation was just at the upstream of this sample point. Also, there was dumping of refuse close to this sample point. Gosselink and Mitsch (2000) established that anions such as chloride, nitrate, phosphate and sulphate as well as cations such as sodium, calcium, mangnesium and iron contribute to the over all conductivity. Effluent value was 25315 uS/cm. The conductivity levels for the influents and effluent were

unsatisfactory compared to EPA guideline value of 1500uS/cm, though there was some form of treatment. According to Kiely (1998) conductivity ranges for rivers, estuarine waters and seawaters are 100-1000, 200-2000 and 40000uS/cm respectively; hence these values are quiet normal for coastal waters.

Table 3. Conductivity (µS/cm)

Source of Sample	Mean	Standard Error±	Min	Max
S1	1233.75	82.77	1140	1481
S2	3025	652.62	1100	3840
S3	3070.75	684.30	1733	4970
S4	36975	2237.33	30500	40800
S5	2920	219.28	2360	3330
S6	29595	6497.62	18380	47600
S7	42900	1819.80	40400	48300
Junction	18732.5	5147.38	4160	28100
Lagoon	23570	7072.52	38400	4580
Effluent	25315	8351.32	8180	46900

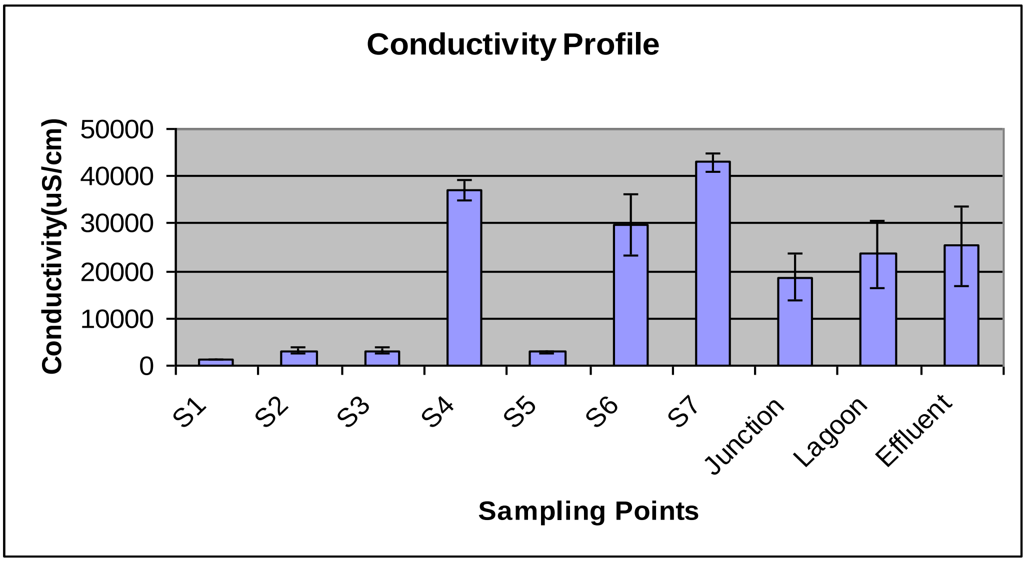

Fig 3. Conductivity Profile

From the graph in figure 3, conductivity of the effluent has been improved considering sample points S4, S6 and S7. Seawater influence and other dissolved ions are factors contributing to the low effluent quality.

4.2.4 Salinity

Salinity of water is determined to detect the suitability of water for irrigation (Metcalf and Eddy, 2003). The mean salinity values ranged between 0.6 mg/l to 32.9 mg/L, which indicates that, the average chloride content is above the EPA guideline value of 250mg/l.

Table 4. Salinity (mg/L)

Source of Sample	Mean	Standard Error±	Min	Max
S1	0.61	0.02	0.57	0.68
S2	1.73	0.38	0.61	2.27
S3	1.33	0.33	0.82	2.27
S4	31.15	4.88	17.60	38.65
S5	0.91	0.07	0.80	1.11
S6	29.83	2.41	24.12	34.54
S7	25.84	7.98	1.96	34.67
Junction	13.37	4.04	2.54	22.08
Lagoon	32.91	21.82	2.67	97.72
Effluent	15.58	4.80	3.95	27.46

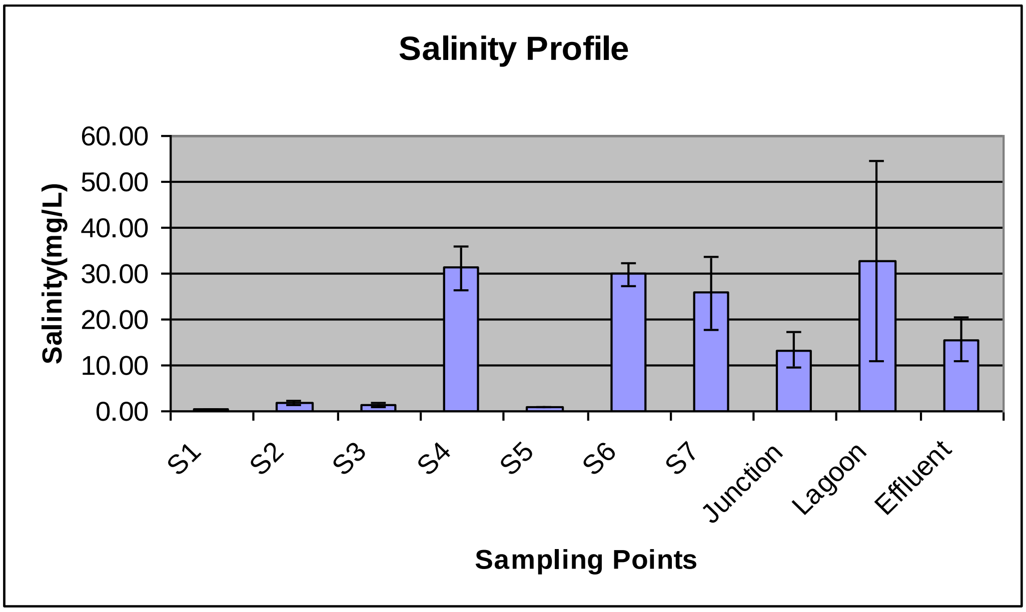

Fig 4. Salinity Profile

The graph above shows that the lagoon has the highest salinity value. This is as a result of refluxes of seawater which is stored in the lagoon, leading to accumulation and increase in salinity level. The sample points S4, S6 and S7 have high values of salinity but the concentration reduces as it gets to the junction of the lagoon. This may be due to the uptake of the dissolved ions by plant species around these sample points. The concentration effluent could be influenced by the sea water which is the main receiving water body.

4.2.5 Turbidity

High levels of turbidity in domestic and industrial effluents contribute large amounts of suspended solids into receiving water bodies. The mean turbidity values were in the range of 22.75 NTU and 282.92 NTU. The influents and effluent values were within the EPA guidelines value of 75 NTU, with the exception of the highly polluted sample point S5.

Table 5. Turbidity (NTU)

Source of Sample	Mean	Standard Error±	min	Max
S1	25.75	4.86	13	35.5
S2	36.78	15.54	13	81.9
S3	22.33	2.78	15	28.5
S4	59.40	14.56	32	99.9
S5	282.98	89.31	99.9	528
S6	31.00	9.79	15.9	59.7
S7	46.78	15.52	22.2	91
Junction	32.75	9.87	19.8	62.1
Lagoon	32.15	10.41	18	63
Effluent	28.30	6.58	12.8	44.3

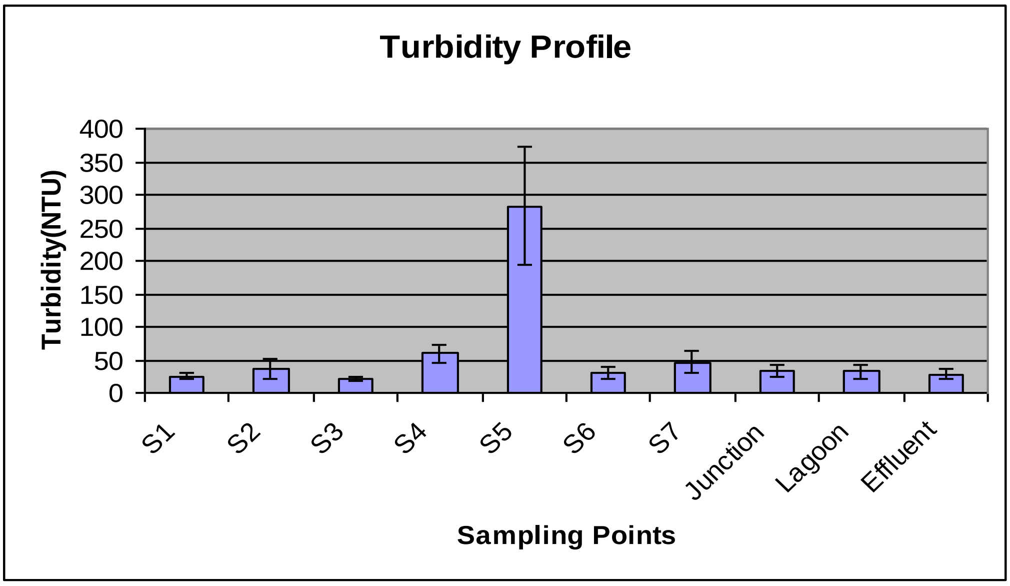

Fig 5. Turbidity Profile

The turbidity profile shows that the outstanding point is S5 and this might be due to the nature of the channel. S5 is a constructed drain with no plant species to serve as filter medium. The treatment received by the greywater is seen in the effluent quality, as one could see the reduced concentration of the effluent. The quality of the effluent could be attributed to sedimentation taking place in the lagoon as a result of the lagoon's low velocity and removal by plant species around the lagoon.

