PHYTOREMEDIATION OF SEWAGE EFFLUENT WITH SOME SELECTED AQUATIC PLANTS FROM ANAEROBICALLY DIGESTED BIOGAS PLANT FROM THE VALLEY VIEW UNIVERSITY BIOGAS FACILITY, OYIBI, ACCRA.

BY

HENRY ASANTE ABOAGYE
(10104118)

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN ENVIRONMENTAL SCIENCE

JULY, 2014

DECLARATION

This is to certify that this thesis is the result of research undertaken by Henry Asante Aboagye towards the award of the Master of Philosophy Degree in Environmental Science at the Institute for Environment and Sanitation Studies, University of Ghana.

…………………………………………… ……………………..

ABOAGYE HENRY ASANTE Date

(STUDENT)

.... ……………………

DR. TED ANNANG Date

(PRINCIPAL SUPERVISOR)

.... ……………………

DR. DANIEL NUKPEZAH Date

(CO-SUPERVISOR)

ABSTRACT

Water is a resource of increasing scarcity due to continual expansion of production, increase in population and urbanization. This work was conducted to assess the quality of sewage effluent from a biogas facility at the Valley View University, Oyibi, Accra and also to investigate into the phytoremediation potential of *Eichhornia crassipes* (Water hyacinth), *Neptunia oleracae* (Water mimosa), *Lemna minor* (Duckweed) and *Ceratophyllum desernum* (Coontail) in remediating contaminants from the sewage effluent. This is in the broader interest of resource recovery (especially water) from sewage effluent which could be used for both essential and non-essential purpose.

Samples of sewage effluent for phytoremediation were taken over a period of six weeks and subjected to microbiological and physico-chemical examination to assess the reductions in levels of pollutants. The studied parameters included Temperature, Hydrogen ion concentration, Turbidity, Nitrate, Nitrite, Ammonia, Phosphate, Biochemical Oxygen Demand, Total Suspended Solids, Total Coliform, Faecal Coliform and Total heterotrophic bacteria. These were used to assess the performance efficiency of the aquatic plants in reducing the polluting strength of the waste water. The data were analyzed using Microsoft excel and Statistical Package for Social Science (SPSS) software packages. One way analysis of variance (ANOVA) was ran to determine significant differences of the parameters per plant.

Results from this study showed that only parameters such temperature (27.3°C), pH (7.47), BOD (38 mg/l), Turbidity (48 mg/l) and TC (348 cfu/100ml) were within EPA limits and hence sewage effluent from the Valley View University biogas facility was not satisfactory to be discharged into the environment. The study also found out that *Eichhornia crassipes*

(Water hyacinth), *Neptunia oleracea* (Water mimosa), *Lemna minor* (duckweed) and *Ceratophyllum demersum* (coontail) have great removal efficiencies for contaminants from sewage effluent. The efficiency in terms of decreasing ranking were *Ceratophyllum demersum* > *Eichhornia crassipes* > *Lemna minor* > *Neptunia oleracea*. This study also determined the public awareness and the potential for acceptance, of reuse applications for the treated sewage effluent. It revealed that both women and men have concerns especially regarding the use of treated wastewater as drinking water and felt that treated wastewater reuse for applications not involving close personal contact was acceptable, due to reduced health risk concerns.

An integrated approach for treatment of the sewage effluent from the Valley View University biogas facility is recommended before any reuse application.

DEDICATION

This work is dedicated to my mother Madam Comfort Aggrey and sister, Mrs. Joyce Yeboah Mensah. Thank you very much for being there for me. May God richly bless you in all your endeavours. Amen.

ACKNOWLEGDEMENTS

Unto Him be the glory and honour for the many blessings, protection and strength that enabled me accomplished this thesis. My greatest appreciation goes to my supervisors Dr. Ted Annang and Dr. Daniel Nupkezah for the patience, guidance, encouragement and constructive criticisms that led to the completion of this thesis.

I express my gratitude to Dr. Iyidan of Biogas Technologies for leading me to have access to the biogas facility. I also wish to thank the Valley View University and the Botany Department of the University of Ghana for their corporation and assistance for allowing me use their facilities.

I owe a great gratitude to all the technical staff of the Ecological laboratory namely Sir Prince, Mr. Amponsah, Christian and especially Mr. Emmanuel Ansah for the contribution towards all laboratory analysis done in this work. Also for the direction and criticisms given to accomplish this work.

My appreciation also goes to my Colleagues: Naomi Adraki, Joseph Quarshie, Bright Frimpong and John Essien for their immense support and contribution towards this work.

Finally, my thanks go my family and friends for their prayers, encouragement and inspiration. God bless you all.

TABLE OF CONTENTS

Content **Page**

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

EPA	-	Environmental Protection Agency
KNUST	-	Kwame Nkrumah University for Science and Technology
DO	-	Dissolved Oxygen
BOD	-	Biochemical Oxygen Demand
COD	-	Chemical Oxygen Demand
TSS	-	Total Suspended Solids
TDS	-	Total Dissolved Solids
FC	-	Faecal Coliforms
TC	-	Total Coliforms
THB	-	Total Heterotrophic Bacteria
WHO	-	World Health Organization

CHAPTHER ONE

INTRODUCTION

1.0 Background

With the increasing population and increasing per capita water demands, certain areas will soon face the problem of needing more water than can be obtained from local water supplies. This projected water deficit has instigated an interest in water reclamation and reuse, using treated waste waters as a public water supply source.

Ghana is no exception to the countries around the world, experiencing high volumes of wastewater that flows out without reclaiming them for use. The high population growth, high urbanization rate, progress in sanitation facilities, economic development and all other activities call for more water. Agbozo *et al.*, 2003, in their work revealed that the total amount of grey and black water produced in urban Ghana is estimated to be approximately 280 million m^3. This quantity of wastewater is mainly from domestic sources since most wastewater from industry is channeled into the ocean. It is estimated that the city accommodates between 2.5 million to 3 million people in terms of socio-economic activities aside the residential dimension. According to the Ghana Statistical Services report on the 2010 population and housing census, the population of Accra is 3,963,264 (Ghana statistical Service, 2012). The city is today one of the most populated and fast growing Metropolis of Africa with an annual growth rate of 3.36%.

It was estimated that urban wastewater generation in Ghana will increase from 530,346 m^3/day in 2000 to 1,452,383 m^3/day in 2020 (36% in 2000 to over 45% in 2020) (Agbozo *et al.*, 2003).

The reuse of effluent can make a significant contribution to the integrated management of our water resources in the country. When water and nutrients in effluent are beneficially utilised, some of the water extracted from rivers can be replaced and also the amount of pollutants discharged into our waterways can be reduced. Encouraging the beneficial use of effluent where it is safe and practicable to do so, provides the best environmental outcome. (Environmental Guidelines, 2004)

The revised National Environmental Sanitation Policy sees reuse as an opportunity for the reduction of waste water production and states that “a desired long term outcome of improving environmental sanitation would be to take steps that will lead to incremental reduction of the proportion of the waste stream that ends up in final disposal, beginning with waste prevention and reduction from all sources, especially at household level and re-use plan for wastewater” Integrated Urban Water Management, (2010). Baran, (2008) in his work concluded that due to the stringent effluents demands as well as protection of the environment from nutrient impacts, treatment of reject water is inevitable since reject water treatment is able to reduce effluent limits by up to 25%.

Therefore, this study is to investigate the sewage effluent water quality characteristics and to evaluate the treatment performance of phytoremediation with floating aquatic plants as a separate treatment alternative with the sole aim of recovery valuable and usable resources such water and nutrients from the sewage effluent for use. Also the reuse potential of the resources recovered will be discussed.

1.1 Research Questions

1. What level of effluent quality exists in the sewage effluent that is discharged into the environment from the biogas plant? Do they conform to EPA and WHO standards?

2. What is the treatment performance level of the biogas plant?

3. To what extent are aquatic plants efficient in remediating sewage effluent by the extraction of contaminants such as nutrients and heavy metals?

4. Can Phytoremediation improve quality of effluent to levels acceptable by both National and International Standards for both essential and non-essential purposes?

1.2 Rationale for the Study

Water is one of the most essential elements in our daily activities. Good quality of water is needed to lead a healthy life. Water shortage problem in Accra is a challenge battling both Government and developmental partners. In the Accra Millennium City: Profile Summary, 2011, it was reported that all distribution networks in Accra consisting of the Weija and Kpong Water works supply about 401,800m^3 volume of water daily, of which there is a daily demand of 532,570m^3. Hence there is a daily short fall in supply of water over 130,000m^3 in Accra alone.

This key challenge has been identified to require critical attention in the Country in the 2010 Ghana Millennium Development Goals Report, 2012 and greatly attributed to the fast pace of urbanization and the need to meet the growing demand for water for consumption, industry and commerce.

Several researches over the years have confirmed loads of nutrients especially nitrogen and phosphorus and other contaminants in reject water that cause pollution of water bodies when discharged into them. According to Abbasi, 1987, the reason which has prompted the spate of papers on the nutrient extraction possibilities of aquatic plants is the increasing awareness of the problems of water pollution - both fresh and salt water - as a consequence of population growth and industrial development, and the disposal of human, animal and industrial wastes into inland waters and the sea. Many examples of the devastating consequences of the waste water on formerly clean and useful rivers and lakes has been eutrophication and its effects have aroused public and scientific awareness of the need not only to arrest the practice of direct dumping but to try and reverse it by extracting the pollutants.

In their work, Tel-Or *et al.*, (1997) and Forni *et al.*, (2001a,b;) brought to bare that aquatic plants have great potential for the removal of organic and inorganic pollutants from waters. Especially, Floating macrophyte-based wastewater treatment systems provide advantages over emergent plants or microorganisms, based on high growth and pollutant removal rates and easy harvest at the end of the treatment.

The main concept of this work, resource recovery, is therefore a laudable approach for sustainable development in the sense that, the quantity and quality of available water resources for Accra and its environs are very inadequate and notwithstanding, accessibility also is a problem in most parts of the city and the country at large. Thus finding out sustainable new alternatives are of commendable effort.

In this present work, attempt is made to help make water available (through reclamation from wastewater) and encourage reuse of wastewater for both essential and non-essential purposes. Phytoremediation, which is a low cost and less technology is employed to remediate sewage effluent using local floating aquatic macrophytes as biological waste purifiers. This is expected to become part of the solution. And in this way, some pressure will be off the already scarce treated drinking water supply system.

The usage of feacal matter for generation of energy and fertilizer is gaining recognition in the country especially the capital. Large volumes of sewage waste water are produced from these operations and are discharged directly into nearby water bodies or channeled into farms for irrigation purposes. This practice is a matter of concern and several interventions are to be developed not only to secure public health or in the interest of environmental sanitation but also to encourage the practice of recovering resources such as nutrients for composts or fertilizers to improve agriculture, biofuels for energy and water for both palatable and non-palatable uses. The Liquid waste management plants and the springing biogas facilities especially in institutions around the country, all deal with huge volumes of sewage that produce considerable amount of effluent which when treated can serve various uses.

1.3 Objective

The study aims at recovering valuable and usable wastes resources towards sustainable sanitation especially water for both essential and non-essential purposes.

1.3.1 Specific Objectives

The specific objectives are:

1. To determine the quality of the effluent from the biogas plant.

2. To evaluate the effectiveness of using aquatic plants for Phytoremediation of sewage effluent.

3. To determine whether treated effluent meets quality standards set by the Environmental Protection Agency (EPA) of Ghana.

4. To compare the rate of uptake or removal of contaminants such as nutrients, heavy metals, pathogens etc amongst the aquatic plants understudy and hence assess which plants are better purifiers.

5. To assess public's acceptability of the treated sewage effluent for possible uses.

1.4 Significance of the Study

1. In ensuring the discharge of quality effluents that meet water quality standards through effective wastewater treatment, receiving water bodies will be less contaminated, making such water bodies become suitable for domestic consumption, agricultural, industrial, aesthetic and recreational uses.

2. The reclamation of water from treated effluent and its effective utilization will ensure that a considerable amount of good quality water is available. This will contribute to the reduction of pressure on the already scarce treated drinking water and help in the attainment of health and environmental objectives of the nation.

3. Evaluating Characteristics of effluent discharged will help ascertain the treatment technology's efficiency in order to help safeguard the environment.

4. To establish a baseline for further improvement in sewage effluent quality. This will help Government and Private Operators make informed decisions and develop appropriate interventions concerning the establishment and operation of such biogas facilities and sewage treatment plants across the nation especially at sites where fresh water bodies may be at the receiving end of the effluent.

CHAPTHER TWO

LITERATURE REIVIEW

2.1 Introduction

The expansion of rural populations, disposal and accumulation of human waste products have rapidly become a health challenge which directly influence growth and development. Hence wastewater treatment is becoming more and more important in the society of today. Aside the connection between the hygiene problems, health issues and wastewater, in dealing with human waste products, new problems have occurred. In principle, the problems moved to the surrounding environment, since the pollutant load on specific recipient waters keep on increasing (Samuelsson, 2005).

Obuobie *et al.*, 2006, in their investigation revealed that domestic sewage contains approximately 1000mg/L of impurities of which about two thirds are organic. Thus sewage is 99% water and 0.1% total solids upon evaporation. When present in sewage, approximately 50% of this material is dissolved and 50% is suspended. Hence the great deal of water lost to flush faeces can be greatly recovered or reclaimed to compensate for the water shortage problem and reused for other purposes.

2.2 Wastewater Concepts

Wastewater may be defined as a combination of liquid or water-carried wastes that are removed from residences and institutions, as well as commercial and industrial establishments (Amoah, 2008).

2.2.1 Municipal Wastewater

According to Raschid-Sally and Jayakody (2008), urban wastewater is usually a combination of one or more of the following which makes it polluted water:

– Domestic effluent consisting of blackwater (excreta, urine and faecal sludge, i.e. toilet wastewater) and greywater (kitchen and bathing wastewater)

– Water from commercial establishments and institutions, including hospitals

– Industrial effluent where present

– Stormwater and other urban run-off.

Due to the high rate of consumption of water in the municipal sector, there are considerably high volumes of wastewater generation and discharge.

2.2.2 Domestic Wastewater

Domestic wastewater usually contains greywater (sullage), which is wastewater generated from washrooms, bathrooms, laundries, kitchens etc. It also contains blackwater made up of urine, excreta and flush water generated from toilets. The mixture is termed sewage if channelled into a sewerage system or septage if it ends up in a septic tank (Obuobie *et al*., 2006).

Sewage is one type of wastewater, and is a major actual or potential source of pollution especially in urban areas. Sewage treatment, or domestic wastewater treatment, is the process of removing contaminants from wastewater. Physical, chemical and biological processes are applied to remove physical, chemical and biological contaminants. Its objective is to produce a waste stream (or treated effluent) and a solid waste or sludge also suitable for discharge or reuse back into the environment (Metcalf and Eddy Inc., 1991).

In Ghana the common 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 (Obuobie *et al*., 2006).

Biological treatment processes at sewage treatment plants could produce selective elimination, changes of proportion or both in the bacterial populations (Mezrioui and Baleux, 1994). Moreover, the sewage treatment plant effluent, as well as urban or industrial waste, can modify some microbial populations in the receiving waters, such as rivers, lakes or lagoons (Sinton and Donnison, 1994).

2.3 WASTEWATER CHARACTERISTICS

2.3.1 Wastewater Quality

The determination of wastewater (sewage effluent) quality can be assessed by its Physical, Chemical and Biological Characteristics (UN-EASCWA, 2003).

2.3.2 Physical Characteristics

The physical parameters of wastewater include temperature, turbidity, colour, suspended solids, conductivity, total dissolved solids and suspended solids etc. These characteristics are used to assess the reuse potential of wastewater and to determine the most suitable type of operation and processes for its treatment (Okoh, 2010).

2.3.2.1 Temperature

The temperature of the wastewater is a very important parameter as it affects the rate of both the chemical and biological treatment. High temperatures increase the solubility of the chemicals for treatment and microbial action is more effective. However low temperatures slow, microbial activity and more chemicals will be required (Drinan & Whiting, 2001).

Wastewater temperature also affects receiving waters. Hot water when discharged in large quantities raises the temperature of receiving streams and disrupt the natural balance of aquatic life. Increased temperature, for example, could cause a change in the species of fish that could exist in the receiving water body (Okoh, 2010).

Another important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen than cool water, so it may be saturated with oxygen but still not contain enough for survival of aquatic invertebrates or certain fish. Some compounds are also more toxic to aquatic life at higher temperatures since rate of reaction increases with increasing temperature.

Generally, high temperatures favour pathogen removal. However, in some instances, it leads to increase in numbers of pathogens (Ahmed and Sorenson, 1995). According to Middlebrooks *et al.*, (1988) high temperature is good for removing wastewater constituents like nitrogen through volatilisation.

2.3.2.3 Turbidity

Turbidity is an expression of the optical property of water/wastewater that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. Turbidity is caused by suspended and colloidal particulate matter such as clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms. It is another test used to indicate water quality of waste discharges and natural waters with respect to colloidal and residual suspended matter. It is measured in NTU (Nephelometric turbidity units) using a turbidity meter, however different readings can be obtained using different kinds of meters (Slaats *et al.*, 2003; APHA/AWWA, 1998). As observed by WHO (1985) high levels of turbidity can protect microorganisms from the effects of disinfection, stimulate the growth of bacteria and exert a significant chlorine demand. In all processes in which disinfection is practised, therefore, the turbidity must always be low, preferably below 1 NTU for effective disinfection. The recommended guideline is 5 NTU (WHO, 1985).

2.3.2.4 Conductivity

Conductivity is the ability of water to conduct electrical current. This depends on the ionic strength of the water sample. Conductivity increases as the concentration of ions increases, since electrical current is transported by ions in solution. The determination of electrical conductivity provides a rapid and convenient way of estimating the concentrations of dissolved ions or estimating the amount of total dissolved salts (TDS). 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 water. The greater the salinity level, the lower the saturation point (Okoh, 2010). 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 have been completely oxidized (Annang, 2000).