4.2.6 Colour

Mean colour values for influent and effluent ranged from 26.25 to 225TCU respectively. The lowest value was recorded at the outfall, with a value of 16.2 TCU and the highest being at S5. The effluent value was within the EPA permissible value of 20TCU but S5 was far above it.

Table 6. Colour (TCU)

Source of Sample	Mean	Standard Error±	Min	Max
S1	26.25	2.39	20	30
S2	30	9.13	10	50
S3	43.75	6.88	30	60
S4	105	19.36	60	150
S5	225	32.27	150	300
S6	42.5	7.50	30	60
S7	50	10.61	30	75
Junction	28.13	5.72	12.5	40
Lagoon	40	11.73	25	75
Effluent	16.25	5.45	7.5	30

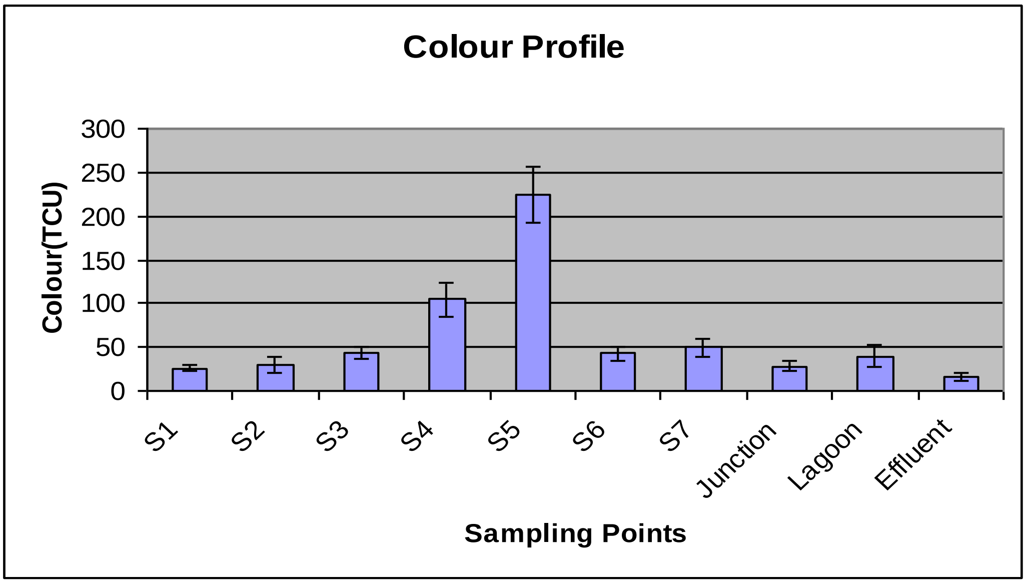

Fig 6. Colour Profile

The sampling points with high values were S4 and S5. The concentration at S4 might be due to the decay of fallen leaves that introduce some amount of colour to the greywater. High concentration at S5 could be due to activities in the community such as dyes and soiled clothes introduced to household greywater, oil and grease from fuel stations and washing bays along the S5 drain, hence the exceptionally high value which is unsatisfactory according to EPA guidelines of 20 TCU.

The improved colour content of the effluent implies that there has been dilution of the greywater in the lagoon and also refluxes from sea water could influence the quality of the effluent.

4.2.7 Total Suspended Solids (TSS)

Mean TSS values for influent and effluent ranged from 11mg/L and 370.75 mg/L. Sample point S5 is highly polluted with suspended solids, hence the highest concentration of 370.75mg/L. The S5 drain suffers dumping of refuse (degradable and non degradable) at the upstream and close to the downstream. There was dumping of solid waste close to S7, hence the high mean value. Sample points S1 to S4 were all within the EPA permissible limit of 50mg/L.

Table 7. Total Suspended Solids (mg/L)

Sample Point	Mean	Standard Error±	min	Max
S1	11	3.082207	7	20
S2	25.75	10.35515	8	55
S3	16.5	1.658312	14	21
S4	48.75	13.75606	19	84
S5	370.75	103.1838	144	639
S6	73.75	19.70776	18	104
S7	100.25	24.87427	53	156
Junction	45.43	17.1157	19	94.7
Lagoon	40.25	13.319	18	76
Effluent	52	31.3608	3	144

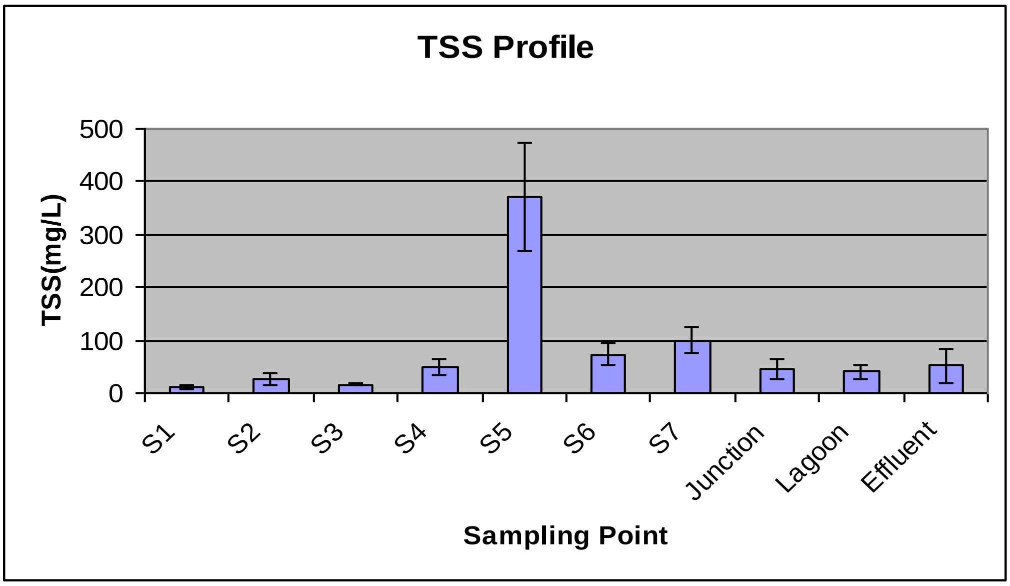

Fig 7. TSS Profile

The graph above shows that there has been improvement in the effluent quality. This may be due to quiescent conditions in the lagoon aiding sedimentation of suspended matter and also removal by the plant species surrounding the lagoon.

4.2.8 Organic Matter

An indication of organic content of the effluent and the receiving water can be assessed from the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels (Tchobanoglous et al, 2003).

4.2.9 Biochemical Oxygen Demand (BOD)

The mean BOD values ranged between 6.7mg/L and 322.5mg/L. As seen in figure 8, only sample point S5 stands out. The high pollution of S5 is due to high organic matter content, as human waste was seen in the greywater throughout the sampling

period. The other sample points were of acceptable concentration according to EPA Ghana guidelines. The concentration of S5 reduces after traveling 60m to S8, the junction of the lagoon. This signifies that the lagoon, being a pollutant sink is able to treat the wastewater by means of biodegradation of organic matter with the aid of microorganisms. It should be noted that the release of excess amounts of organic matter into surface waters could result in a significant depletion of oxygen and subsequent mortality of fishes and other oxygen dependent aquatic or marine organisms (DeBusk, 1999).