The ability of the water to conduct a current is very temperature dependent. All specific electrical conductivity (EC) readings are referenced to 25°C to eliminate temperature difference associated with season and depth (http://www.waterontheweb.org/under/waterquality/conductivity.html).

2.3.2.5 Total Dissolved Solids (TDS)

TDS are a measurement of inorganic salts, organic matter and other dissolved materials in water and are commonly correlated to Electrical conductivity (EC). TDS includes positive and negative ions, such as dissolved chloride, sulphate, phosphate, carbonate, bicarbonate, sodium, calcium, magnesium, potassium and other inorganic and organic matter.

They can be naturally present in water or the result of mining or some industrial or municipal treatment of water. In the water industry TDS are critical contaminants commonly used as general indicators of salinity.

TDS cause toxicity through increases in salinity, changes in the ionic composition of the water, and toxicity of individual ions. Salinity affects the beneficial reuse of effluent for irrigation and can also impact the quality of fresh water streams. A high salt content in water can increase the salinity of soil and hence affect the growth and productivity of plants and/or crops (CISRO, 2006).

2.3.2.6 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) is a common measure of water quality and refers to all suspended particulate matter in the water column. Suspended solids are the solids retained by a filter of 2.0 um (or smaller) pore size under specific conditions (APHA/AWWA, 1995). High TSS is indicative of poor water quality (Shaw, 2000). The suspended solids are a collection of organic and inorganic materials of various sizes and density. TSS can also be categorized into settleable and nonsettleable components, where settleability is a function of particle size (mass), flow and turbulence (FWPCA, 1968). Total suspended solids test results are used routinely to assess the performance of conventional treatment processes and the need for further effluent filtration for reuse applications (Tchobanoglous *et al*., 2003).

2.3.3 Chemical Characteristics

Chemical parameters associated with the organic content of wastewater include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and total oxygen demand (TOD). Inorganic chemical parameters include salinity, hardness, pH, acidity and alkalinity, as well as concentrations of ionized metals such as iron and manganese, and anionic entities such as chlorides, sulphates, sulphides, nitrates and phosphates.

2.3.3.1 pH

The pH of a sample of water or wastewater is a measure of the concentration of hydrogen ions. It is the negative logarithm of hydrogen-ion (H+) concentration (Pankraz, 2000). The pH scale ranges from 0 to 14. A pH of 7 is considered to be neutral. Substances with pH of less than 7 have increase hydrogen- ion concentration and are acidic; substances with pH greater than 7 are basic and show less hydrogen- ion concentration. All micro-organisms have an optimum pH at which they grow best; a minimum pH which is the most acid range in which they will not grow and a maximum pH which is the most alkaline range that enhances their growth. Tchobanogolous *et al.,* (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.

Levels of pH greater than 9 are effective in pathogen removal (Pearson *et al*., 1992, Curtis, 1990). pH is measured using a portable pH meter.

2.3.3.2 Biochemical Oxygen Demand (BOD)

One of the most commonly measured constituents of wastewater is the Biochemical Oxygen Demand, or BOD. Wastewater is composed of a variety of inorganic and organic substances. BOD measures the oxygen consumed by microorganisms as they decompose organic matter and includes any chemical oxidation of inorganic compounds. Effluents high in BOD can deplete oxygen in receiving waters, causing fish kills and ecosystem changes. The BOD test measures the amount of oxygen consumed during a specified period of time, usually 5 days at 20 °C and so is called BOD_5. By measuring the initial concentration of a sample and the concentration after five days of incubation at 20°C, the BOD_5 can be determined (Greenberg *et al*., 1992).

2.3.3.3 Chemical Oxygen Demand, (COD)

COD is often measured as a rapid indicator of organic pollutant in water. It is attractive as the test yield results within two hours. It is normally measured in both municipal and industrial wastewater treatment plants and gives an indication of the efficiency of the treatment process. COD measures biodegradable and non-biodegradable organic matter of wastewaters. 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.

2.3.3.4 Ammonia-Nitrogen, Nitrate-Nitrogen and Nitrite-Nitrogen

Nitrogen occurs in natural waters as nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and organically bound nitrogen. All these forms of nitrogen as well as nitrogen gas (N_2), are components of the nitrogen cycle and are biochemically interconvertible (American Public Health Association, 1989). Total nitrogen TN, is simply the sum of the various nitrogen forms. The total nitrogen concentration in municipal wastewaters ranges from 15 to over 50 mg/L, on average (Reed and Brown, 1995).

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 fertilizer, which could be carried into natural waters by storm water runoff.

Nitrate levels in surface water is found to be generally low. However, some groundwaters may attain high levels. In excessive amounts, it contributes to the illness known as methemoglobinema in infants ("blue-baby syndrome"). The Canadian Water Quality Guidelines, developed by Environment Canada has imposed a limit of 10 mg/l Nitrate-Nitrogen on drinking water to prevent this disorder (Agriculture and Agri-food Canada (2000).

In excess amount, nitrate leads to eutrophication in freshwaters (Horne, 1995). Excessive nitrate stimulate growth with algae and other plants, which later decay and increase biochemical oxygen demand as they decompose. In a wastewater treatment plant, ammonia is normally oxidised to nitrites and then to nitrates. The first oxidation to nitrite sometimes referred to as notrosofication is by *Nitrosomonas* bacteria. The second groups of bacteria

(Nitrobacter) take the nitrite and oxidize it to nitrate. Nitrite concentration in wastewater effluent is from 15 to 20 mg/l as N. Nitrite is extremely toxic to most fishes and other aquatic species so usually present in low concentrations. Ammonia, nitrite, nitrate and organic nitrogen concentrations are determined by colorimetric method (Tchobanoglous *et al*., 2003).

2.3.3.5 Phosphorus

Phosphorus is usually present as phosphate (PO_4^{3-}) in water medium. Phosphorus is found in wastewater in three principal forms: orthophosphate ion, polyphosphates or condensed phosphates and organic phosphorus compounds (Mahmut and Ayhan, 2003). Organically bound phosphorus originates from body and food waste and, upon biological decomposition of these solids, is converted to orthophosphates. Polyphosphates are used in synthetic detergents, and used to contribute as much as one-half of the total phosphates in wastewater. Polyphosphates can be hydrolyzed to orthophosphates. Thus, the principal form of phosphorus in wastewater is assumed to be orthophosphates, although the other forms may exist. Orthophosphates consist of the negative ions PO_4^{3-}, HPO_4^{2-}, and $H_2PO_4^-$. These may form chemical combinations with cations (positively charged ions). According to Clark, *et al*., (1997) and Sedlak, (1991) the phosphorus concentrations in secondary effluent stand usually within the range of 3-7 mg/L, which mostly consist of orthophosphate and about 1 mg/L of organic phosphorus. Thus, it is necessary to reduce the concentration of phosphorus in secondary wastewater to prevent the algal bloom. Other sources of phosphorus aside human waste include animal wastes, industrial waste, soil erosion and fertilizers.

2.3.3.6 Trace Metals

Heavy metals are the group of metals that have density greater than 4 g/cm^3. Under this group, the following elements are included: arsenic, cadmium, chromium, copper, lead, mercury, zinc, nickel, molybdenum, and manganese (FAO, 1992). Heavy metals are important because they are often toxic and they impede or interfere with the biological treatment process when in excessive quantities.

They are essentially non-biodegradable and therefore accumulate in the environment. The accumulation of heavy metals in soils and waters pose risks to the environment and human health. These elements accumulate in the body tissues of living organisms (bioaccumulation) and their concentrations increase as they pass from lower trophic levels to higher trophic levels (a phenomenon known as biomagnification).

Depending upon the metal and the species, all the reactions are pH dependent (Russell, 2006).

Most heavy metals are essential to plant growth at low concentrations. Nevertheless, these heavy metals become toxic and harmful at high concentrations. Toxicity generally results in impaired growth, reduce yields and cause plant death (FAO, 1992). Heavy metals have adverse effects on human health and therefore heavy metal contamination of food chain deserves special attention. Another reason for concern is that heavy metals may be transferred and accumulated in the bodies of animals or human beings through food chain, which will probably cause DNA damage and carcinogenic effects due to their mutagenic ability (Knasmuller *et al.*, 1998).

2.3.4 Biological Characteristics

Biological parameters include coliforms, faecal coliforms, and specific pathogens, and viruses.

2.3.4.1 Coliforms and Faecal coliforms

Wastewater usually contains millions of microorganisms per milliliter. However many of these organisms are harmless. Few disease-causing microorganisms called pathogens invade some part of the host and either grow and multiply or produce toxin which interferes with normal body processes. They are divided into categories with the most common groups associated with water pollution being bacteria, viruses, protozoa, helminthes (intestinal worms) and algae. These can exist naturally or can occur as a result of contamination from human or animal waste. Contact with the contaminated water may lead to diseases such as typhoid, cholera and gastrointestinal problems.

Coliform tests are useful for determining whether wastewater has been adequately treated and whether water quality is suitable for drinking, recreation or reuse. Coliforms are a family of bacteria common in soils, plants and animals. Because they are very abundant in human wastes, coliform bacteria are much easier to locate and identify in wastewater than viruses and other pathogens that cause severe diseases. For this reason, coliform bacteria are used as indicator organisms for the presence of other, more serious pathogens. Coliforms are frequently monitored as total or faecal coliforms.

Total coliform (TC) is defined as a large group of anaerobic, nonspore forming, rod -shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C (Chapra, 1997).

Total coliform bacteria are a collection of relatively harmless microorganisms that live in large numbers in soils, plants and in intestines of warm-blooded (humans) and cold-blooded animals. Some pathogens enter the human body through the skin but more commonly they are ingested with drinking water.

Faecal coliform (FC) is a subgroup of TC that comes from the intestines of warm-blooded animals. However, since they do not include soil organisms, they are preferable to TC as an indicator organism. World Health Organization Guidelines for Drinking Water Quality states that as an indicator organism, faecal coliform *Escherichia coli (E-coli*) provides conclusive evidence of recent faecal pollution and should not be present in water meant for human consumption.

It is generally assumed that the higher the number of coliform organisms found in a 100 ml sample, the higher the risk for waterborne disease (http://en.wikipedia.org/wiki/Indicator_bacteria). They are measured by running the standard total coliform test at an elevated temperature (44 °C) (Chapra, 1997).

There are two commonly used methods for determining the presence and density of coliform bacteria. The membrane filter (MF) technique provides a direct count of colonies trapped and then cultured. The multiple tube fermentation method provides an estimate of the most probable number (MPN) per 100 milliliters from the number of test tubes in which gas bubbles form after incubation.

2.4 Phytoremediation

Phytotechnologies (an emerging technique during the last two decades) and plant based bioremediation technologies that have been collectively termed as phytoremediation. This refers to the use of the green plants to clean up contaminated soil and groundwater. The generic term "Phytoremediation" consists of the Greek prefix phyto (plant), attached to the Latin word remedian (to correct or remove an evil) (Prasad, 2004). Phytoremediation is an attractive alternative or complementary technology that can be used along with or, in some cases in place of mechanical conventional cleanup treatments that often require high capital inputs, more

labour and energy intensive (Cunningham *et al.*, 1996). Phytoremediation has also been called green remediation, botano-remediation, agro remediation and vegetative remediation (Erakhrumen, 2007). It is less destructive to the environment, cost effective and with aesthetic value. It is the most suitable environmental pollutants removal approach for developing countries (Pivertz, 2001). There are several ways by which plants cleanup or remediate contaminated sites.

2.4.1 Plant-based technologies of phytoremediation

Techniques of phytoremediation include phytoextraction (or phytoaccumulation), phytofiltration, phytostabilization, phytovolatilization, and phytodegradation (Alkorta *et al.*, 2004). Others include rhizodegradation and phytodesalination.

2.4.1.1 Phytoextraction

Phytoextraction (also known as phytoaccumulation, phytoabsorption or phytosequestration) is the uptake of contaminants from soil or water by plant roots and their translocation to and accumulation in aboveground biomass i.e., shoots (Sekara *et al.*, 2005; Yoon *et al.*, 2006; Rafati *et al.*, 2011). Pollutants accumulated in stems and leaves are harvested with accumulating plants and removed from the site. Phytoextraction can be divided into two categories: continuous and induced, (Salt *et al.*, 1998). Continuous phytoextraction requires the use of plants that accumulate particularly high levels of the toxic contaminants throughout their lifetime. The roots of the established plants absorb metal elements from the soil and translocate them to the above-ground shoots where they accumulate (hyperaccumulators), while induced phytoextraction take place if metal availability in the soil is not adequate for sufficient plant uptake, chelates or acidifying agents may be used to liberate them into the soil solution (Huang *et al.*, 1996; Huang *et al.*, 1997; Lasat *et al.*, 1998).

2.4.1.2 Phytofiltration

Phytofiltration is the removal of pollutants from contaminated surface waters or waste waters by plants (Mukhopadhyay and Maiti, 2010). Phytofiltration may be rhizofiltration (use of plant roots) or blastofiltration (use of seedlings) or caulofiltration (use of excised plant shoots; Latin caulis = shoot) (Mesjasz-Przybylowicz *et al.*, 2004). In phytofiltration, absorption and adsorption of contaminants by plant roots play a key role in this technique, and consequently large root surface areas are usually required, thus minimizing pollutants movement to underground waters.

2.4.1.3 Phytostabilization

Phytostabilization or phytoimmobilization is the use of certain plants for stabilization of contaminants in contaminated soils (Singh, 2012). This technique is used to reduce the mobility and bioavailability of pollutants in the environment, thus preventing their migration to groundwater or their entry into the food chain (Erakhrumen, 2007). Plants can immobilize heavy metals in soils through sorption by roots, precipitation, complexation or metal valence reduction in rhizosphere (Barcelo and Poschenrieder, 2003; Ghosh and Singh, 2005; Yoon *et al.*, 2006; Wuana and Okieimen, 2011).

Phytostabilization limits the accumulation of heavy metals in biota and minimizes their leaching into underground waters. However, phytostabilization is not a permanent solution because the heavy metals remain in the soil; only their movement is limited. Actually, it is a management strategy for stabilizing (inactivating) potentially toxic contaminants (Vangronsveld *et al.*, 2009).

2.4.1.4 Phytovolatilization

Phytovolatilization is the uptake of pollutants from soil by plants, their conversion to volatile form and subsequent release into the atmosphere. This technique can be used for organic pollutants and some heavy metals like Hg and Se. However, its use is limited by the fact that it does not remove the pollutant completely; only it is transferred from one segment (soil) to another (atmosphere) from where it can be re-deposited. Phytovolatilization is the most controversial of phytoremediation technologies (Padmavathiamma and Li, 2007).

However, this remediation method has the added benefits of minimal site disturbance, less erosion, and no need to dispose off contaminated plant material (Rugh *et al.*, 2000).

2.4.1.5 Phytodegradation

Phytodegradation is the degradation of organic pollutants by plants with the help of enzymes such as dehalogenase and oxygenase; it is not dependent on rhizospheric microorganisms (Vishnoi and Srivastava, 2008). Plants can accumulate organic xenobiotics from polluted environments and detoxify them through their metabolic activities. From this point of view, green plants can be regarded as 'Green Liver' for the biosphere. Phytodegradation is limited to the removal of organic pollutants only because heavy metals are non-biodegradable. Recently, scientists have shown their interest in studying phytodegradation of various organic pollutants including synthetic herbicides and insecticides. Some studies have reported the use of genetically modified plants (e.g., transgenic poplars) for this purpose (Doty *et al.*, 2007). For instance, the major water and soil contaminant trichloroethylene (TCE) was found to be taken up by hybrid poplar trees, *Populus deltoides x nigra*, which breaks down the contaminant into its metabolic components (Huang and Cunningham, 1996). TCE and other chlorinated solvents can be degraded to form carbon dioxide, chloride ion and water (Newman *et al.*, 1997).

2.4.1.6 Rhizodegradation

Rhizodegradation refers to the breakdown of organic pollutants in the soil by microorganisms in the rhizosphere (Mukhopadhyay and Maiti, 2010). Rhizosphere extends about 1 mm around the root and is under the influence of the plant (Pilon-Smits, 2005). The main reason for the enhanced degradation of pollutants in the rhizosphere is likely the increase in the numbers and metabolic activities of the microbes. Plants can stimulate microbial activity about 10−100 times higher in the rhizosphere by the secretion of exudates containing carbohydrates, amino acids, flavonoids. The release of nutrients-containing exudates by plant roots provides carbon and nitrogen sources to the soil microbes and creates a nutrient-rich environment in which microbial activity is stimulated. In addition to secreting organic substrates for facilitating the growth and activities of rhizospheric microorganisms, plants also release certain enzymes capable of degrading organic contaminants in soils (Kuiper *et al.*, 2004; Yadav *et al.*, 2010).

2.4.1.7 Phytodesalination

Phytodesalination refers to the use of halophytic plants for removal of salts from salt-affected soils in order to enable them for supporting normal plant growth (Manousaki and Kalogerakis, 2011; Sakai *et al.*, 2012). Halophytic plants have been suggested to be naturally better adapted to cope with heavy metals compared to glycophytic plants (Manousaki and Kalogerakis, 2011). According to an estimation, two halophytes, *Suaeda maritima* and *Sesuvium portulacastrum* could remove 504 kg and 474 kg of sodium chloride respectively from 1 ha of saline soil in a period of 4 months. Therefore, S. *maritima* and S. *portulacastrum* could be successfully used to accumulate NaCl from highly saline soils and enable them for crop production after a few repeated cultivation and harvest (Ravindran *et al.*, 2007). Phytodesalination is a recently reported and emerging technique (Zorrig *et al.*, 2012).

2.5.1. Advantages and disadvantages of Phytoremediation Techniques

When using different forms of phytoremediation, there are many positive and negative aspects to consider. The advantages and disadvantages are listed below in table 3.1.