Table 8. BOD (mg/L)

Source of Sample	Mean	Standard Error±	min	Max
S1	6.7	2.82	0	13.8
S2	14.9	3.17	6.6	22
S3	34.88	1.88	30	39
S4	36.7	7.33	16.8	50
S5	322.5	133.50	120	690
S6	12.825	2.32	6	16
S7	18	2.71	10	22
Junction	22.25	5.40	6.5	30
Lagoon	23.45	5.53	12	33.8
Effluent	16.45	5.51	0	23.5

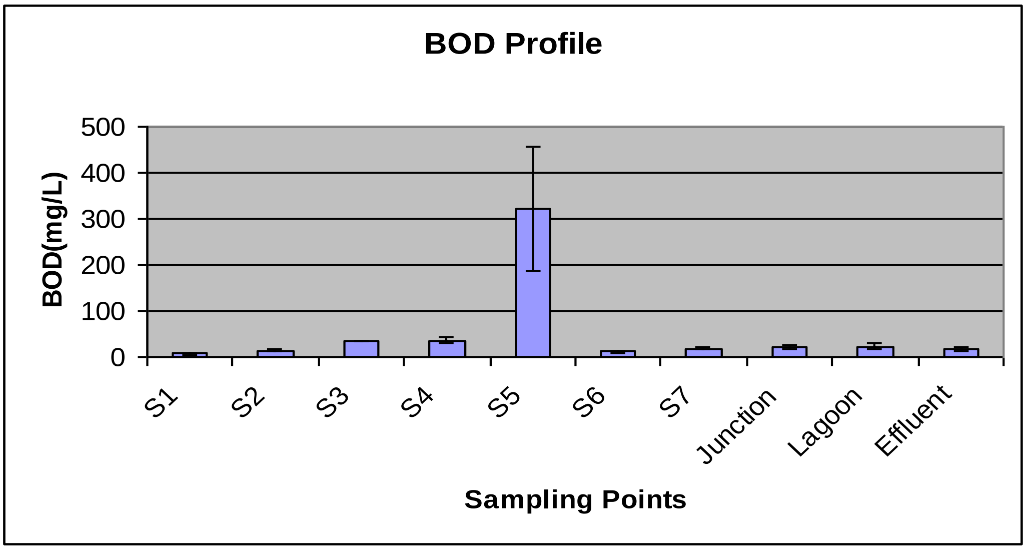

Fig 8. BOD Profile

Metcalf and Eddy (2007) established that BOD/COD ratio of untreated wastewater range from 0.3 to 0.8. If ratio is 0.5 or greater it means wastewater can be easily treated by biological means. If ratio is below 0.3 then waste have some toxic components. In the case of this study, the BOD/COD ratio was 0.12 signifying that the greywater contain some toxic substances hence cannot be easily treated by biological mean. Pre-treatment of the incoming greywater may be needed.

4.2.10 Chemical Oxygen Demand (COD)

The mean COD values ranged from 50.05 mg/L and 938.6 mg/L. The low and high concentrations of COD were recorded at S1 and S5 respectively, giving an indication that S5 is highly polluted. The common interferences for COD, which causes it to be higher than BOD, include sulphides, sulphites, thiosulphates, and chlorides (Russel, 2006).

The high mean COD at S5 could be due to pollution of greywater from washing bays along S5 and this confirms the work done by Russel (2006): washing of automobile

cars introduce many compounds into the already polluted greywater from the community, hence the high COD value.

Table 9. COD

Source of Sample	Mean	Standard Error±	min	Max
S1	50.05	9.34	30.9	75.4
S2	74.05	17.70	40.8	123.7
S3	107.38	14.35	66.5	132.8
S4	160.95	22.31	122	220.3
S5	938.63	275.51	470	1712
S6	172.53	48.68	91	313.8
S7	155.33	47.39	60.7	259.5
Junction	105.125	26.51	50.1	172
Lagoon	99.5	37.03	25.1	199.2
Effluent	136.23	31.44	90.9	229.3

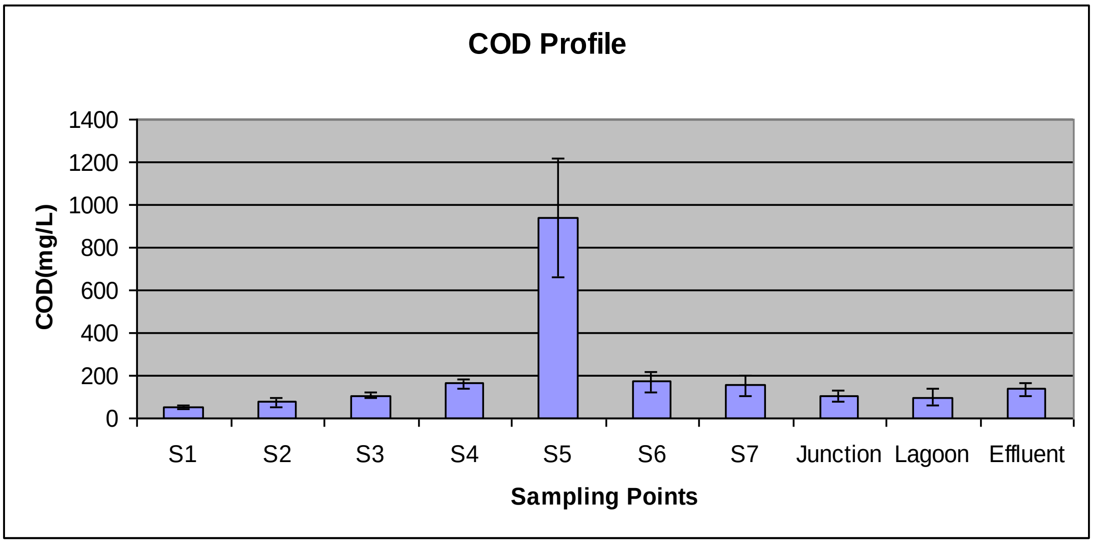

Fig 9. COD Profile

From the graph above, only S5 is above the EPA permissible level of 250mg/l. All the other sampling points were well within EPA Ghana guideline. The lagoon is able to

treat the wastewater but S5 needs pretreatment, to improve upon effluent quality of the lagoon.

4.2.11 Nutrients

The ammonia, nitrate, nitrite and phosphate concentrations were determined to obtain an indication of the nutrient content of the effluent and the receiving water body.

4.2.12 Ammonia- Nitrogen (NH_3-N)

Ammonia-nitrogen mean values ranged from 0.98 mg/L and 4.21mg/L. All the points fall outside the EPA guideline limit of 1.0mg/L except S1. Sample point S3 has the highest ammonia concentration and this is as a result of farming activities at the upstream of S3. The farmers use fertilizers on their farm and the residue is washed off into the S3 channel whenever they water their crops with the greywater from the upstream. Open defecation around S4, S5 and S6 contribute to its relatively high concentration.

Table 10. NH_3-N (mg/L)

Source of Sample	Mean	Standard Error±	Min	Max
S1	0.98	0.34	0.08	1.55
S2	2.40	0.35	1.56	3.09
S3	4.21	0.65	2.44	5.54
S4	3.76	2.69	0.06	11.75
S5	3.11	0.82	1.40	4.815
S6	3.06	0.46	2.17	4.37
S7	2.63	1.86	0.07	7.96
Junction	1.06	0.66	0.00	2.7
Lagoon	2.67	2.19	0.00	9.15
Effluent	2.04	0.05	1.91	2.11

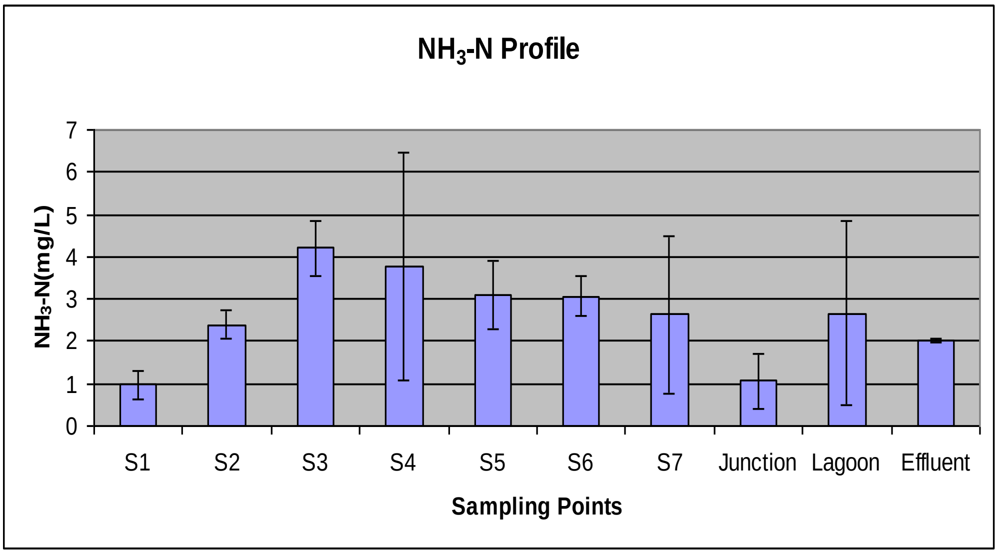

Fig 10. NH_3-N Profile

High ammonia concentration in the wastewater is converted to nitrites and nitrates and quickly absorbed by plants (Awuah, 2006). Volatilization process takes place in the course of traveling to the lagoon and this is seen in the concentration of the junction. Though the effluent quality of ammonia nitrogen is above the EPA permissible level, the concentration is an improvement on the influent.