Table 3.1: Advantages and disadvantages of Phytoremediation Techniques.

Methods	Advantages	Disadvantages
Phytoextraction	1. Phytoextraction is fairly inexpensive. 2. The contaminant is permanently removed from the soil (Henry, 2000).	1. Metal hyperaccumulators are generally slow- growing with a small biomass and shallow root systems. 2. Plant biomass must be harvested and removed, followed by metal reclamation or proper disposal of the biomass (Prasad, 2004).
Rhizofiltration	1. The ability to use both terrestrial and aquatic plants for either *in situ* or *ex situ* applications. 2. The contaminants do not have to be translocated to the shoots (Henry, 2000).	1. The constant need to adjust pH. 2. Plants may first need to be grown in a greenhouse or nursery (Henry, 2000).
Phytostabilization	1. The disposal of hazardous biomass is not required. 2. The presence of plants also reduces soil erosion and decreases the amount of water available in the system (Henry, 2000).	1. Contaminant remaining in soil. 2. Application of extensive fertilization or soil amendments, mandatory monitoring is required (Henry, 2000).
Phytovolatilization	1. Contaminants could be transformed to less-toxic forms, such as elemental mercury and dimethyl selenite gas. 2. Contaminants or metabolites released to the atmosphere might be subject to more effective or rapid natural degradation processes such as photodegradation (Prasad, 2004).	1. The contaminants or a hazardous metabolite might accumulate in vegetation such as fruit or lumber. 2. Low levels of metabolites have been found in plant tissue (Prasad, 2004).

2.5.2 Phytoremediators

2.5.2.1 *Eichhornia crassipes* (Water hyacinth)

Eichhornia crassipes (water hyacinth) is a rapidly growing floating aquatic plant which is native to tropical and sub-tropical South America, and is now widespread in all tropical climates. It can double its biomass in a few days and this makes it one of the world's most troublesome weeds (Dhote and Dixit 2009). This trait has also made it a candidate for use in phytoremediation. It is a prolific aquatic weed of cosmopolitan distribution with a huge potential for the removal of vast range of pollutants from waste water (Prasad, 2004). The potential of Water hyacinth on the nutrient regime of a lake ecosystem for sewage treatment has been found out by researchers such as Lorber *et al.*, (1984); Polprasert and Khatiwada (1998).

According to Jain (2000) water hyacinth has ideal characteristics for water purification and pollution control. *Eichhornia crassipes* has a high capacity for the uptake of heavy metals, including Cd, Cr, Ni, Co, Pb, and Hg which could make it suitable for the biocleaning of industrial water (Abou-Shenab *et al.*, (2007); Upadhyay *et al.*, (2007). Although water hyacinth is an invasive plant in most countries all over the world, it is also used as a resource in agricultural production and waste water treatment, Gunnarsson and Petersen, (2007). The effectiveness of sewage purification by water hyacinth and water lettuce has been shown by Zimmels *et al.*, (2006) in the laboratory and on a pilot scale.

2.5.2.2 *Lemna minor* (Duckweed)

Duckweed is a small, free floating aquatic plant belonging to Lemnaceae family (Cheng *et al.*, 2002). It has been found that *lemna* species have many unique properties ideal for phytoremediation plant species: they have fast growth and primary production; high bioaccumulation capacity; ability to transform or degrade contaminant; ability to regulate chemical speciation and bioavailability of some contaminant in their milieu; resilient to extreme contaminant concentration; and can be applied on multiple pollutants simultaneously. In addition, they have properties significant for public health livestock production and aquaculture and ecological function. Duckweed wastewater treatment systems have been studied for a wide range of wastewater types. Most of the studies have focused on nutrient removal efficiencies and removal rates between 50-95% have been reported for duckweed covered systems (Korner *et al.*, 1998; Korner and Vermaat, 1998; Korner *et al.*, 2003).

Duckweed is used in water quality studies to monitor heavy metals and other aquatic pollutants, because it may selectively accumulate certain chemicals and may serve as biological monitors (Yang *et al.*, 2001). The elimination of organic material in terms of BOD and COD is lower in *Lemna* species in comparison to other vascular plants which are rich in cellulose. However, the nitrogen removal is same or higher (Gerard *et al.*, 2002). Investigations made by Rose, (2000) inferred that *Lemna minor* is efficient in removing BOD, solids and nutrient from wastewater.

2.5.2.3 Ceratophyllum demersum (Coontail)

C. *demersum* (Coontail or hornwort) is a completely submerged plant and commonly seen in ponds, lakes, ditches, and quiet streams with moderate to high nutrient levels. It does not produce roots, instead it absorbs all the nutrients it requires from the surrounding water. If it is growing near the lake bottom, it will form modified leaves, which it uses to anchor to the sediment. However, it can float free in the water column and sometimes forms dense mats just below the surface. *Ceratophyllum demersum* belongs to the order Nymphaeales and family Ceratophyllaceae (the family of hornworts), grows in shallow, muddy, quiescent water bodies at low light intensities. *C. demersum* is a convenient plant for laboratory toxicity bioassays (Kumar and Prasad, 2004).

2.5 Wastewater Use in Ghana

Only about 10% of urban wastewater emanating from domestic and municipal sources is disposed off through sewage networks connected to treatment plants. Hence, virtually all commercial and industrial wastewaters are disposed of into the natural environment (ocean, streams and wetlands) untreated.

According to Cornish *et al.,* (2001) wastewater usage in Ghana falls under the informal irrigation sector due to the fact that wastewater is used predominantly as diluted untreated wastewater, untreated wastewater or partially treated wastewater. Also, it is estimated that over 500ha of land is being cultivated county-wide using wastewater with an average farm size of 0.02ha. According to Agodzo *et al.*, (2003) if only 10% of the 280 million m^3 of wastewater from urban Ghana could be (treated and) used for irrigation, the total area that could be irrigated with wastewater alone could be up to 4,600 ha, and with an average dry-season farm size of 0.5

ha, this could provide livelihood support for about 9,200 farmers in the peri-urban areas of Ghana. However, inadequate sewage conveyance capacity in most cities and towns makes untreated wastewater flow from drains into streams, which are usually used for irrigation.

2.6 Reuse Applications of treated Wastewater

Uses for reclaimed municipal wastewater can be classified into the following categories: urban, industrial, agricultural, groundwater recharge and augmentation of potable supplies, recreational, and habitat restoration/enhancement.

Urban reuse systems provide reclaimed wastewater for various non-potable purposes including irrigation of public parks, recreation centers, athletic fields, schoolyards, playing fields, highway medians and shoulders, landscaped areas, and golf courses. Alternative non-potable uses include commercial applications such as vehicle washing, window washing, mixing water for pesticides, herbicides, and liquid fertilizers, use in ornamental landscape and decorative water features (such as fountains, reflecting pools and waterfalls), dust control and concrete production on construction projects, fire protection, and toilet/urinal flushing in commercial and industrial buildings (EPA, 1992).

Industrial wastewater reuse represents a significant potential market for reclaimed water in the U.S. and other developed countries. Prospective uses include: evaporative cooling water, boiler-feed water, process water, and irrigation/maintenance of plant grounds. Reclaimed municipal wastewater has also been used for cooling tower makeup water in Maryland (Brown and Mountain, 1998), and in cooling systems for office buildings in Japan (Asano *et al.*, 1996).

The use of reclaimed municipal wastewater in agriculture has been well accepted and is still the major application for water reuse. California uses over 40% of its $4.32\times10^5 m^3/yr$ reclaimed water for agriculture or landscape irrigation (Asano, 1996). There are numerous successful projects that demonstrate the various beneficial aspects of wastewater reuse.

Landscape irrigation projects have been particularly successful applications of reclaimed wastewater. In Tunisia, golf courses are regularly irrigated with treated secondary effluent stored in a landscape impoundment (Bahri *et al.*, 2001).

In addition to non-potable applications, indirect uses of reclaimed wastewater also exist. Indirect potable reuse occurs when treated municipal wastewater is discharged into a water body that subsequently is used as a source of drinking water. An alternative indirect potable reuse application involves injection of reclaimed water into the groundwater for storage and subsequent use to augment potable supplies. An example of this application is the groundwater replenishment system in the Orange County Water District of California which will provide 120 million gallons of reclaimed water per day to help satisfy the overall potable water demand in the area (Crook, 1999).

Ornamental and recreational reuse have also been carried out, including the discharge of treated municipal wastewater into city streams during dry seasons (Okun, 1997) and river flow augmentation (Juanico and Friendler, 1999). Additional applications of municipal wastewater reuse include creation or enhancement of wetland habitat and direct potable reuse (Bahri *et al.*, 2001).

2.7 Wastewater Reclamation

Wastewater reclamation is the treatment of wastewater up to standards that make it reusable, and water reuse is the use of reclaimed wastewater, Leverenz and Asano (2011). Wastewater can be treated to the extent required for any re-use purpose. This is brought to potable standards through appropriate processes of treatment and disinfection. Water recovered from wastewater is commonly referred to as “reclaimed” or “renovated water”. Resources From Waste: A Guide to Integrated Resource Recovery (2009), outlines benefits from the use of reclaimed water as:

- Cost Considerations

Costs for reclaimed water increase with the degree of treatment used. Taking an integrated approach, it is possible for the extra cost to be offset by reduced infrastructure costs and increased value in the community. If potable water demand can be reduced by using reclaimed water for non-potable purposes (such as irrigation or street cleaning), local governments can delay an expansion of potable water supplies and distribution systems. Additional savings can result from the reduced pumping costs for potable water and wastewater.

- Environmental Benefits

Reclaimed water can be put to many environmental uses. It can be used to recharge groundwater supplies, to augment stream flows during dry periods for fish protection and generally to reduce the consumption of potable water.

- Economic Benefits

Reduced demand on potable water sources and systems delays investment in new infrastructure. Additional benefits include both capital and operating cost savings over the lifecycle of the infrastructure.

- Social Benefits

Reclaimed water can be used to create water features which provide amenity and can serve as meeting places. Green spaces irrigated by reclaimed water can enhance healthy, active communities. The green spaces will not only have social and ecological value, but can serve as natural cooling cells in the hot months.

2.8 Challenges in reusing treated wastewater

Adewumi *et al.*, (2010) in their work in Cape Town identified some of the following challenges which influence the reuse of treated wastewater.

2.8.1 Source quality, public health and willingness

The quality of treated wastewater is largely determined by the efficiency of the WWTWs and influent qualities and the effluent quality must be as specified according to standards. When these are adhered to, treated wastewater will be suitable for the potential reuses.

Related to the quality of treated wastewater is public health. Protecting public health is achieved by reducing pathogenic micro-organisms, controlling the quantities of different chemical constituents within the treated wastewater, and limiting the public's exposure (physical contact, inhalation and ingestion) to the treated wastewater. Public exposure to the wastewater directly influences willingness to reuse and where physical contact is likely, willingness to reuse is generally low.

Willingness to reuse wastewater has determined the success of many reuse projects with some schemes failing because decision-makers underestimated the need to engage the benefitting community. Willingness to reuse is also influenced by political will and the perceptions of risk associated with reuse. Research has shown that 88% of respondents perceive risks associated with wastewater reuse to be low. This perception thus encouraged reuse amongst respondents (Adewumi *et al.*, 2010).

2.8.2. Public trust in the service provider and knowledge of reuse

Service providers of drinking water are continually faced with the challenges pertaining to uninterrupted drinking water supply. Interruptions encourage apathy and negate consumers' trust in a service provider's ability to provide reliable service irrespective of whether it is drinking water supply or treated wastewater. Respondents' trust in the service provider to supply the appropriate quality of treated wastewater was 48% in survey by Po *et al.*, 2004. This response is poor and likely influenced by the poor qualities of treated wastewater that have been supplied these respondents over time prompting further on-site treatment of the effluent.

Closely related to trust is knowledge of reuse. The more knowledgeable potential users are, the better empowered they are in deciding to (or not to) embrace reuse. Knowledge involves an

awareness of local drinking water supply problems and the potential for treated wastewater to satisfy some water requirements, an understanding of the quality of treated wastewater that can be produced using the available technology, and an assurance that the treated wastewater system will involve minimal risk to the public. When potential consumers are educated about reuse, the decision to (or not to) embrace reuse is usually clearly articulated.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

All sewage effluent samples were taken from the Valley View University Biogas Facility at Oyibi, Accra and experimental set-up done at the Green House of the Botany Department, University of Ghana, Legon, Accra.

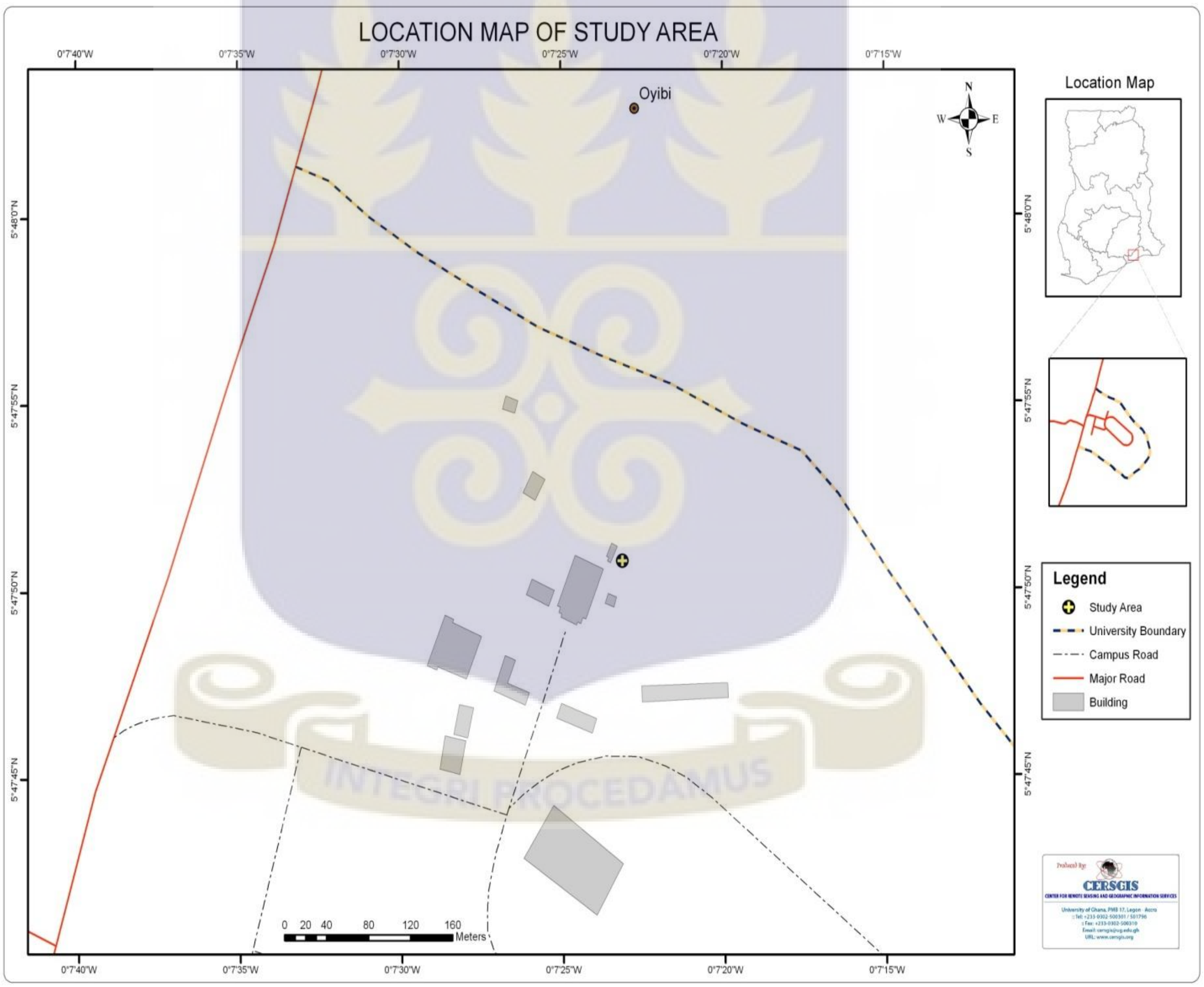


Figure 3. 1 Map of Valley View University showing Sampling Location.

Plate 3.1: Biogas facility at Valley View University

3.2 Preliminary Screening of Selected Plants for survival on application of Effluent

Before the main set-up was done, the ability of the aquatic plants to survive in the effluent were assessed. Six aquatic plants including *Eichhornia crassipes* (water hyacinth), Pistia sp.(watter lettuce), *Neptunia oleracea* (water mimosa), *Ceratophyllum desernum* (coontail), *Lemna minor* (duckweeds) and *Salvinia* sp. were assessed. All six aquatic plants were put into three set of containers containing the final effluent, 50% dilution of effluent and water (control) for a two-week period.

Four out of the six aquatic plants could survive in final effluent namely *Eichhornia crassipes* (Water Hyacinth), *Neptunia oleracea* (Water mimosa), *Lemna minor* (Duckweed) and *Ceratophyllum demersum* (Coontail). Hence, the four aquatic plants were used to treat the sewage effluent in this work.

3.3 Characterization of Effluents

Three sampling events of sewage effluent from the final out-let point of the biogas plant were collected in a week and analysis done for Physcio-Chemical Properties including Temperature, pH, Conductivity, Colour, Turbidity, Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids, Total Dissolved Solids, Nitrate, Nitrite, Ammonia, Phosphorus, Heavy metals (Pb, Cd, Cu, Ni, Zn, Fe, Cr,) and Microbiological parameters such as Total and Faecal coliforms and THB. The effluent mean values were recorded

3.4. Aquatic Plant Materials

The various aquatic plants species were collected from the Volta Lake Head Point at Kpong with exception of Water hyacinth which was collected from the Botany Research Garden Pond, Department of Botany, University of Ghana, Legon. The plants were rinsed and transferred into large bowls containing tap water. Aquatic plants considered included:

Eichhornia crassipes (Water hyacinth), *Lemna minor* (Duckweeds), *Neptunia* oleracea (Water mimosa) and *Ceratophyllum demersum* (Coontail).