4.2.13 Nitrate-Nitrogen (NO_3-N)

Mean influent and effluent values range between 0.83mg/L and 3.84mg/L. The nitrate concentrations of all the sampling points were low and within the EPA Ghana guideline value of 75mg/l hence acceptable. This may be due to denitrification by bacteria, where nitrate converted into gaseous nitrous oxide and molecular nitrogen into the atmosphere under anaerobic conditions.

4.2.14 Phosphate-Phosphorus (PO_4-P)

Mean phosphate values range between 0.07 mg/L and 3.73mg/L. Various activities in the study area contributed to the high concentration of phosphate at some of the sampling points. The high concentration of phosphate at S5 could be attributed to the continuous use of detergents for washing of cars at the washing bays just along the S5 channel and from domestic greywater. Crop vegetation at the upstream of S3 could also contribute to the high levels of phosphate, as a result of the use of fertilizers on the farm.

Table 11.PO_4-P(mg/L)

Source of Sample	Mean	Standard Error±	Min	Max
S1	0.07	0.07	0.001	0.27
S2	0.38	0.13	0.03	0.64
S3	1.76	0.17	1.40	2.10
S4	1.40	0.20	0.82	1.66
S5	3.73	1.03	0.92	5.91
S6	0.52	0.14	0.27	0.88
S7	0.82	0.08	0.59	0.93
Junction	0.29	0.10	0.001	0.48
Lagoon	0.34	0.15	0.001	0.63
Effluent	2.78	2.23	0.36	9.46

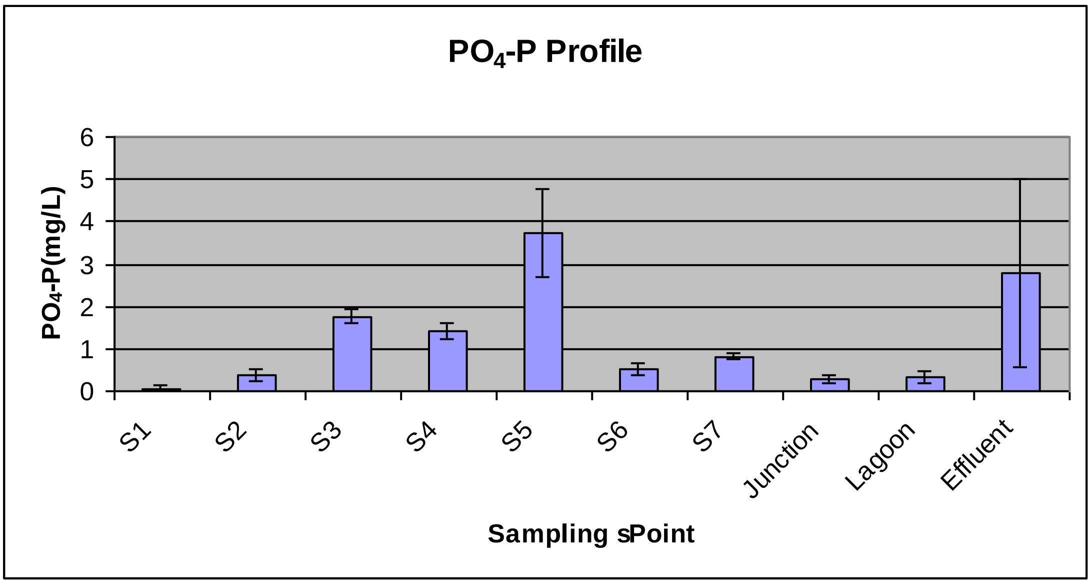

Fig 11. PO_4-P Profile

In aquatic environment, phosphorus is normally removed by these mechanisms: plant uptake, adsorption by clay particles and organic matter, chemical precipitation by Ca^{2+},Fe^{3+}, Al^{3+} and microbial uptake (adapted from Awuah 2006: Iqbal, 1999)

There is a significant variation between the lagoon and the effluent in terms of concentration.

The high concentration of phosphate may be due to re-suspension of phosphorus due to high pH and DO (Mara and Pearson, 1986; Reed et al., 1988; Awuah, 2006). High phosphate concentrations at the effluent could be attributed to a by-pass greywater discharge from the La Pleasure Beach Hotel. The EPA Ghana guideline value is 2 mg/L and S5 and the effluent are above this permissible limit.

4.2.15 Faecal Coliforms

The mean faecal coliforms count for the study area was between 7.65E+01 and 5.12E+05 FC/100ml. Figure 12 shows the faecal coliforms profile at the study area and it is clear that S5 recorded the highest value with S6 having the lowest value.

According to Millipore (1991), under the auspices of WHO, stipulated permissible limits for various water use are as follows: 200 per 100ml for primary contact (swimming) and 5000 per 100ml for secondary contact (fishing, boating), adapted from Annang (2000).

The exceptionally high values recorded for S5 and S3 implied wastewater (blackwater) input by inhabitants in the areas of S5 and S3. Human waste was seen in the greywater samples taken at these sample points. Coliform bacteria in environmental samples, is an indication that pathogenic organisms associated with fecal contamination may be present (Polz, 2007).

It was evident that human waste was scattered all over the study area and these are washed by the incoming greywater into the lagoon.

Table 12. Faecal Coliforms (FC/100ml)

Source of Sample	Mean	Standard Error±	min	Max
S1	4.31E+03	1480.46	600	6700
S2	3.47E+04	14650.68	200	59000
S3	3.56E+05	170865.58	36400	651000
S4	6.76E+04	37204.30	0	132000
S5	5.12E+05	175925.10	500	744000
S6	7.65E+01	22.17	10	100
S7	1.74E+05	71888.79	5	292000
Junction	2.01E+05	73221.44	24800	372000
Lagoon	2.95E+05	68288.34	102300	392000
Effluent	2.80E+05	107474.42	72000	465000

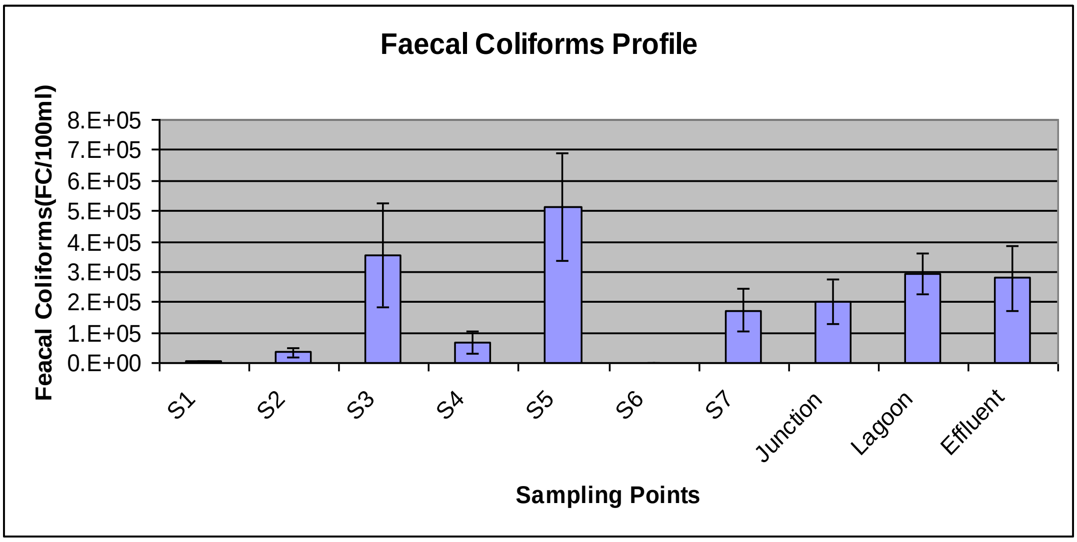

Fig 12. Feacal Coliforms Profile

The lagoon is a source of income for the inhabitants of La community and is actually for fishing, of which the body contact with the water should be secondary but is primary body contact. This is because no boat is used for fishing and the average value is far above the permissible limit of 5000 per 100ml according to WHO standards.

The effluent quality is not acceptable due the high value recorded. The high faecal coliforms count at the effluent may due to open defecation around the outfall.