3.4.1 Plant Sampling

Four dominant aquatic macrophytes species were selected and identified. Three of them were floating species namely *Eicchornia crassipes* (water hyacinth), *Lemna minor* (duckweed), *Neptunia oleracea* (water mimosa), and one submerged species; *Ceratophyllum demersum* (coontail). Only healthy aquatic macrophytes individuals were selected at the population level for estimating the potential loading or bioaccumulation of seven heavy metals. Individual plants were carefully collected, washed with water to remove periphyton, and other debris.

Samples of all the plants were immediately transferred to the laboratory in clean plastic bags, oven dried 80 – 90°C for 48 h in paper bags, ground into very fine powders, stored in glass bottles and labeled for further analysis.

3.4.2 Chemical Analysis of Plant Samples:

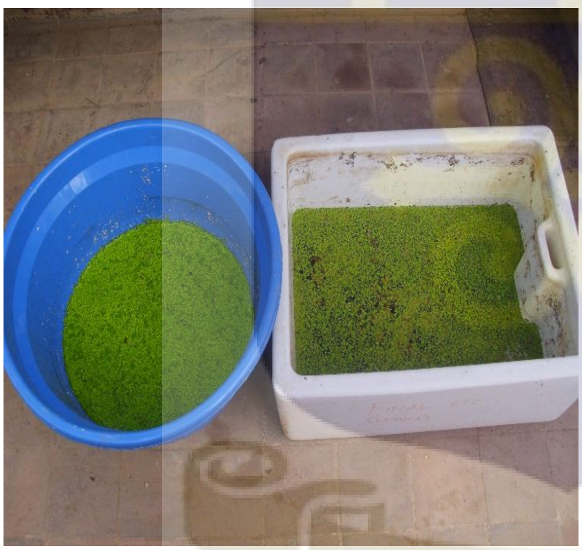
The samples of plants were analyzed for the detection of heavy metals (Cd, Cr, Cu, Ni, Pb, Zn and Fe) before and after phytoremediation. One gram of dry powder of each sample was weighed and digested using the digestion mixture of Conc. HNO_3, H_2SO_4 and H_2O_2 in the following ratio 1:3:3. The metal concentration in plant material were measured by atomic absorption and expressed in mg/l.

3.5 Experimental Design for Phytoremediation

Four 20 litres bowls were labeled with each plant species and then filled with the sewage effluent samples collected from treatment facility discharge point (final out-let).

a. *Eichhornia crassipes*

b. *Neptunia oleracea*



c. *Lemna minor*

d. *Ceratophyllum demersum*

Plate 3.2(a,b,c,d): **Experimental setup for Phytoremediation**

The aquatic plants were planted in the bowls and given two weeks from the time planted to acclimatize to its new environment.

Samples were taken weekly for analysis starting from the end of the two week stabilization time. The aquatic plants in final effluent were set-up for each plant unit and data collected on the physico-chemical parameters and microbial load. A control (water) was also set up for each plant unit.

3.6 Analysis of Treated Effluent

Starting from the second week, effluent samples undergoing treatment by Phytoremediation were taken on a weekly basis and analyzed for TSS, TDS, BOD, DO, COD, Nitrogen, Phosphorus, Heavy metals and Microbial load (FC, TC and THB) for six weeks. At the end of the experimental period, samples of the plant materials used were analyzed to determine heavy metal content accumulation.

3.7 Treatment of sample containers and sampling procedure

Strict measures were adhered to in avoiding contamination of samples during sampling; handling and storage, working conditions were carefully selected. At the sampling site, effluent was collected into a plastic bucket for in-situ measurements. Temperature, pH and conductivity were measured using a digital meter (Model YSI 63), Turbidity was measured using turbidimeter (Model HACH 2100P) NTU and Total dissolved solids (TDS) was measured with a portable digital TDS meter (Model HI 99301).

A Two-litre polyethylene sampling container was filled with effluent at the site. The sampling containers with well-fitted stoppers were pre-treated by washing with acetone to get rid of organic substances such as grease and fat residues. They were then washed with detergent and rinsed with de-ionised water and then soaked in 0.1 M nitric acid solution for

48 hours. The containers were finally rinsed several times with de-ionised water before used for taking and holding water samples. Water samples that were not analyzed immediately at the site were transported to the laboratory at controlled temperature levels where they were stored in a refrigerator below 4^{o}C. Precautions were taken as to the number of days the samples should be stored to avoid inaccuracy.

3.8 Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO) Sampling

Two bottles, one plain and the other dark (painted with bitumen to prevent possibility of photosynthetic production of oxygen) were used for sampling. The plain ones were used for dissolved oxygen sampling and the dark bottles were used for BOD sampling. The bottles were filled with the wastewater to overflow in order to avoid any air bubbles from getting trapped in the bottles. The dissolved oxygen samples were fixed on site with 2 ml each of Winkler 1 (Manganous chloride) and Winkler 2 (alkaline-iodide-azide reagent). Samples, which were not analyzed within 2 hours of collection, were kept at or below 4^{o}C but brought to ambient temperature before analysis in the laboratory.

3.9 Trace Metals Sampling

Water samples for trace metal analysis (Iron, Cadmium, Copper Nickel, Zinc, Lead and Chromium) were collected in plastic vials and fixed on the field with nitric acid. It was the kept at or below 4^{o}C but brought to ambient temperature before analysis in the laboratory.

3.10 Bacteriological Sampling

Wastewater samples for bacteriological analysis were taken from the intermediary and the final out-let sampling points for assessment of the biogas facility's performance. All other samples were taken from the final out-let for analysis. Glass bottles with a metal cap were used to collect the water samples. These bottles were sterilized before use and the mouths covered with aluminum foil to avoid contamination during sample collection. Upon collection, the samples were stored on ice to avoid multiplication of bacteria.

3.11 Laboratory Analysis

Physico-chemical and Bacteriological analyses were carried out in the Ecological Laboratory which is located at the Department of Geography and Resource Development, University of Ghana. A summary of the various parameters measured is shown in the table below:

Table 3.2: Laboratory Analysis done for parameters of study

PARAMETERS	ANALYSIS
Physico-chemical	Nitrogen-Nitrate, Nitrogen-Nitrite, Nitrogen-Ammonia, Phosphate-Phosphorus, Total Suspended Solids (TDS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Temperature, Electrical Conductivity, Copper, Cadmium, Chromium, Zinc, Lead, Nickel and Total Iron.
Bacteriological	Total Coliform, Faecal Coliform and Total Heterotrophic Bacteria (THB).

3.12 Analysis of Water Samples

All the sampling and preservation procedures for water samples were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, 1998, 1995), and the Examination of Water for pollution Control (WHO) and Guidelines for drinking water quality (WHO, 1982, 1996)

Nitrogen-Nitrate, Nitrogen-Nitrite, Nitrogen-Ammonia, Phosphate-Phosphorus, and Total Dissolved and Suspended solids were determined using the HACH Direct Reading Spectrophotometer (2010 model). The trace metals were analysed employing Atomic Absorption Spectrometry (Perkin Elmer 3110 model). BOD and DO were determined by Dissolved Oxygen meter. Total coliform counts and faecal coliform counts were determined using the Paqualab system.

3.12.1 Nitrogen-Nitrate (NO_3^- -N) Analysis

Nitrates are a form of nitrogen, which is found in several different forms in terrestrial and aquatic ecosystems. These forms of nitrogen include ammonia (NH_3), nitrates (NO_3), and nitrites (NO_2). Nitrates are essential plants nutrients, but in excess amounts they can cause significant water quality problems. Together with phosphorus, nitrates in excess amounts can accelerate eutrophication, causing dramatic increases in aquatic plant growth and changes in the types of plants and animals that live in the stream. This, in turn, affects dissolved oxygen, temperature, and other indicators.

The method used for the nitrate analysis was the Cadmium Reduction Method (Using Powder Pillows). The nitrate level in each sample was measured using Nitrate Powder

Pillows in a direct reading Hach Spectrophotometer Model DR 2000. Twenty five (25) ml of the sample was measured into sample cell of the spectrophotometer. One Nitraver 5 Nitrate Reagent Powder Pillow was added to the sample. The mixture was then shaken vigorously for 1 minute. Five minutes was allowed for the solution to react. An orange colour of the mixture indicates the presence of nitrate. After five minutes, another cell was filled with 25 ml of only the sample (blank). The blank sample was placed in the Spectrophotometer for calibration. The prepared sample was placed into the cell holder to determine the nitrate concentration at 500 nm in mg/l (HACH 1996).

3.12.2 Nitrogen Nitrite (NO_2^-) Analysis

The nitrite level in each sample was measured using Nitrite Powder Pillows in a direct reading Hach Spectrophotometer Model DR. 2000. A Twenty five (25) ml of the sample was measured into sample cell. One Nitri Ver 3 Nitrate Reagent Powder Pillow was added to the sample and shaken to dissolve the powder. A 15-minute reaction period was allowed. A pink colouration indicated the presence of Nitrogen Nitrite. After the 15 minutes, another sample cell was filled with 25 ml of only the sample (blank). The blank sample was placed in the sample cell of the Spectrophotometer for calibration (zeroing). The prepared sample was placed into the cell holder to determine the Nitrite concentration at 507nm. The result was displayed in mg/l (HACH 1996).

3.12.3 Phosphate (PO_4^{3-}) Analysis

There are many sources of phosphorus, both natural and human. These include soil and rocks, wastewater treatment plants, runoff from fertilized lawns and cropped, failing septic systems, runoff from natural manure storage areas, disturbed land areas, drained wetlands, water treatment, and commercial cleaning preparations.

A 25 ml of water sample (the prepared sample) was placed in the sample cell. Phos Ver 3 Phosphate Powder Pillow was added to the cell content and swirled immediately to mix. A two-minute reaction period was allowed. A blue colouration of the mixture indicates the presence of phosphate. Another sample cell (the blank) was filled with 25 ml of sample and placed into the cell holder to calibrate it. After reaction period, the prepared sample was placed into the cell holder and the level of phosphorus was determined at 890 nm. The Spectrophotometer displayed the results in mg/l^{-} PO_4^{3-} (HACH 1996).

3.12.4 Nitrogen Ammonia (NH_3-N)

Ammonia can indicate faecal contamination. Its presence can compromise disinfection, efficiency, because of taste and odour problems, results in nitrite formation in distribution systems, and causes the failure of filters for the removal of manganese (WHO, 1996).

The Salicylate method was used to determine Ammonia-nitrogen at a determination wavelength of 655 nm. A 25 mL aliquot of the sample was poured into a graduated mixing cylinder. A 25 mL of deionisded water was also poured into a second cylinder. One ammonia Salicylate Reagent Powder Pillow was added to the contents of each cylinder and shaken to dissolve. A 3-minute reaction period was allowed. One Ammonia Cyanurate

Reagent Powder Pillow was added to the contents of each cylinder and shaken to dissolve. A green color present indicates the presence of ammonia nitrogen. A 15-minute reaction period was then allowed. The blank was poured into a sample cell and put into the machine for calibration or zeroing. The prepared sample was poured into a second sample cell and placed into the cell holder and the level of ammonia-nitrogen was determined at 655 nm. The Spectrophotometer displayed the results in mg/l of NH_3-N (HACH 1996).

3.12.6 Total Suspended Solids Analysis

The photometric (non filterable residue) method was used. A 500 ml of sample was blended at high speed for two minutes. This was poured into a 600 ml beaker. The sample was stirred and 25 ml immediately poured into a sample cell. The stored programme number for suspended solids, 630, was centered. The wavelength was set to 810 nm. A sample cell was filled with 25 ml demineralised water (blank). This is placed into the cell holder and standardized. Next, the sample was placed into the cell holder and the reading taken in mg/l suspended solids (HACH, 1996).

3.12.7 Heavy Metal Analysis

Atomic Absorption Spectrometry was used to determine the level of each heavy metal in the sample. The heavy metals whose concentrations were determined included: Cadmium (Cd), Copper (Cu), Nickel (Ni), Zinc (Zn), Lead (Pb), Iron (Fe) and Chromium (Cr).

In flame atomic absorption spectrometry, a sample is aspirated into a flame and atomized. A light beam is directed through the flame, into a monochromator, and onto a detector that measures the amount of light absorbed by the atomized element in the flame.

For some metals, atomic absorption exhibits superior sensitivity over flame emission. Because each metal has its own characteristics absorption wavelength, a source lamp composed of that element is used; this makes the method relatively free from spectral or radiation interferences.

The amount of energy at the characteristic wavelength absorbed in the flame is proportional to the concentration of iron in the sample over a limited concentration range. Most atomic absorption instruments also are equipped for operation in an emission mode (APHA, 1995).

3.12.8 Biological Oxygen Demand (BOD)

Biochemical Oxygen Demand, or BOD, measures the amount of oxygen consumed by microorganisms in decomposing organic matter in stream water. BOD also measures the chemical oxidation of inorganic matter (i.e. the extraction of oxygen from water via chemical reaction). A test is used to measure the amount of oxygen consumed by these organisms during a specific period of time (usually 5 days at 20^{o}C).

The 5-day BOD test was used. This method consists of filling with sample an airtight bottle of the specific size and incubating it at the specific temperature for 5 days. Dissolved oxygen was measured initially and after incubation, and the BOD was computed from the difference between the initial and the final DO. In cases of dilution due to less amount of oxygen, BOD was computed from the formula below:

Calculation: $BOD_5\ mg/l = \frac{D_1 - D_2}{P}$

Where;

D1 = DO of diluted sample immediately after preparation, mg/l

D2 = DO of diluted sample after 5 day incubation at 20 ^{0}C, mg/l

P = Decimal Volumetric fraction of sample used.

3.12.9 Chemical Oxygen Demand (COD)

The Closed tube reflux method was used for COD analysis. The digestion tubes and caps were washed with 4M sulphuric acid first to prevent contamination. Five milliliter (5 ml) of the sample or a diluted aliquot is transferred into a labeled culture tube and 3 ml potassium dichromate solution (digestion solution) added. Seven millilitres (7 ml) H_2SO_4 reagent (silver sulphate in sulphuric acid) was added carefully to form an acid layer under the sample-digestion layer. The tube was tightly capped, shaken and inverted several times to mix completely. The tubes were placed in a digester at 1500C and reflux for two hours, and then cooled to room temperature. 1-2 drops of ferroin indicator was added and titrated with standard Ferrous Ammonium Sulphate (FAS) solution until the colour changes from blue-green to reddish brown or wine (endpoint). The procedure was repeated for a blank sample containing the reagents and a volume of deionised water equal to that of the sample.

Calculation:

$$COD\ mg\ O_2/l = \frac{(A-B)xMx8000}{V}$$

A = volume of FAS used for blank, ml

B = volume of FAS used for sample, ml

M = molarity of FAS

V = volume of sample

8000 = milliequivalent of oxygen x 1000 ml/l

3.13 Analysis of Bacteriological Parameters

The Total and Faecal coliforms present in water samples were determined using the Membrane Filter (MF) technique (HACH, 1996; WHO, 1997). Membrane filter with 0.45 µm pare size was sterilized in a system and used to filter 100 ml of water mixed with 10 ml of the sampled water. The results obtained from the colony counting were then multiplied by 10 to obtain the actual count per 100 ml. The membrane filter was lifted from the system with a sterilized forceps and carefully placed on the sterile media in Petri dish.

M-lauryl sulphate broth was used as growth medium for the incubation of coliforms in a Petri dish. Two milliliters of sterilized M-lauryl sulphate broth was poured on an absorptive pad placed in a small Petri dish. The Petri dish was then covered and inverted into ELE paqualab (model 50) for incubation at 37^{o}C for total coliform and 44^{o}C for faecal coliform. After 24 hours, the Petri dishes were removed from the incubator and the colonies counted and recorded in coliform forming units per 100 ml (cfu/100 ml).

3.14 Statistical Analysis

One way Analysis of Variance (ANOVA) was used to assess the differences in means of removal efficiencies of the aquatic plants. The Post Hoc tests (LSD) was used to determine the least significant differences among the mean values. Pearson correlation coefficient was calculated to test the relationships between the parameters of concern.

CHAPTER FOUR

RESULTS

4.1 Characterization of Sewage Effluent

The physico- chemical parameters used to assess the quality of sewage effluent discharged into the environment from the biogas facility are temperature, pH, conductivity, turbidity, colour, biochemical oxygen demand, chemical oxygen demand, total suspended solids, total dissolved solids, nitrate, nitrite, ammonia, and phosphate and heavy metals such as lead, copper, zinc, cadmium, chromium, and iron. The microbial quality parameters include total coliforms, faecal coliforms and total heterotrophic bacteria. A summary of the wastewater results of the study is given below (Table 4.1).

Table 4.1 <u>Characteristics of Sewage Effluent and Comparison with EPA Ghana 2000, Guidelines for Treated Wastewater</u>

Parameter	Effluent Discharged	EPA Ghana Guidelines, 2000
pH	7.47	6-9
Temperature (^{o}C)	27.3	<30(above ambient)
Conductivity (µS/cm)	6613	1500
D.O (mg/l)	3.8	<1
BOD (mg/l)	38	50
COD (mg/l)	640	250
TSS (mg/l)	92	50
TDS (ppm)	3310	1000
Turbidity (NTU)	48	75
Ammonia-Nitrogen (mg/l)	8.2	2
Nitrate-Nitrogen (mg/l)	17.8	0.1
Nitrite-Nitrogen (mg/l)	9.5	3
Phosphates-P (mg/l)	14.5	1.5
Faecal Coliform (cfu./100ml)	101	10-100
Total Coliform (cfu/100ml)	348	400
Total heterotrophic bacteria (cfu)	1124	-
Ni (mg/l)	0.943	0.02
Cd (mg/l)	0.273	0.003
Fe (mg/l)	0.722	0.3
Zn (mg/l)	0.632	3
Cr (mg/l)	ND*	0.05
Cu (mg/l)	2.24	2
Pb (mg/l)	1.122	0.01

ND*- Not Detectable

The contaminant levels of the sewage effluent from the VVU biogas facility were compared with that of the Ghana EPA guidelines for effluent discharge into the environment. From the Table 4.1, only temperature, pH, BOD and TDS conformed to the standard while EC, TSS, COD, Nitrate, Nitrite, Ammonia, Phosphate, all heavy metals (with the exception of Chromium which was not detected) and all the microbiological parameters recorded values that are higher than the EPA guideline.

4.2 Phytoremediation Potential of Aquatic Plants

The results for the assessment of the effectiveness and the comparison of pollutant removal rate between phytoremediators will be based on the following: physical parameters, organic load (BOD, COD), nutrients, heavy metals and microbial quality.

4.2.1 Physical parameters

The physical parameters considered in this study included pH, Temperature, Conductivity, TSS, TDS and Turbidity.

4.2.1.1 pH

The graphical representation in figure 4.1 shows a fluctuating pH trend for the sewage effluent. A drastic fall in pH was observed in week 2 which then increased in week 3 for Mimosa and Water hyacinth and latter recorded mean pH of 7.31 and 6.57 at the 6th week. *Lemna* and *Ceratophyllum* however, followed a gradual pattern of changing pH and recorded 6.64 and 7.84 respectively at the end of the study.

Analysis of variance at 95% confidence interval revealed a statistically significant difference ($P<0.05$) in pH of effluent for the various plants (Appendix E). When the Least significant difference (LSD) was used to compare the means, it revealed statistically that significant difference exist between concentrations for Water hyacinth and *Ceratophyllum*, Mimosa and *Ceratophyllum* and *Lemna* and *Ceratophyllum*. Appendices A, B, C and D show concentrations recorded for the entire study.

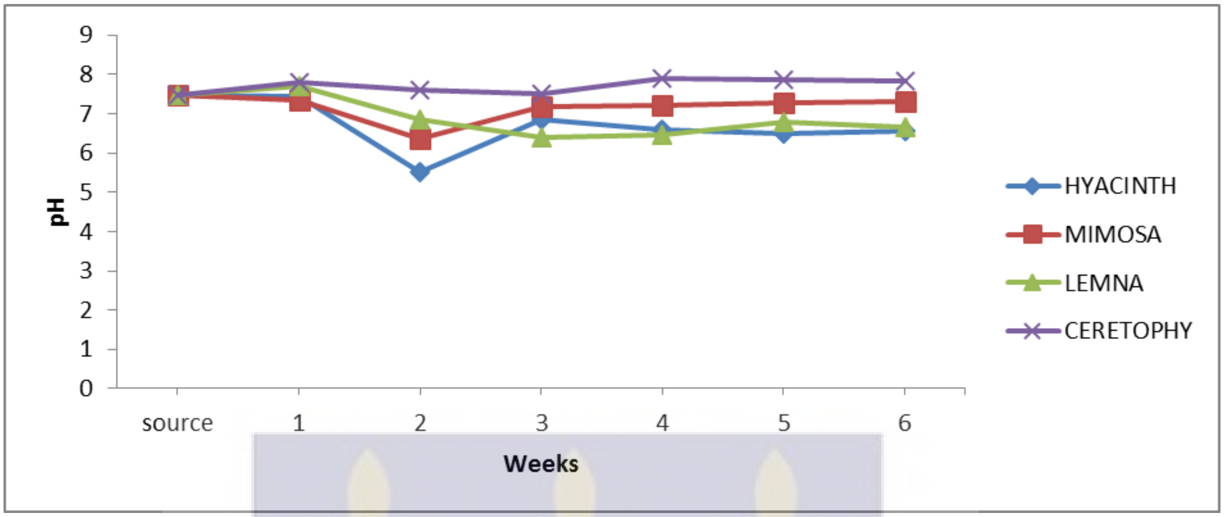


Figure 4. 1 Variation in Effluent pH in relation to Aquatic plants

4.2.1.2 Temperature

Temperature readings of the effluent fluctuated within the weeks and mean values of 29.2°C, 29.9°C, 31.2°C, and 30.1°C were recorded for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively at the end of the study. Almost a similar changing pattern of temperature was observed for all plants to the end of the study.

Analysis of variance at 95% confidence level did not reveal any statistically significant difference ($p>0.05$) in temperature among plants in their respective effluents over the entire study period. However, there were variations in temperature and *Lemna minor* recorded the highest mean temperature whilst Water hyacinth recorded the lowest mean temperature of the effluent.

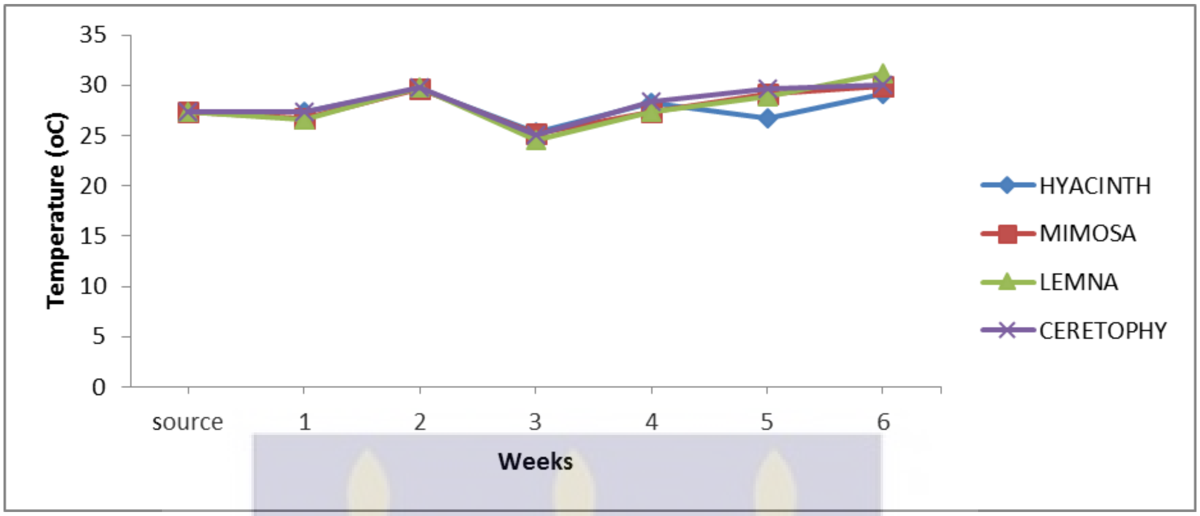


Figure 4. 2 Variation in Effluent Temperature in relation to Aquatic plants

4.2.1.3 Electrical Conductivity

The graphical representation of the Conductivity in shown in fig.4.3. A general decline in EC from the source value of 6613 µS/cm was observed for all the plants. Reductions recorded were 4600 µS/cm, 4370 µS/cm, 3514 µS/cm, and 1755 µS/cm for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively at the end of the study. The removal efficiencies of plants for EC was 30.4 %, 33.9 %, 46.9% and 73.5% for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively in the study.

Analysis of variance at 95% confidence level did reveal a statistically significant difference ($p>0.05$) in EC over the entire study period. When the LSD was used, significant differences were shown between Water hyacinth and *Ceratophyllum*; and Mimosa and *Ceratophyllum*. The removal ability of EC among the plants is given in this decreasing order: *Ceratophyllum* > *Lemna* > Mimosa > Water hyacinth.

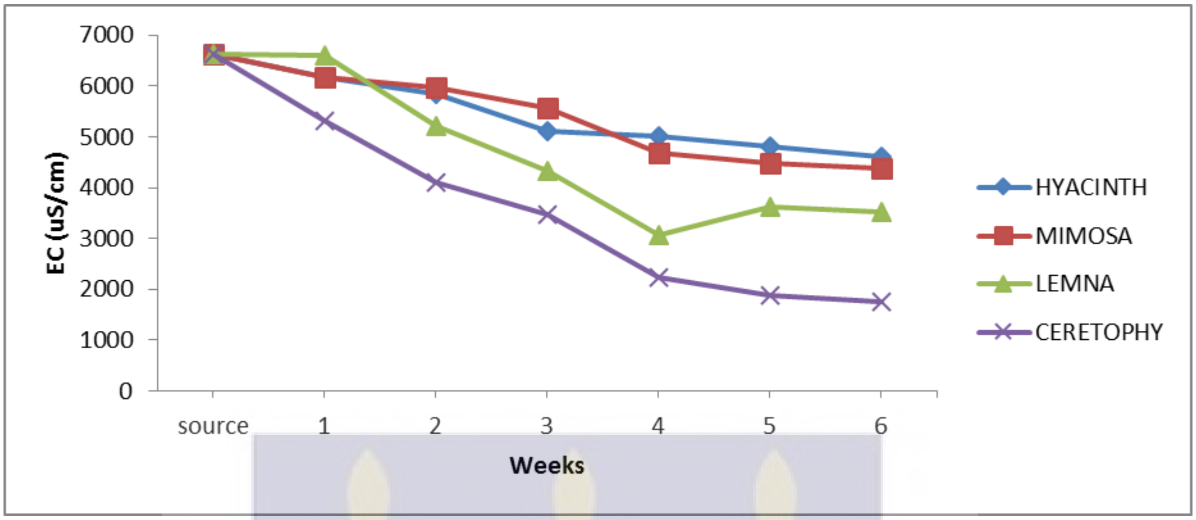


Figure 4. 3 Variation in effluent conductivity in relation to aquatic plants

4.2.1.4 TSS

TSS concentration at source was 92 mg/l. A general decreasing pattern was observed in the first two weeks and afterwards. However, Water hyacinth and *Lemna* showed increasing values to the 6th week with 258 mg/l and 150 mg/l recorded respectively. Mimosa and *Ceratophyllum* however had decreased TSS of 27 mg/l and 7 mg/l respectively. Hence removal efficiencies recorded for Mimosa and *Ceratophyllum* were 70.7 % and 92.4 % respectively.

Analysis of variance at 95% confidence level revealed statistically significant difference ($p>0.05$) in TSS. When the LSD was used to compare the means, significant difference were observed between that of Water hyacinth and *Ceratophyllum*; Mimosa and *Ceratophyllum*; and *Lemna* and *Ceratophyllum*. The decreasing order of ability to remove TSS is given as *Ceratophyllum* > Mimosa > *Lemna* > Water hyacinth.

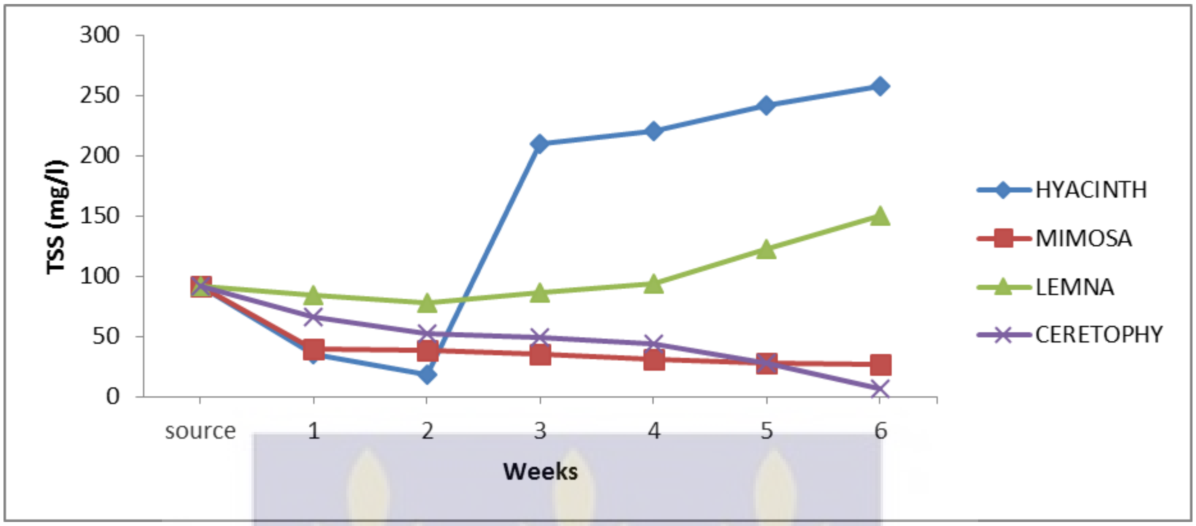


Figure 4. 4 Variation in Effluent Total Suspended Solids in relation to Aquatic plants

4.2.1.5 TDS

TDS concentrations amongst plants in the effluent showed reductions from the source value of 3310 mg/l. At the end of the study, 2300 mg/l, 2685 mg/l, 1757 mg/l and 878 mg/l were recorded for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively. The removal efficiencies recorded were 30.5 %, 18.9 %, 46.9 % and 73.5 % for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively in the study. Analysis of variance at 95% confidence level did not reveal any statistically significant difference ($p>0.05$) in TDS.

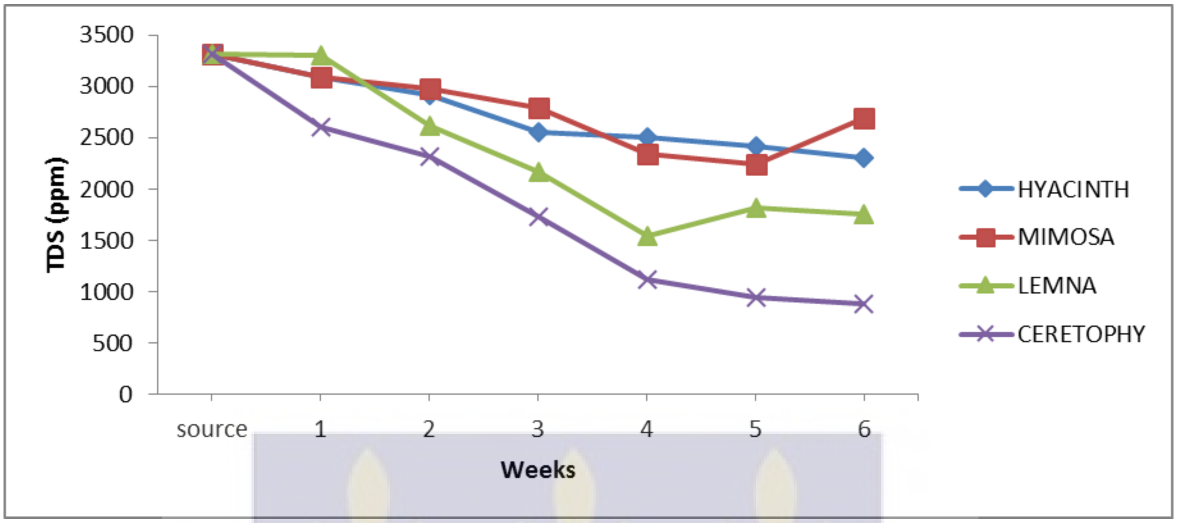


Figure 4. 5 Variation in Effluent Total Dissolved Solids in relation to Aquatic plants

4.2.1.6 Turbidity

At a source concentration of 48 mg/l, fig 4.6 shows the pattern for turbidity in the study. Water hyacinth, Mimosa and *Lemna* increased turbidity to 55.3 mg/l, 54.0 %, and 74.0 % respectively. However, *Ceratophyllum* drastically reduced turbidity to 3.5 mg/l in this study. Analysis of variance at 95% confidence level revealed statistically significant difference ($p>0.05$) in Turbidity. When the LSD was used to compare the means, significant difference were observed between that of Water hyacinth and *Lemna*; Mimosa and *Lemna*; and *Lemna* and *Ceratophyllum*. The decreasing order of ability to reduce turbidity is given as *Ceratophyllum* > Water hyacinth > Mimosa > *Lemna*.

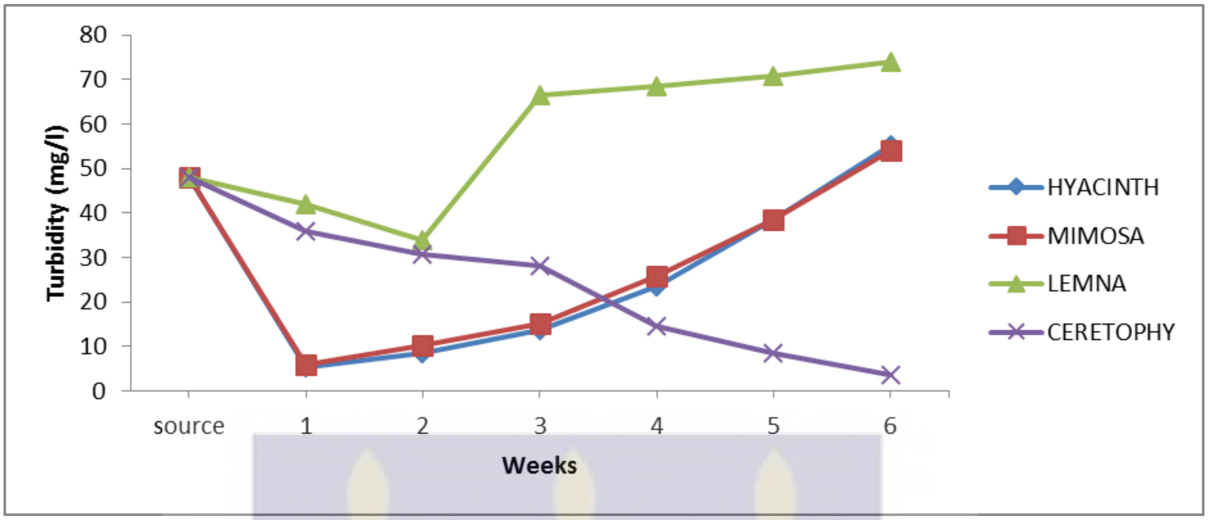


Figure 4. 6 Variation in Effluent Turbidity in relation to Aquatic plants

4.2.2 Organic Load Removal

The Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) parameters were used to assess the organic load in the sewage effluent.