Many researchers (Davies-Colley et al 1999; Pearson et al 1987; Awuah 2006) attributed pathogen removal in ponds to several factors such as direct sunlight, high pH levels and DO concentrations. Sample points S1 and S6 show low faecal coliform population. This might be due to pH 7.9 and 8.4 respectively and the effect of direct sunlight and sedimentation.

4.3 TRACE METALS

Concentrations of cadmium, lead, manganese and copper were determined to obtain the content of trace metals of the receiving water and the effluent, whether they are of acceptable values.

4.3.1 Cadmium

The average cadmium levels for the greywater were within the EPA guideline value of 0.1mg/L. This shows that the wastewater that enters the lagoon is not much polluted with high cadmium concentrations. The effluent quality was acceptable according to the EPA limits.

Table 13. Cadmium (mg/L)

Source of Sample	Mean	Standard Error±	min	Max
S1	0.003	0.0006	0.002	0.004
S2	0.002	0	0.002	0.002
S3	0.002	0	0.002	0.002
S4	0.003	0.0006	0.002	0.004
S5	0.0045	0.0012	0.002	0.007
S6	0.002	0	0.002	0.002
S7	0.002	0	0.002	0.002
Junction	0.0043	0.0013	0.002	0.007
Lagoon	0.002	0	0.002	0.002
Effluent	0.002	0	0.002	0.002

4.3.2 Lead

The EPA Ghana guideline for lead is 0.1mg/L. The mean values ranged between 0.005mg/L to 0.008mg/L, which are all within the Ghana EPA limit. Lead concentrations present in the greywater are satisfactory.

Table 14. Lead (mg/L)

Source of Sample	Mean	Standard Error±	min	max
S1	0.005	0	0.005	0.005
S2	0.005	0	0.005	0.005
S3	0.005	0.0003	0.005	0.0063
S4	0.0083	0.0033	0.005	0.0182
S5	0.005	0	0.005	0.005
S6	0.005	0.0003	0.0038	0.005
S7	0.005	0	0.005	0.005
Junction	0.005	0	0.005	0.005
Lagoon	0.006	0.0009	0.005	0.0086
Effluent	0.005	0	0.005	0.005

4.4.3 Copper

Mean copper values were between 0.006 mg/L and 0.015mg/L. Adsorption and chemical precipitation, are mechanisms of heavy metal removal according to Crites et al (2005), hence the low concentration of wastewater might be due to this form of treatment. The levels of copper are acceptable and within the EPA limit of 2.5mg/l.

Table 15. Copper (mg/L)

Source of Sample	Mean	Standard Error±	min	Max
S1	0.008	0.003	0.005	0.015
S2	0.008	0.003	0.005	0.016
S3	0.009	0.004	0.005	0.019
S4	0.006	0.001	0.005	0.007
S5	0.015	0.006	0.005	0.026
S6	0.009	0.004	0.005	0.022
S7	0.007	0.002	0.005	0.013
Junction	0.010	0.005	0.005	0.023
Lagoon	0.009	0.004	0.005	0.02
Effluent	0.008	0.003	0.005	0.018

4.3.3 Manganese

The mean manganese values for this study ranged from 0.1 mg/L to 1.9mg/L. The concentrations are unsatisfactory compared to EPA value of 0.1mg/L. According to Metacalf and Eddy (2003), manganese is toxic to a number of crops at a few tenths mg/L, but only in acid soils. Considering the soil analysis, S3 has acidic soil of pH 6.37 and there was farming activities at the upstream where farmers use the waste water on their crops. This may be toxic to some of the crops on the farm, though this was not investigated.

Table 16. Manganese (mg/L)

Source of Sample	Mean	Standard Error±	min	Max
S1	0.73	0.096	0.448	0.878
S2	1.92	0.517	0.645	2.954
S3	0.52	0.071	0.331	0.649
S4	0.69	0.104	0.397	0.887
S5	0.20	0.056	0.039	0.28
S6	0.10	0.018	0.058	0.144
S7	0.11	0.020	0.056	0.156
Junction	0.29	0.063	0.181	0.429
Lagoon	0.24	0.035	0.201	0.343
Effluent	0.19	0.061	0.025	0.322

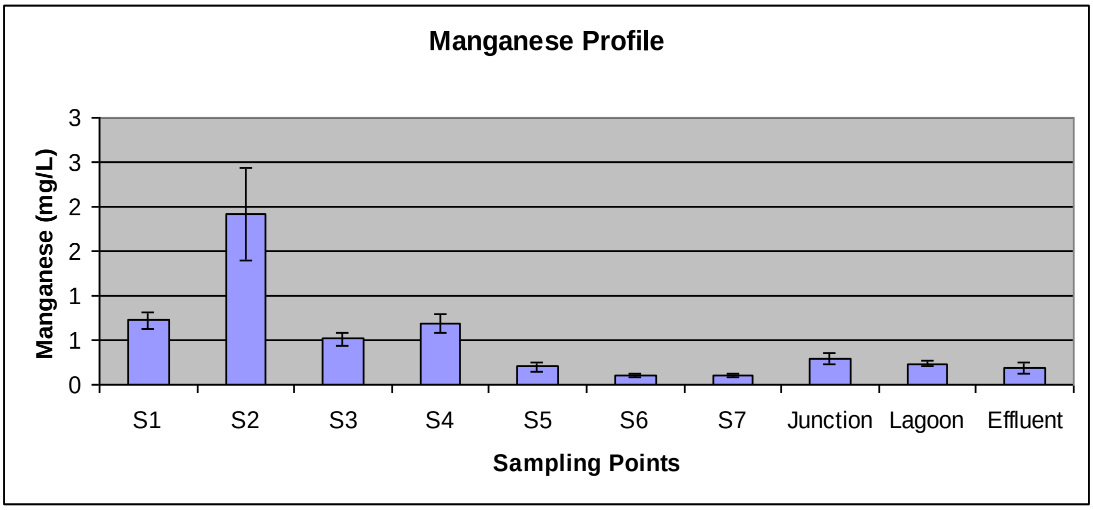

Fig 13. Manganese Profile

The high levels of manganese, especially at S2 may be due to the anaerobic conditions resulting in the decrease in the redox potential in transforming manganese from manganic to manganous compounds which are soluble (Gosslink and Mitsch, 1993) as shown in the equation below.

$$MnO_2 + 2e^- + 4H^+ \rightarrow Mn^{2+} + 2H_2O$$

4.4 FLOW RATE MEASUREMENT

The average daily influent flow from sampling point S5, La Community was 647.65m^3/s. The data shows continuous fluctuations in the flow; this is shown in Fig 14 below. The fluctuations were due to the daily activities around the S5 channel. The regression part of the line shows a decrease in flow rates due to low consumption

of the water by habitats and activities at that time. On the contrary it shows peak flow between 7am -10am and 3pm-9pm, (Fig 14). During the time of sampling no rain effect was observed.

The area of the La drain is 1.94m^2 hence the hydraulic loading rate to the lagoon is 333.84m/s.

Due to site limitations, the flow rates for the other sampling points and the effluent could not be taken.

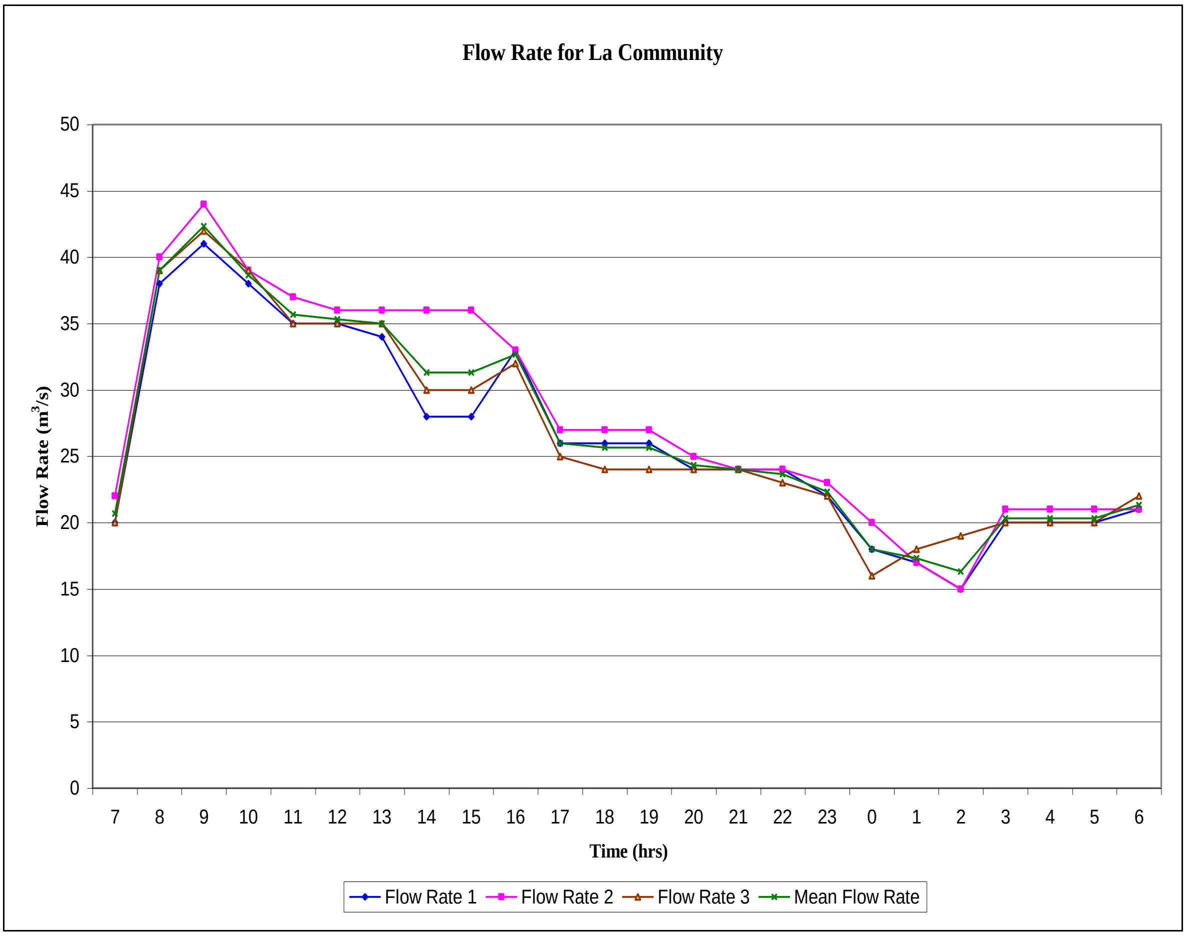

Fig 14. Flowrate Measurement

4.5 SPECIES IDENTIFICATION

One of the most important requirements for pollutants removal in a natural wetland, which is also a natural treatment system, is the type and emergent plant species present. The role plants play in treatment process is to provide attachment for organism's growth to assist in the decomposition of organic matter (Crites et al., 2005).

(Kadlec and Knight, 1996; Gosselink and Mitsch, 2000) established that a wetland without plant species will have limited potential for particulate and dissolved pollutants reduction. There is a large number of plant species that may be suitable for treatment wetland but evaluation studies on them are few to date (Gosselink and Mitsch, 2000).

The under listed plant species were dominant in the study area and apparently contributed to the pollutants removal.

Sesevium portulacastum (Sea Purslane)

Avicennia germinans (Black Mangrove)

Paspalum polystachyum (Koda Grass)

The plant species closest to the lagoon is *Avicennia germinans.*

4.6 SOIL CHARACTERISTICS

4.6.1 Physical Analysis

The soil texture of a wetland is based on the percentage of sand, silt and clay content (www.ag.ndsu.edu). The type of soil at the mangrove swamp was clay loam, with the

following percentages: sand 23%, silt 39% and clay 38%. Since the area closest to the lagoon is the mangrove swamp, its soil characteristics was used for this discussion but a summary of the soil characteristics of other sampling points have been shown at the appendix11, table 20.

Crites et al (2005) established that adsorption and chemical precipitation are mechanisms of heavy metal removal. The physical characteristics of the soil played a major role in the removal of trace metals through adsorption and chemical precipitation; hence the low concentrations of trace metals in the greywater except manganese. Generally, 15% of clay is suitable and recommended for wetland treatment systems, (Kadlec and Knight, 1996).

4.6.2 Chemical Analysis

A number of metals are required in small amounts for plant or animal growth .Some of these micro nutrients may be found in certain types of wastewater. The analysis conducted indicated that the soil is mostly organic. Removal of metals in wetlands may occur through a number of processes; including plant uptake, soil adsorption and precipitation. Wetland soils are potentially effective traps, or sinks for metals due to the relative immobility of most metals in wetland soils (DeBusk,1999).

According to Kadlec and Knight (1996), chemical reactivity relates to the surface electrical charge of the soil particle and soil charge is typically highest in clays and organic soil particle. The electrical conductivity was as high as 12.18 dS/m, which confirms the salinity of the soil, hence no agricultural activity in the mangrove.

Table 18 showed that organic matter and organic carbon were 3.03% and 1.76% respectively. According to DeBusk (1999), this is utilized by a wide array of micro organisms as a source of energy to break down organic carbon to carbon dioxide.

The pH value was 7.6 which is moderately alkaline (Soil Research Institute of CSIR, 2007) and the range of 5.6-8 is suitable for most plants (Crites et al. 2005). Available K and P were 1104mg/kg and 55.1mg/kg, indicating high concentrations respectively. The high levels may be attributed to farming activities at the upstream, where excess fertilizer are washed down to the soil.

Organic matter was high; 3.03%. The high level may be due to the decay of fallen leaves from mangrove swamp and open defaecation in and around the mangrove. Percentage nitrogen (% nitrogen) and available sodium were 0.25 and 0.017 respectively, were found to be adequate.

Cd, Cu and Pb were between <0.002 and <0.005 mg/kg. The low concentrations may be due to the uptake by plants species present and the concentration of manganese was 0.04 mg/kg.

Table 18 Soil Characteristics

PARAMETER	CONCENTRATION
Na mg/kg	0.02
K mg/kg	1104
P mg/kg	55.1
pH	7.6
% O/M	3.03
% O/C	1.76
% N	0.25
EC µS/cm	12.18
Cd mg/kg	<0.002
Mn mg/kg	0.04
Pb mg/kg	<0.005
Cu mg/kg	<0.005

CHAPTER FIVE

5. CONCLUSION

The conclusions drawn from this study were as follows:

The lagoon has a high potential of removing pollutants and could be used for better treatment of greywater if it is well managed by the La Sub Metro authorities.

The removal efficiencies of nitrite, colour, BOD, Mn and turbidity were between 61% and 80%. TSS, COD, $NH_{3,}$ Cd, Pb, Cu had their removal efficiencies between 20% and 50%. Conductivity, salinity, PO_4, NO_3 and faecal coliforms are the only parameters that increased in its concentration.

The plant species around the lagoon play a major role in the treatment process by taking up some pollutants such as trace metals and nutrients from the incoming greywater.

The soil type, which spans from clay loam and sand loam, also contribute to the treatment process by removing some pollutants such as the trace metals, phosphates, nitrites and ammonia through soil adsorption and precipitation.

5.1 RECOMMENDATION

- The communities should be educated on the economic and environmental importance of lagoon.
- Greywater should be pre treated by introducing a primary sedimentation tank, especially for greywater from sample point S5 (La community) before discharged into the Lagoon.
- The communities should be educated to desist from open defaecation and dumping of solid waste into open drains and channels. These cause aesthetic nuisance around the lagoon, at the beach (the outfall) and also affect the quality of the effluent.
- The mangrove and other plants around the lagoon should not be removed.
- The lagoon should be dredged occasionally to ensure efficient performance.
- Places of convenience should be provided to the communities which do not have them.
- The laws should be enforced by the La Sub Metro authorities to sanction those who abuse and misuse the Lagoon by cutting trees and dumping of solid wastes.
- The lagoon would have less faecal coliforms concentration if its surroundings are free from human excreta which might have contributed to high faecal coliforms count in the effluent

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APPENDICES

APPENDIX 1

ANALYTICAL METHODS

Dissolved Oxygen (DO)

Azide Modification of the Wrinkler's Method

Principle

The Wrinkler or iodometric test is the most precise and reliable titrimetric procedure for DO analysis. It is based on the addition of divalent manganese solution, followed by a strong alkali, to the sample in a glass stoppered bottle (BOD bottle). DO rapidly oxidizes an equivalent amount of the dispersed divalent manganous hydroxide precipitate to hydroxide of higher valency states. In the presence of iodide ions in an acidic solution, the oxidized manganese reverts to the divalent state, with libration of iodine equivalent to the original DO content. The iodine is then titrated with a standard thiosulphate.

PROCEDURE

Collect the sample carefully into a 300ml BOD bottle, then add 1ml manganous sulphate followed by 1ml alkali-iodide azide. Hold the pipet tips just above the liquid. The bottle is stoppered to exclude air bubbles and mixed by inverting the bottle few times.

1ml concentrated sulphuric acid is added and swirled gently to dissolve the flocs. 200ml of the mixture is titrated with 0.025M sodium thiosulphate to pale straw colour, then 1-2ml starch solution added and titration continued until first disappearance of blue colour (Kruis 1999).

The number of ml of sodium thiosulphate consumed indicates the dissolved oxygen content of the sample in mg/l.