4.2.2.1 Biological Oxygen Demand (BOD)

Figure 4.7 shows the graphical illustration of the decreasing mean BOD trend of the sewage effluent for the various plants. A drastic fall in concentration for *Lemna* was observed in the first week. However, a mild decreasing pattern continued to the end of the sixth week with a concentration of 2.5 mg/l. Significant removal efficiencies of 84.2 %, 76.3 %, 93.4 % and 88.9 % were recorded for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance at 95% confidence interval showed statistically significant differences ($P<0.05$) in biological oxygen demand in relation to the plants (Appendix E).When the LSD was used to compare the means, it revealed statistically that significant difference existed between concentrations for Mimosa and *Lemna*. A decreasing order of ranking with respect to the plant's ability to remove BOD from sewage effluent is as follows: *Lemna* > Hyacinth > *Ceratophyllum* > Mimosa.

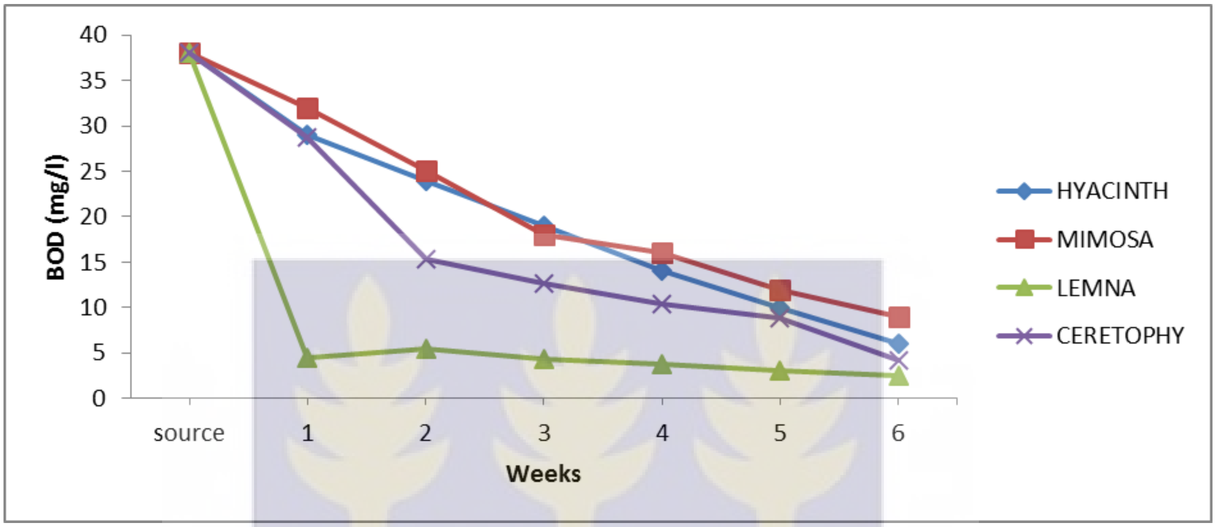


Figure 4. 7 Variation in Effluent Biological Oxygen Demand in relation to Aquatic plants

2.2.2. Chemical Oxygen Demand (COD)

The COD concentration in effluent sample at source was 640 mg/l. A constant decline was achieved within the weeks and recorded mean values of 150 mg/l, 200 mg/l, 480 mg/l, 380 mg/l for Water hyacinth, Mimosa, *Lemna minor* and *Ceratophyllum* respectively at the end of the study (Fig.4.8). A total removal efficiency of 76.6 % was recorded for Water hyacinth and 68.8 %, 25 % and 40.6 % for Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance at 95% confidence level revealed a statistically significant difference ($p<0.05$) in COD over the entire study period. When the Least Significant Difference (LSD) was used to compare the means, there was difference between Water hyacinth and *Lemna*. A decreasing order of ranking with respect to the plant's ability to remove COD is as follows: Water Hyacinth > Mimosa > *Ceratophyllum* > *Lemna*.

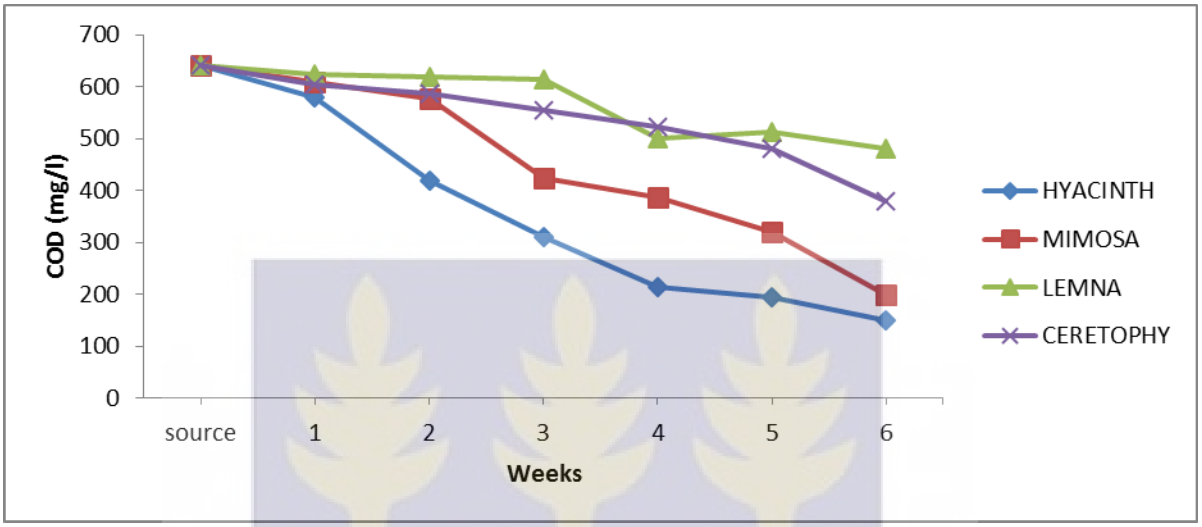


Figure 4. 8 Variation in Effluent Chemical Oxygen Demand in relation to Aquatic plants

4.2.3 Nutrient Removal ability of selected plants

The nutrients in this study include Phosphate-Phosphorus, Nitrate-Nitrogen, Nitrite-Nitrogen and Ammonia-Nitrogen.

4.2.3.1 Phosphate-Phosphorus (PO_4^{3-})

The concentration of Phosphate in effluent sample at source was 14.5 mg/l. After the first week of phytoremediation, there was a sharp decline of concentration to 4.16 mg/l, 5.4 mg/l, 6.76 mg/l, and 5.56.96 mg/l for Hyacinth, Mimosa, *Lemna minor* and *Ceratophyllum* respectively (Fig. 4.9) after which there was a slight gradual decrease in concentration to the 6th week. A total removal efficiency of 71.3 % was recorded for water hyacinth and 62.8 %, 53.4 %, 61.7 % for Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance at 95% confidence level did not reveal any statistically significant difference ($p>0.05$) in phosphate concentrations among the four plants over the entire study period. However, *Lemna minor* recorded the highest mean value whist Water hyacinth recorded the lowest mean value. The decreasing order of ranking with respect to the plant's ability to absorb phosphates from sewage effluent are as follows: Hyacinth > Mimosa > *Ceratophyllum* > *Lemna*.

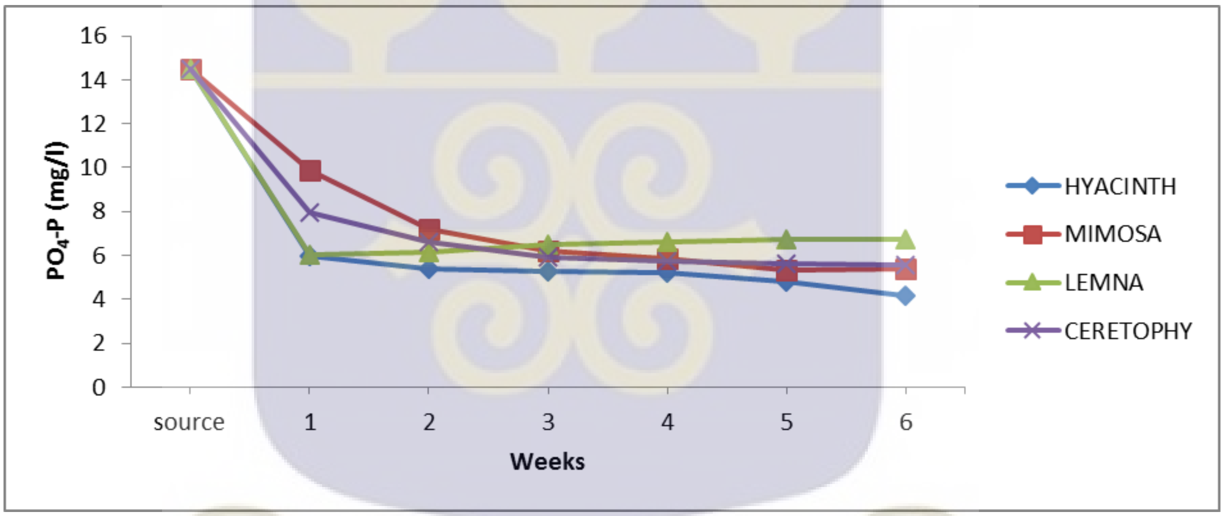


Figure 4. 9 Variation in Effluent Phosphates in relation to Aquatic plants

4.2.3.2 Nitrate-Nitrogen (NO_3^-)

The concentration of nitrate in the effluent sample at source was 17.8 mg/l. Figure 4.10 shows a sharp decline in concentration of nitrates from 17.8 mg/l to 0.2 mg/l for *Ceratophyllum* and a slight decrease in concentration to 1.6 mg/l for Mimosa, 1.5 mg/l for *Lemna* and 2.24 mg/l for Water hyacinth. The percentage removal efficiencies recorded for

Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* are 87.4 %, 91.0%, 91.6 % and 98.9 % respectively (Appendices A, B, C, D).

Analysis of variance at 95% confidence level revealed a statistically significant difference ($p<0.05$) in nitrates over the entire study period. When the Least Significant Difference (LSD) was used to compare the means, there were differences between Water hyacinth, Mimosa and *Ceratophyllum*. The decreasing order of ranking with respect to the plant's ability to absorb nitrates are as follows: *Ceratophyllum* > *Lemna* > Mimosa > Water Hyacinth.

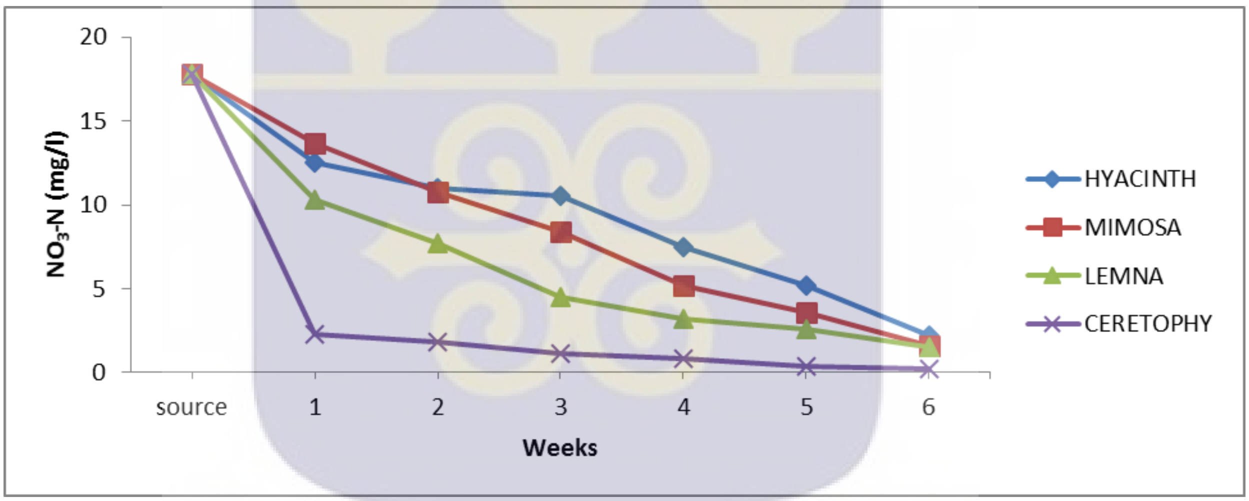


Figure 4. 10 Variation in Effluent Nitrate-Nitrogen in relation to Aquatic plants

4.2.3.3 Nitrite-Nitrogen (NO_2-N)

A sharp decrease in concentration from 9.5mg/l to mg/l, mg/l, mg/l for *Lemna*, *Ceratophyllum*, and Mimosa respectively was recorded for the first week (Fig 4.11). There were subsequent decreases in concentration from the 2nd week to the 6th week for all the plants. Values recorded are 0.023 mg/l, 0.005 mg/, 0.25 mg/l, 0.076 mg/l for Mimosa, *Ceratophyllum*, *Lemna* and Water hyacinth respectively. Significant removal efficiencies of

99.2 %, 99.8 %, 99.7 % and 99.9 % for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively were achieved (Appendices A, B, C, D).

Analysis of variance did not reveal any statistically significant differences ($p>0.05$) in the nitrite for all the plants. However, there was variation in concentration amongst the plants with Water Hyacinth having the least phytoremediating ability for nitrite and *Ceratophyllum* having the greatest ability to absorb nitrite from sewage effluent. The decreasing order of ranking with respect to ability of plant to remove nitrite from sewage effluent is given as: *Ceratophyllum* > Mimosa > *Lemna* > Water hyacinth.

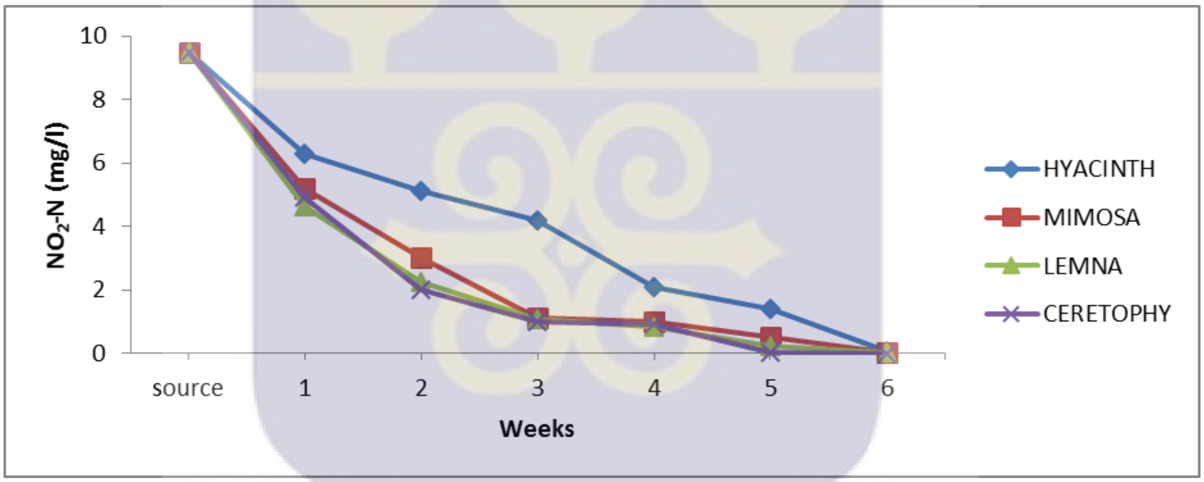


Figure 4. 11Variation in Effluent Nitrite-Nitrogen in relation to Aquatic plants

4.2.3.4 Ammonia-Nitrogen (NH_3-N)

Figure 4.12 shows a gradual decease in concentration of ammonia at source from 8.2 mg/l to 6.8 mg/l, 6.74 mg/l, 4.58 mg/l and 6.24 mg/l for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively at the end of the first week. Continuous weekly decrease in concentrations for Water hyacinth, Mimosa and *Ceratophyllum* occurred up to the 6th week recording mean values of 0.9 mg/l, 1.95mg/l, and 0.15mg/l respectively. However, the decrease in concentration for *Lemna* was very slight within the other weeks and recorded 1.97 mg/l at the 6th week. The removal efficiencies recorded were 89%, 76.2 %, 75.9 % and 98.2 % for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance did not reveal any statistically significant differences ($p>0.05$) in the concentrations of ammonia for all the plants. However, there was variation in concentration amongst the plants, with *Lemna* having the least phytoremediating ability for ammonia and *Ceratophyllum* having the highest ability absorb ammonia from sewage effluent. A decreasing order of ranking relating to the ability to remove ammonia from sewage effluent is as follows: *Ceratophyllum* > Water hyacinth > Mimosa > *Lemna*.