Also DO can be calculated instead of using the volume of the titrant by using the formula below:

DO mg/l = V*N*8* 1000/Vs-2: where

V = ml of sodium thiosulphate used

N = molarity of sodium thiosulphate

Vs = sample volume

Biochemical Oxygen Demand (BOD)

Dilution Method

Principle

The BOD determination is an empirical test in which standardised laboratory procedures are used to determine the relative oxygen requirements of waste waters, effluents and polluted waters. The method consist of DO determination before and after incubation for five days at 25oC, the BOD is computed from the initial and final DO.

PROCEDURE

A desired quantity of sample, say 20ml is made up to 1 litre with dilution water. This is mixed well with a mixing rod. The mixed dilution is siphoned into two BOD

bottles excluding air bubbles. Initial DO on one of the bottled samples is determined and the other bottle stoppered and incubated in the dark for five days at 25oC. Incubation in the dark prevents photosynthetic action by any algae

contained in the sample that might give oxygen to interfere with the BOD determination.

Calculation:

BOD_5 mg/l = D_0-D_1 / S where:

D_0 = initial DO

D_1 = final DO

S = volume of sample used

Chemical Oxygen Demand (COD)

Closed Tube Method

Principle

Most types of organic matter are oxidized by a boiling mixture of chromic and silver catalyst in strong sulphuric acid. The sample is refluxed in strongly acid solution with a known excess potassium dichromate. After digestion, the remaining unreduced potassium dichromate is titrated with ferrous ammonium sulphate (FAS), using ferroin as indicator. Chloride interference is suppressed by addition of mercuric sulphate to the reaction mixture.

PROCEDURE

The digestion tubes and caps are washed with 4M sulphuric acid first to prevent contamination. 10ml of standard or sample is transferred into the digestion tube and 6ml digestion solution added. 14ml sulphuric acid is carefully run down inside the tube to form an acid layer under the sample-digestion solution layer. The tubes are tightly capped and inverted several times to mix completely. The samples are refluxed for 2 hours and then cooled to room temperature. The samples are transferred to a larger container for titration. 1-2 ml ferroin indicator

is added and titrated with 0.1M FAS until the colour changes from blue-green to reddish-brown.

This procedure is repeated for the blank sample.

Calculation:

CODmg/l = (B-C)*M*8000/ Vs: where

B = volume of FAS used for blank

C = volume of FAS used for sample

M = molarity of FAS

Vs = volume of sample used

Total Suspende Solids (TSS)

Principle

Well mixed sample is filtered through a weighed standard glass-fiber filter and the residue retained on the filter is dried to a constant weight at 103 to 105oC. The increase in weight of the filter represents the total suspended solids.

Calculation

TDS mg/l = (A-B)*1000/ sample volume, ml: where

A =weight of filter + residue

B = weight of filter

APPENDIX 11

Table 17. EPA Ghana Guidelines

	COLUMN 1	**COLUMN 2**	**COLUMN 3**
	PARAMETER/DESCRIPTION	**MAXIMUM PERMISSIBLE LEVEL (new Facilities)**	**MAXIMUM TARGET (PERMISSIBLE) LEVEL (Existing Facilities)**
1.	Ph	6 - 9(in the range of)	6 – 9
2.	Temperature*	<3°C above ambient	<3°C above ambient
3.	Colour (TCU)	20	100
4.	Oil and Grease (mg/l)	20	20
5.	Oil	No visible floating oil	No visible floating oil
6.	BOD (mg/l)**	50	200
7.	COD (mg/l)**	250	1000
8.	Total Dissolved Solids (mg/l)	1000	1000
9.	Total Suspended Solids (mg/l)	50	50
10.	Turbidity (NTU) **	75	75
11.	Conductivity (μS/cm)**	1500	1500
12.	Total Coliforms (MPN/100ml)	400	400
13.	E. Coli (MPN/100ml)	10	10
14.	Ammonia as N (mg/l)**	1.0	10
15.	Nitrate (mg/l)**	75	100
16.	Flouride (mg/l)**	10	20
17.	Phenol (mg/l)	1.0	1.0
18.	Sulphide (mg/l)	1.5	1.5
19.	Total phosphorus (mg/l)**	2.0	10.0
20.	Total Cyanide (mg/l)	1.0	1.0
21.	Free Cyanide (mg/l)	0.2	0.2
22.	Cyanide as Weak Acid Dissociable (mg/l)	0.6	0.6

23.	Total Arsenic (mg/l)	0.5	0.5
24.	Soluble Arsenic (mg/l)	0.1	0.1
25.	Cadmium (mg/l)	<0.1	<0.1
26.	Chromium (+6) mg/l	0.1	0.1
27.	Total chromium (mg/l)	0.5	0.5
28.	Copper (mg/l)	2.5	2.5
29.	Lead (mg/l)	0.1	0.1

Source : EPA Ghana Guidelines 2000

TABLE A2:Soil test analysis	
Soil pH	
<5	Very acidic
5.1 – 5.4	Acidic
5.5 - 6.4	Moderately acidic
6.1 – 6.4	slightly acidic
6.5 – 7.0	Neutral
7.1 – 7.4	slightly alkaline
7.5 – 8.0	moderately alkaline
>8.0	Alkaline

Units:

- **ppm = mkg**

The SI units for ppm = kg soil

- **m.e/100g soil = cmol (+) kg soil K.Na (monovalent cations)**

e,g. 5 m.e K/100g/100 soil = 5 cmol (+) kg soil

- **For divalent cations (Ca and MG)**

5 m.e.K.100g soil = 5 cmol(+)kg soil

Extractable Cu	
<0.3mg/kg	Very low
0.3 – 1.5	Low
2.0 – 3.0	Moderate
4.0 – 7	Very high
Extractable Zn	
< 0.2 mg/kg	Very low
0.2 – 1.0	Low
2.0 – 3.0	Moderate

4.0 – 5.0	High
> 5.0	Very high
>5.0	Very high

Source: SRI (Soil Research Institute)

TABLE A3:Soil test analysis	
Total nitrogen: <0.1 %	Low
0.1 – 0.2	Medium
> 0.2	adequate
Organic matter: < 1.5%	Low
1.5 – 3.0	Medium
> 3.0	High
Bray's No. 1P :< 3.0ppm	Very low
3 – 10	Low
11- 20	Medium
> 20	High
Bray's K: <50 mg/kg soil	Low
50 -100	Medium
>100	High
Exchangeable Ca: <5.0 m.e./100g soil	Low
50-100	Medium
>10.0	High
Exch :Mg :<1.0 m.e./100g soil	Low
1.0 – 3.0	Medium
>4.0	High
Exch: K :< 0. 15 m.e./100g	Low
0.15 – 0.25	Medium

>**0.25**	High
Base saturation	
<**50%**	Low
50 – 70	Medium
70 – 90	High
>**90**	Very high

Source: SRI (Soil Research Institute)

Table 18. FLOW RATE MEASUREMENT (L/S)

Hour	4/10/2007	11/10/2007	18/10/2007	Mean
7	20	22	20	20.67
8	38	40	39	39
9	41	44	42	42.33
10	38	39	39	38.67
11	35	37	35	35.67
12	35	36	35	35.33
13	34	36	35	35
14	28	36	30	31.33
15	28	36	30	31.33
16	33	33	32	32.67
17	26	27	25	26
18	26	27	24	25.67
19	26	27	24	25.67
20	24	25	24	24.33
21	24	24	24	24
22	24	24	23	23.67
23	22	23	22	22.33
0	18	20	16	18
1	17	17	18	17.33
2	15	15	19	16.33
3	20	21	20	20.33
4	20	21	20	20.33
5	20	21	20	20.33
6	21	21	22	21.33

Table 19. Physical Characteristics of Soil in the Study Area

Station	Depth (cm)	%Sand	%Silt	%Clay	Texture
S3	0-45	89	5	6	Sand
S4	0-45	23	39	38	Clay Loam
S6	0-45	74	21	5	Sandy Loam
S7	0-45	65	23	12	Sandy Loam

Table 20. Chemical Analysis of Soil in the Study Area

Parameter	S3	S4	S6	S7
Ph	6.37	7.6	8.7	7.85
Conductivity dS/m	0.33	12.18	8.37	3.16
Phosphate mg/kg	295.8	55.1	24.41	23.72
Potassium mg/kg	82.8	1104	386.4	308.2
Na mg/kg	0.01	0.02	0.01	0.02
Cd mg/kg	0	0	0	0
Mn mg/kg	0.01	0.04	0.01	0.02
Pb mg/kg	0	0	0	0
Cu mg/kg	0	0	0	0
%N	0.01	0.25	0.03	0.06
%O/C	0.08	1.76	0.25	0.47
%O/M	0.14	0.81	0.43	3.03

Table 21. Grey water Characteristics

Parameter	Units	Av Inf	Lagoon	Effluent	Max. Perm
Temperature	oC	29.11	29.25	30	<3 above amb
PH		7.84	7.51	7.55	6-9
Conductivity	µS/cm	17102.79	23570	25315	1500
Turbidity	NTU	72.14	32.15	28.3	75
Salinity	mg/l	13.06	32.91	15.58	
Colour	TCU	74.64	40	16.25	20
TSS	mg/l	92.39	40.25	52	50
BOD	mg/l	63.79	23.45	16.45	50
COD	mg/l	236.99	99.5	136.23	250
Ammonia-nitrogen	mg/l	2.87875	2.666	2.036	1
Nitrate	mg/l	2.04	1.308	1.217	75
Nitrite	mg/l	0.10	0.076	0.025	-
Phosphate	mg/l	1.24	0.341	2.784	2

Cadmium	mg/l	0.003	0.002	0.002	<0.1
Lead	mg/l	0.005	0.006	0.005	0.1
Manganese	mg/l	0.609	0.238	0.187	0.1
Copper	mg/l	0.009	0.009	0.008	2.5
F.Coliforms	FC/100ml	163955.9	294575	279500	400 MPN/100

Table 22. Summary of field and Laboratory results.