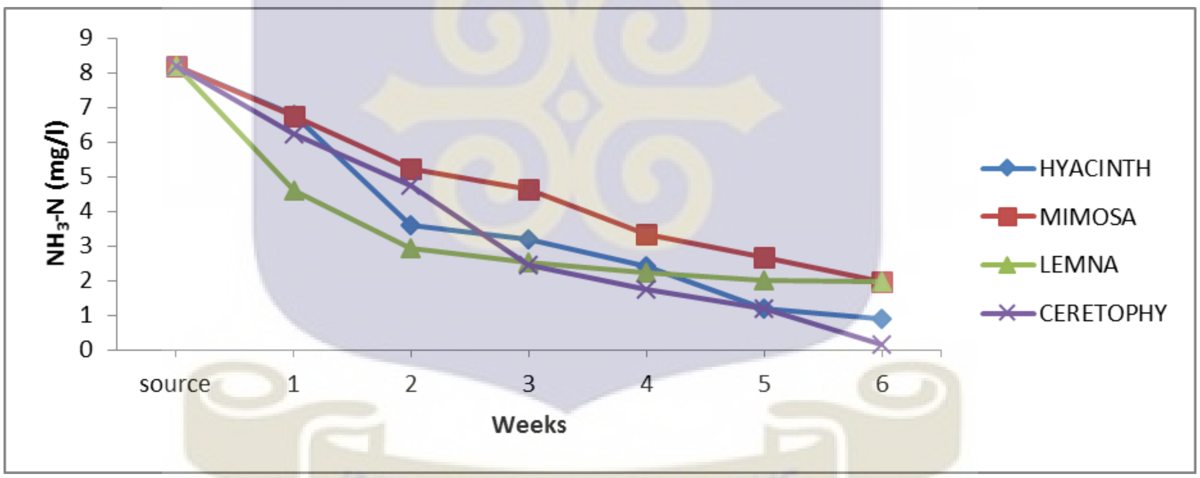


Figure 4. 12 Variation in Effluent Ammonia-Nitrogen in relation to Aquatic plants

4.3 Heavy metal Removal ability of selected plants

4.3.1 Cadmium

Figure 4.13 shows the decreasing nature of cadmium concentrations in the effluent for the various plants. From the source value of 0.273 mg/l, concentrations reduced weekly to the

6th week with recorded values of 0.045 mg/l, 0.105 mg/l, 0.046 mg/l and 0.056 mg/l for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively. Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* recorded removal efficiencies of 83.5%, 61.5 %, 83.2 % and 79.5 % respectively (Appendices A, B, C, D).

Analysis of variance at 95 % confidence interval did not reveal any statistically significant difference in Cadmium concentrations ($p>0.05$). However, variations existed between Water hyacinth and Mimosa plants. A decreasing order in concentration with respect to ability to remove cadmium is shown as follows: Water hyacinth > *Lemna* > *Ceratophyllum* > Mimosa.

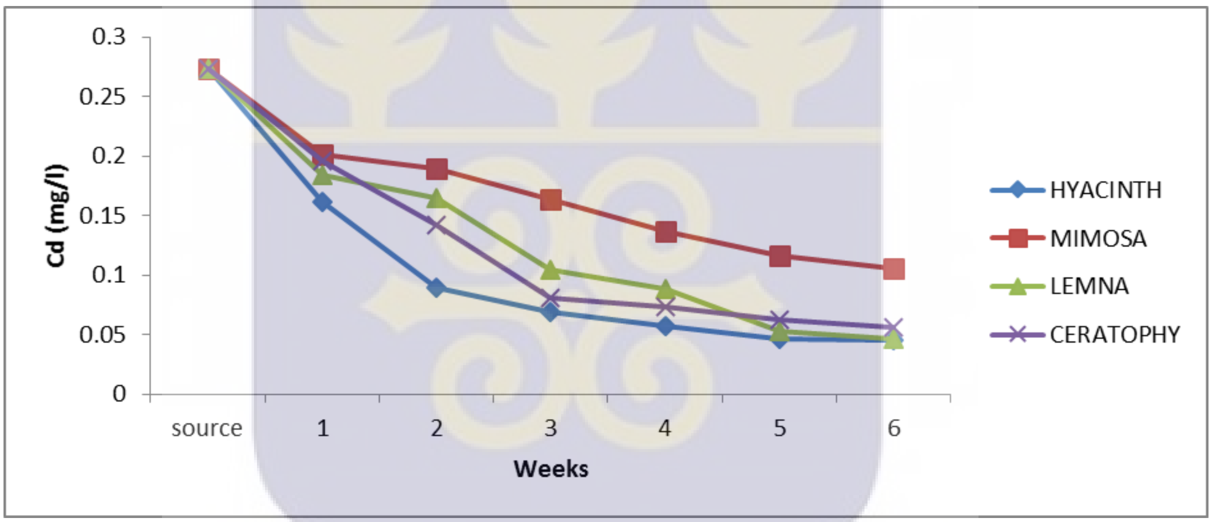


Figure 4. 13 Variation in Effluent Cadmium in relation to Aquatic plants

4.3.2 Lead

At a lead concentration of 1.122 mg/l from source, *Ceratophyllum* drastically reduced it to 0.118 mg/l in week 1 and with a fairly lower reductions through to the 6th week ending with 0.09 mg/l; Water hyacinth also recording significant reductions in the early weeks and finally with 0.12 mg/l at week 6; very slight decreases for *Lemna* and Mimosa occurred in the first four weeks but with sharp decreases at week 6 recording 0.528 mg/l and 0.852 mg/l respectively (Fig.4.14). The removal efficiencies recorded were 89.3%, 24.1%, 52.9% and 92% for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance at 95% confidence interval revealed a statistically significant difference ($P<0.05$) in lead concentrations for the various plants (Appendix E). When the Least significant difference (LSD) was used to compare the means, it revealed statistically that significant difference existed between concentrations for (Water hyacinth and *Ceratophyllum*, Mimosa and *Lemna*); Mimosa and *Ceratophyllum*; *Lemna* and *Ceratophyllum*. The concentrations recorded for the entire study are shown in Appendices A, B, C and D. The decreasing order of ability to remove lead was observed as *Ceratophyllum* > Water hyacinth > *Lemna* > Mimosa.

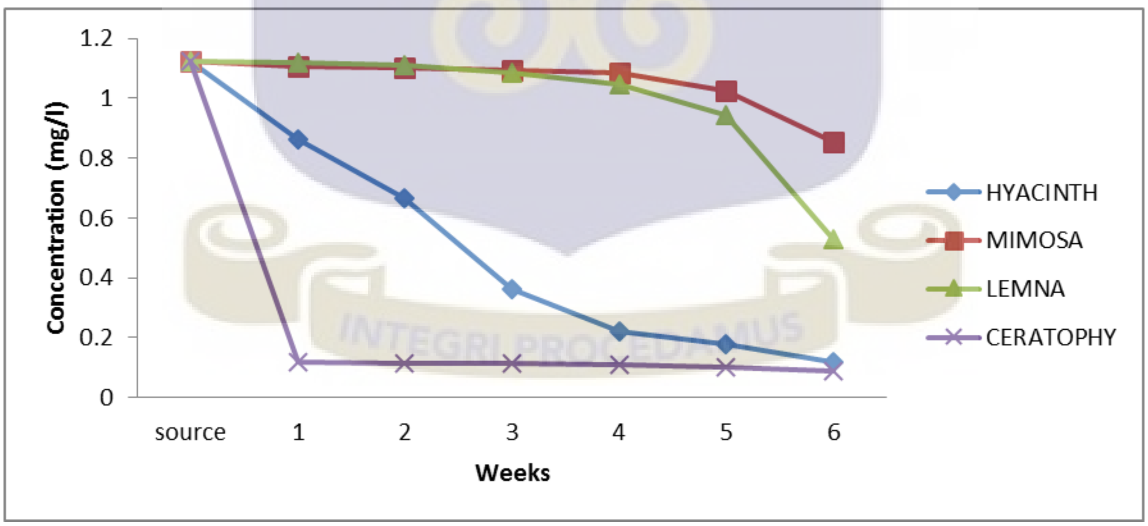


Figure 4. 14 Variation in Effluent Lead in relation to Aquatic plants

4.3.3 Nickel

The source concentration of Nickel was reduced from 0.943 mg/l to 0.311 mg/l, 0.547 mg/l, 0.282 mg/l and 0.023 mg/l by Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively at the end of the study. All plants showed considerable removal of Nickel weekly but *Ceratophyllum* had greatest weekly removal especially in week 1 and 2. The removal efficiencies of the plants for Nickel were 67 %, 41.9 %, 70.1% and 97.6% for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively.

Analysis of variance at 95% confidence level did not reveal any statistically significant difference ($p>0.05$) in Nickel concentration over the entire study period (Appendix E). The removal ability of the plants for Nickel is given in this decreasing order: *Ceratophyllum* > *Lemna* > Water hyacinth > Mimosa.

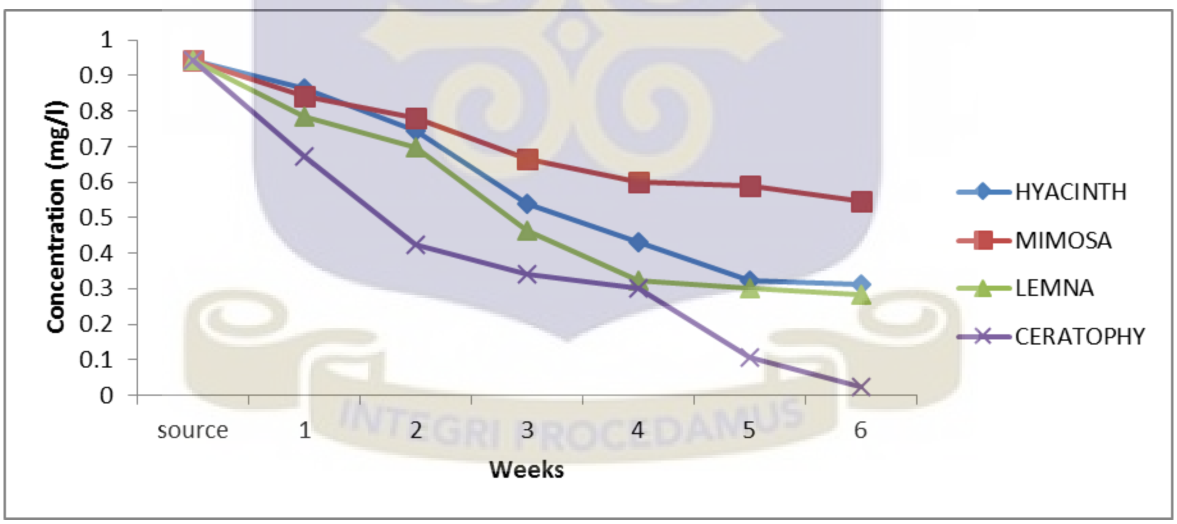


Figure 4. 15 Variation in Effluent Nickel in relation to Aquatic plants

4.3.4 Zinc

Figure 4.16 shows Zinc reduction in the effluent from a source of 0.632 mg/l. In week 1, *Lemna* and *Ceratophyllum* showed strong reduction with 0.481 mg/l and 0.487 mg/l respectively than Water hyacinth and Mimosa which recorded 0.601 mg/l and 0.611 mg/l respectively. At the end of the study, reduced values of 0.45 mg/l, 0.382 mg/l, 0.261 mg/l and 0.286 mg/l were recorded for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively. The removal efficiencies recorded were 28.8%, 39.6%, 58.7% and 54.7% for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D). Analysis of variance at 95% confidence interval revealed a statistically significant difference ($P<0.05$) in lead concentration for the various plants (Appendix E). When the Least significant difference (LSD) was used to compare the means, it revealed statistically that significant difference existed between concentrations for Water hyacinth and *Ceratophyllum*, Water hyacinth and *Lemna*; Mimosa and *Lemna*; Mimosa and *Ceratophyllum*. Plants' ability to remove zinc is given in the decreasing order as *Lemna* > *Ceratophyllum* > Mimosa > Water hyacinth.

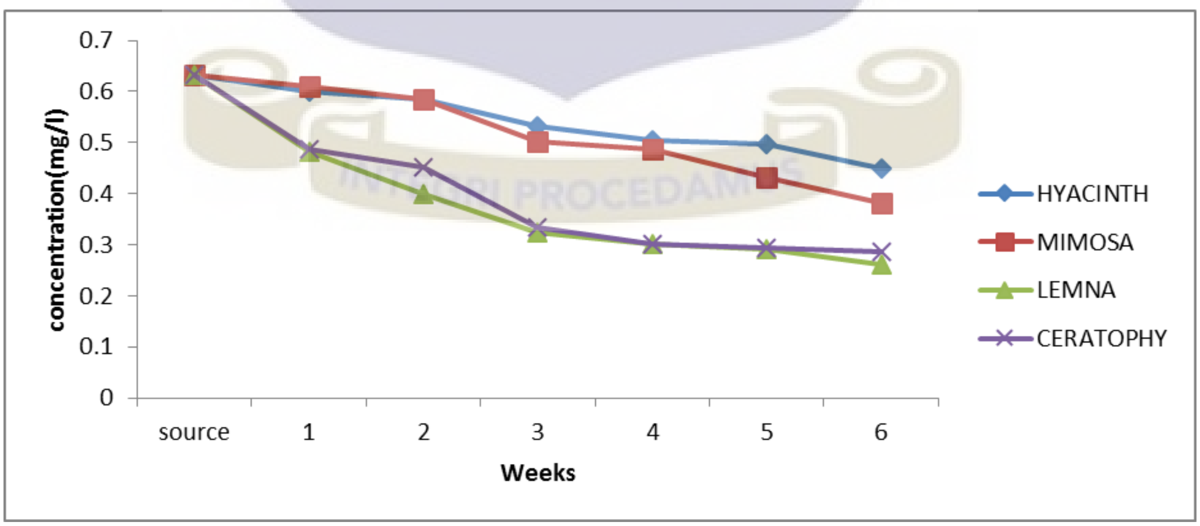


Figure 4. 16 Variation in Effluent Zinc in relation to Aquatic plants

4.3.5 Copper

The effluent source concentration of Copper was 2.24 mg/l. Concentrations were greatly reduced in the 1st to the 3rd weeks and continued slightly to lower values at 0.017 mg/l, 0.001 mg/l and 0.008 mg/l for Mimosa, *Lemna* and *Ceratophyllum* respectively. Water hyacinth however, shoed low reductions and recorded 1.75 mg/l at the 6th week. The removal efficiencies recorded were 21.9%, 99.2%, 99.9% and 99.6% for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance at 95% confidence interval revealed a statistically significant difference ($P<0.05$) in lead concentration for the various plants (Appendix E). When the Least significant difference (LSD) was used it revealed statistically significant difference between Water hyacinth and *Ceratophyllum*, Water hyacinth and Mimosa; Water hyacinth and *Lemna*; *Lemna* and *Ceratophyllum*. A decreasing order of ranking with respect to the plant's ability to remove copper is *Lemna* > *Ceratophyllum* > Mimosa > Water hyacinth.

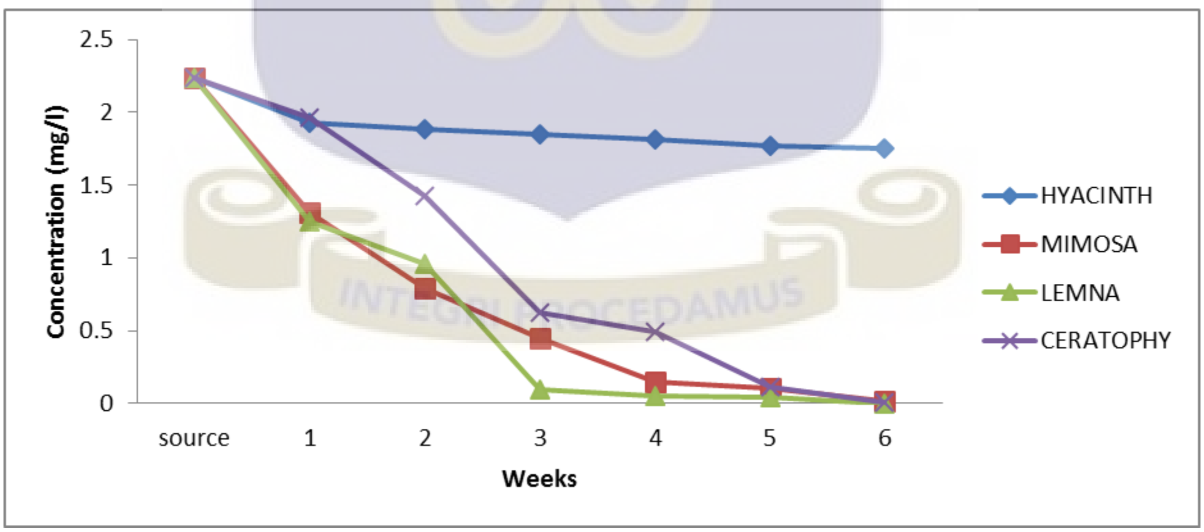


Figure 4. 17 Variation in Effluent Copper in relation to Aquatic plants

4.3.6 Iron

At a source concentration of 0.722 mg/l, a general reduction in iron was observed for all the plants to the end of the study with 0.225 mg/l, 0.333 mg/l, 0.305 mg/l and 0 mg/l for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively. The removal efficiencies recorded were 68.8%, 53.9%, 57.8% and 100% for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance at 95% confidence interval revealed a statistically significant difference ($P<0.05$) in iron concentration for the various plants (Appendix E). When the Least significant difference (LSD) was used to compare the means, it revealed statistically that significant difference existed between concentrations for Water hyacinth and *Ceratophyllum*, Mimosa and Ceratophyllum); Lemna and Ceratophyllum. The order of ability to remove iron is given as *Ceratophyllum* > Water hyacinth > Lemna > Mimosa.