	Temp	PH	Conductivity	Turbidity	Salinity	Colour	TSS	DO	BOD	COD	NH3-N	NO3-N	NO2-N	PO4-P	Cadmium	Lead	Manganese	Copper	F.Coliforms
10/10/2007																			
1	27	7.57	1173	24	0.568	30	7	8.78	13.8	30.9	0.084	9.98	0.075	0.001	0.002	0.005	0.448	0.005	6.70E+03
2	27	7.4	3330	20.3	2.002	20	8	3.54	22	71	3.09	8.31	0.231	0.643	0.002	0.005	2.533	0.005	2.04E+04
3	27	7.71	4970	28.5	2.271	60	14	5.66	30	111	4.52	1.1	0	1.404	0.002	0.005	0.6	0.005	8.37E+04
4	27	7.59	38300	58.7	37.851	90	19	0	16.8	122	0.058	0.001	0	1.56	0.002	0.005	0.887	0.005	6.40E+03
5	31	7.82	2790	263	0.819	300	308	0	120	470	4.815	0.001	0	0.923	0.002	0.005	0.266	0.005	5.00E+02
6	31	8.75	30300	59.7	33.011	60	99	10	13.8	91	2.855	5.19	0.178	0.875	0.002	0.005	0.058	0.005	100
7	30	8.76	40400	45.3	34.445	60	64	8.88	19.8	91	0.068	2.21	0.191	0.594	0.002	0.005	0.056	0.005	1.12E+05
Junction	29	7.79	19870	19.8	14.28	30	19	5.15	24	120	0.001	0.001	0.654	0.001	0.002	0.005	0.36	0.005	1.58E+05
Lagoon	30	7.73	23300	21.7	15.266	30	22	4.95	33.8	105	0.001	6.39	0.1	0.001	0.002	0.005	0.343	0.005	1.02E+05
Effluent	30	7.78	28900	31.4	15.445	30	28	0	21.3	114	2.105	0.001	0	9.46	0.002	0.005	0.322	0.005	7.20E+04
17/10/07																			
1	28	8.03	1481	13	0.678	20	7	5.76	0	75.4	0.84	0.62	0.138	0.001	0.004	0.005	0.878	0.005	3255
2	28	7.46	3830	13	2.015	10	15	1.62	15.9	123.7	2.09	0.93	0.6	0.326	0.002	0.005	2.954	0.005	59000
3	28	7.83	2610	15	0.822	30	17	0	39	132.8	4.32	1.04	0.001	2.011	0.002	0.005	0.649	0.005	651000
4	27	8.13	40800	47	38.651	150	38	0	50	220.3	1.58	1.24	0.001	1.664	0.004	0.005	0.706	0.005	132000
5	32	7.79	3330	528	0.801	200	639	0	690	1712	4.15	5.97	0.128	4.055	0.003	0.005	0.039	0.026	744000
6	31	8.58	47600	26	34.544	30	18	0.91	6	313.8	2.86	1.11	0.024	0.363	0.002	0.005	0.098	0.005	98
7	30	8.46	48300	91	34.668	75	53	0	10	259.5	0.078	1.42	0.024	0.931	0.002	0.005	0.156	0.005	292000
Junction	30	7.74	22800	23	14.582	30	26	0	28.5	172	0.001	4.24	0.029	0.333	0.006	0.005	0.429	0.005	24800
Lagoon	30	7.67	38400	18	15.997	30	18	1.11	12	199.2	0.001	1.793	0.112	0.632	0.002	0.005	0.205	0.005	392000
Effluent	30	7.99	46900	12.8	15.455	7.5	3	3.43	0	229.3	2.11	4.22	0.029	0.661	0.002	0.005	0.025	0.005	465000
24/10/07																			
1	29	8.12	1141	35.5	0.613	25	20	4.25	6.5	43.9	1.55	0.601	0.118	0.27	0.004	0.005	0.814	0.005	6700
2	28	7.38	1100	81.9	0.613	50	55	1.53	15.1	40.8	1.56	1.3	0.607	0.512	0.002	0.005	1.556	0.005	59000
3	28	7.58	1733	23.1	0.881	35	21	1.83	34.5	119.2	2.44	0.74	0.001	1.517	0.002	0.005	0.487	0.005	651000

4	27	7.35	30500	32	17.596	60	54	0	45	131.7	1.66	1.64	0.001	0.818	0.004	0.005	0.766	0.005	132000
5	31.5	7.27	2360	241	1.106	150	144	0	130	633.4	2.07	6.07	0.126	5.912	0.006	0.005	0.218	0.005	744000
6	31	8	22100	22.4	27.634	30	74	1.12	16	137.9	4.37	1.01	0.023	0.588	0.002	0.005	0.108	0.005	98
7	31	8.23	41200	28.6	32.294	35	156	1.23	20.2	210.1	7.96	1.32	0.024	0.825	0.002	0.005	0.112	0.005	292000
Junction	28.5	7.4	4160	62.1	2.539	40	42	4.01	30	50.1	1.55	5.24	0.027	0.479	0.007	0.005	0.184	0.005	248000
Lagoon	28.5	7.38	4580	63	2.674	75	45	4.11	32	25.1	1.51	0.793	0.092	0.204	0.002	0.005	0.203	0.005	392000
Effluent	30	7.29	8180	44.3	3.951	7.5	33	2.34	21	90.9	1.91	4.17	0.025	0.358	0.002	0.005	0.2	0.005	465000
7/11/2007																			
1	29	8.02	1140	30.5	0.588	30	10	4.24	6.5	50	1.45	0.52	0.09	0.001	0.002	0.005	0.768	0.015	600
2	28	6.96	3840	31.9	2.271	40	25	5.66	6.6	60.7	2.855	0.154	0.024	0.026	0.002	0.005	0.645	0.016	200
3	28	7.48	2970	22.7	1.329	50	14	2.4	36	66.5	5.542	0.497	0.027	2.097	0.002	0.0063	0.331	0.019	36400
4	27	7.59	38300	99.9	30.502	120	84	1.45	35	169.8	11.753	0.441	0.032	1.564	0.002	0.0182	0.397	0.007	0
5	31.5	7.69	3200	99.9	0.926	250	392	0	350	939.1	1.401	3.32	0.207	4.04	0.007	0.005	0.28	0.022	558000
6	31	8.22	18380	15.9	24.124	50	104	0.89	15.5	147.4	2.172	0.027	0.009	0.268	0.002	0.0038	0.144	0.022	10
7	31	7.64	41700	22.2	1.957	30	128	0.9	22	60.7	2.414	0.303	0.052	0.929	0.002	0.005	0.105	0.013	5
Junction	28.5	7.25	28100	26.1	22.077	12.5	94.7	3.8	6.5	78.4	2.7	0.548	0.011	0.332	0.002	0.005	0.181	0.023	372000
Lagoon	28.5	7.24	28000	25.9	97.718	25	76	4.01	16	68.7	9.15	0.198	0.001	0.528	0.002	0.0086	0.201	0.02	292000
Effluent	30	7.15	17280	24.7	27.455	20	144	3.02	23.5	110.7	2.018	0.1	0.045	0.656	0.002	0.005	0.202	0.018	116000

PICTURES OF THE STUDY AREA

Plate 1 1. Wetland filled with construction demolition in study area.

Plate 1 2. Farming at the upstream of study area

Plate 1 3. Junction of the Kpeshie Lagoon

Plate 1 4. Main Lagoon

Plate 1 5. Mangrove Swamp around the Kpeshie Lagoon

Plate 1 6. Drain carrying greywater from La Community

Plate 1 7. A Section of Africa Lake