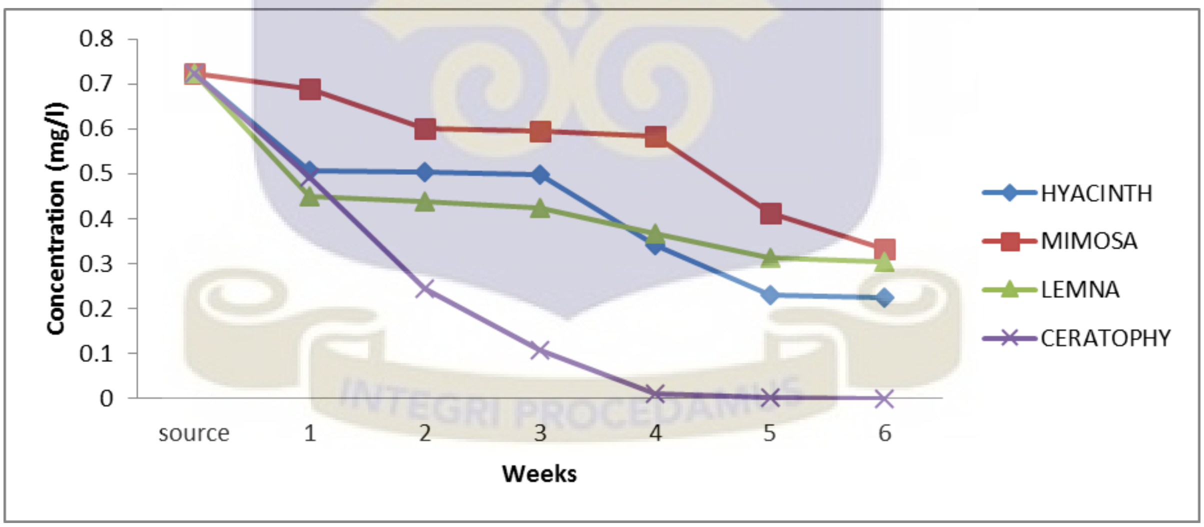


Figure 4. 18 Variation in Effluent Iron in relation to Aquatic plants

4.4 Microbial removal ability of selected plants

The microbial parameters considered in this study are Total Coliforms (FC), Faecal Coliforms (FC) and Total Heterotrophic bacteria (THB). The results are presented as follows:

4.4.1 Total Coliforms (TC)

Figure 4.19 shows the trend for TC removal in the effluent with a source value of 348 cfu /100ml. A great fall in TC counts reaching 58 was recorded in week 1 and gradually decreasing to a minimum count of 12 in week 6 for *Lemna*. However, all other plants showed minimal reduction in week 1 but at the end week 6 were able to record 22 cfu, 65 cfu and 9 cfu values for Water hyacinth, Mimosa and *Ceratophyllum* respectively. The removal efficiencies of TC recorded were 93.4%, 81.3 %, 96.6 % and 97.4 % for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance at 95% confidence interval showed statistically significant differences ($P<0.05$) in the means of total coliforms (Appendix E).When the LSD was used to compare the means, it revealed statistically that significant difference existed between concentrations for (Mimosa and *Lemna*) and (Water hyacinth and *Lemna*). A decreasing order of ranking with respect to the plant's ability to remove TC from sewage effluent is as follows: *Ceratophyllum* > *Lemna* > Water hyacinth > Mimosa.

4.4.2 Faecal Coliforms (FC)

The FC trend shown in Figure 4.20 shows a similar trend in all the plants. There is a general decrease from the source value of 101 cfu/100ml throughout the weeks and reached 8 cfu/100ml, 30 cfu/100ml, 5 cfu/100ml, and 4 cfu/100ml for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively at the 6^{th} week. The removal efficiencies of FC recorded were 92.1%, 70.3 %, 95 % and 96 % for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance did not reveal any statistically significant differences (p>0.05) in the means of faecal coliforms in the effluent. However, there was variation in concentration amongst the plants, with *Lemna* having the least phytoremediating ability for ammonia and *Ceratophyllum* having the highest ability to remove ammonia from sewage effluent. A decreasing order of ranking relating to the ability to remove ammonia from sewage effluent is as follows: *Ceratophyllum* > Water hyacinth > Mimosa > *Lemna*.

4.4.3 Total Heterotrophic Bacteria (THB)

The removal efficiencies of plants recorded were 66.5%, 24.9 %, 78.6 % and 92.5 % for Water hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendices A, B, C, D).

Analysis of variance at 95% confidence interval showed statistically significant differences (P<0.05) in the means of THB (Appendix E).When the LSD was used to compare the means, it revealed statistically that significant difference existed between counts for (Mimosa and *Lemna*), (Mimosa and *Ceratophyllum*) and (Mimosa and Water hyacinth). A decreasing order of ranking with respect to the plant's ability to remove THB from sewage effluent is as follows: *Ceratophyllum* > *Lemna* > Hyacinth > Mimosa.

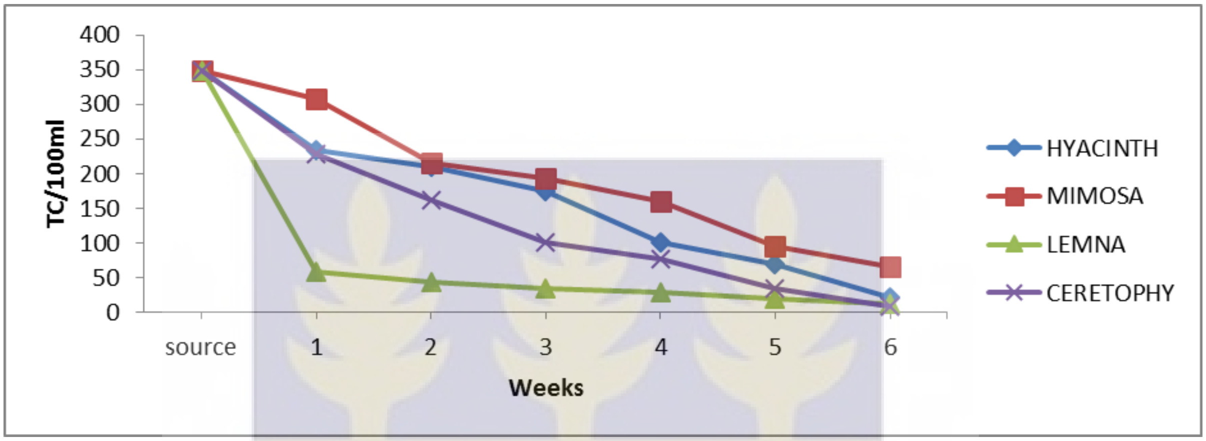


Figure 4. 19 Variation in Effluent Total Coliforms in relation to Aquatic plants

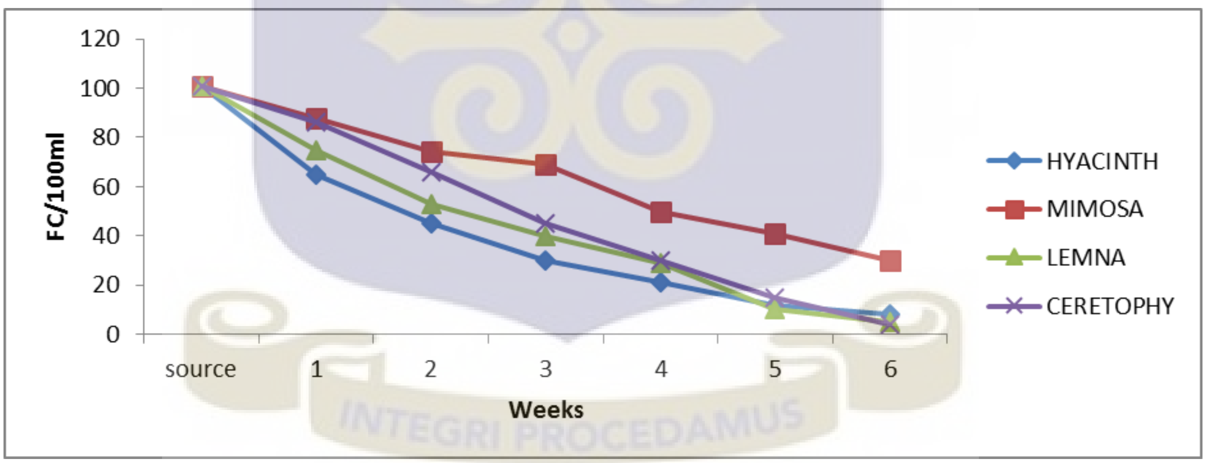


Figure 4. 20 Variation in Effluent Faecal Coliforms in relation to Aquatic plants

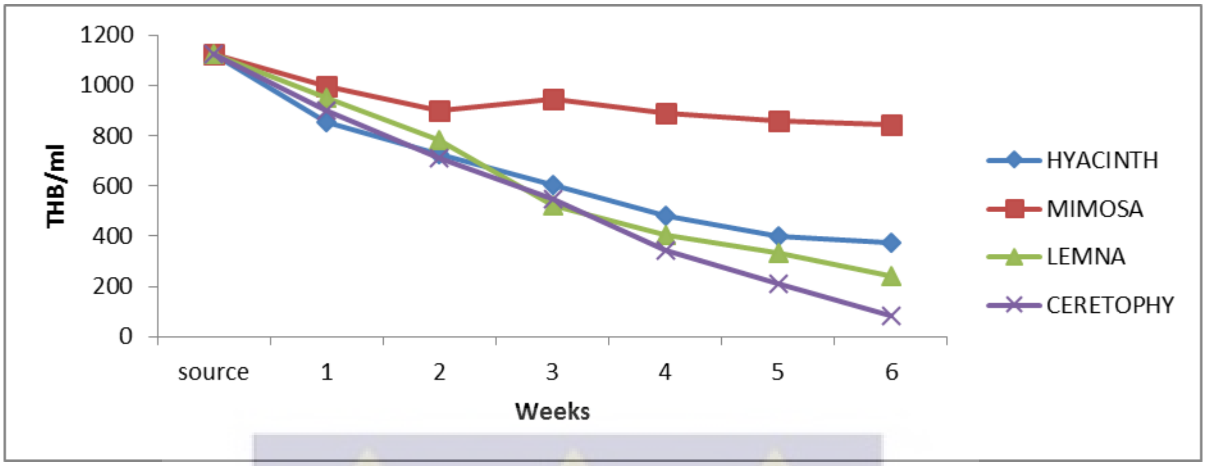


Figure 4. 21Variation in Effluent Total Heterotrophic Bacteria in relation to Aquatic plants

4.5 Socio-Economic Survey

Interview guides were used to assess the public's knowledge and acceptability of treated wastewater for both essential and non-essential purposes. A total of 100 respondents were involved.

4.5.1 Demographic Data

Table 4.2: Demographic information of respondents

Demographic Characteristics		**Percent**
Gender	Male	38
	Female	62
Age	<20	8
	20-29	13
	30-39	33
	40-49	27
	50-59	17
	>60	2
Education	Non-formal	11
	Primary/JHS	20
	SHS/6th Form	31
	Tertiary	38
Monthly Income	<500	26
	500-1000	20
	1000-1500	43
	1500-2000	8
	>2000	3

4.5.2 Awareness and knowledge on wastewater reuse applications

96% of the respondents expressed the opinion that water resources have been polluted and consumed rapidly in recent times, and that the majority of participants (70.4%) have taken some precautions to reduce water consumption in their daily lives. Fig.4.22 shows the response to the question 'Are you aware of the water reuse applications'? When the all results were considered, 52% of respondents were unaware of the reuse applications. 59 % males and 41 % females were aware of wastewater reuse applications.

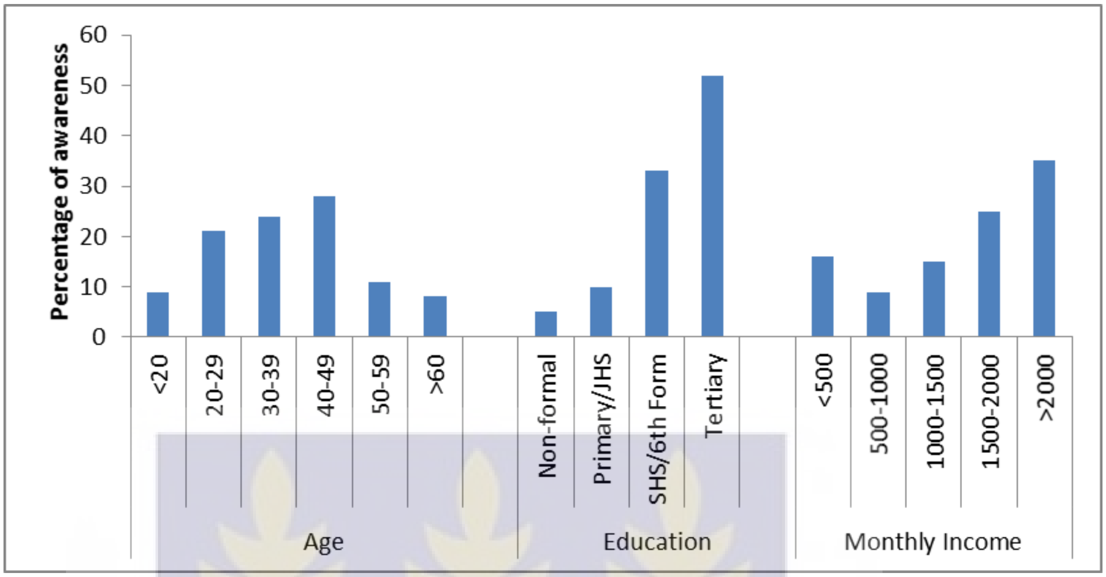


Figure 4. 22 Awareness about the treated wastewater reuse applications.

4.5.3 Acceptance of wastewater for reuse

Figure 4.23 shows the responses to the question "Which water reuse alternatives are most applicable in your opinion?

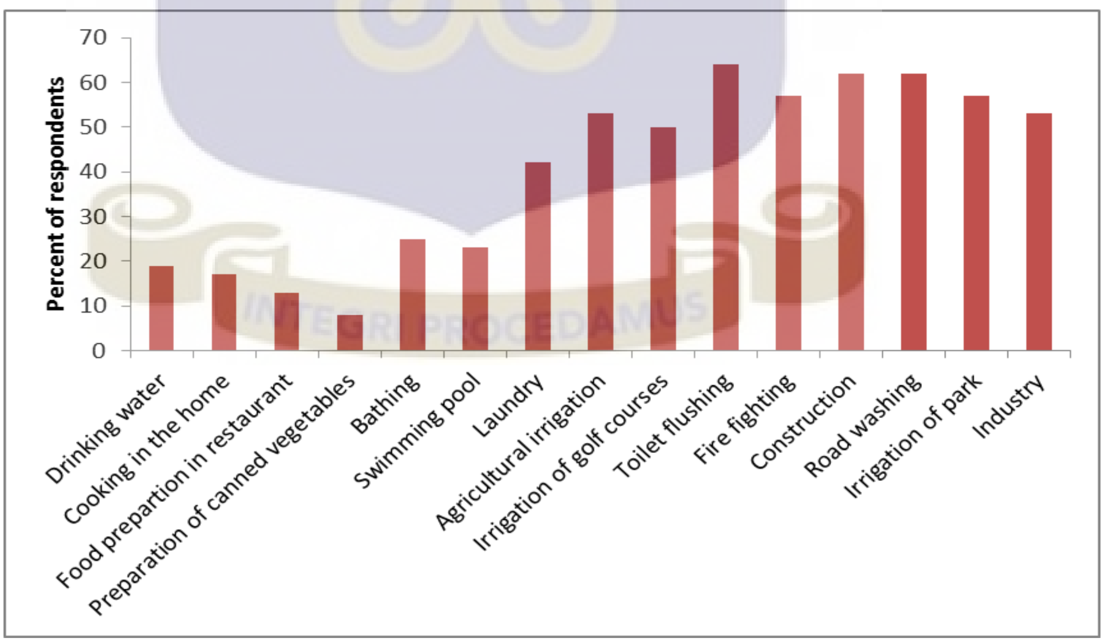


Figure 4. 23 Tendencies toward to wastewater reuse options.

The study showed 31 % males and 69 % females responded positively (yes) to wastewater reuse for drinking. A summary of the result is shown in fig 4.24.

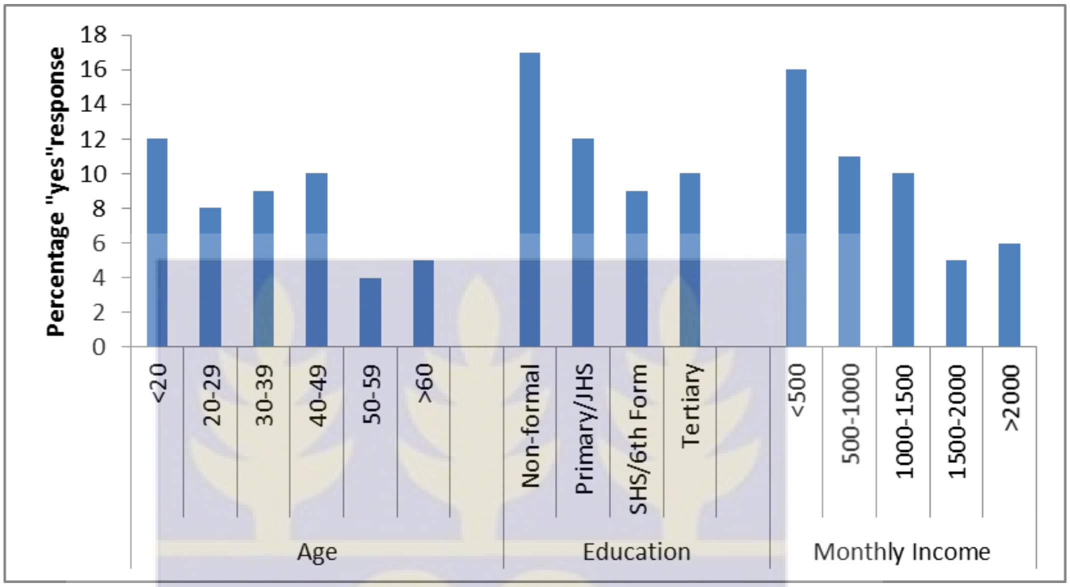


Figure 4. 24 Percentages of positive responses to the question of "If the quality of treated wastewater is certified as best quality, can you use this water for drinking purposes?"

The results of the question about types of wastewater preferred for reuse applications after following required wastewater treatment processes are shown in Fig.4.25. The public perception of wastewater reuse in general is positive. Only 5% of participants are against the reuse applications. A greater part of respondents (45%) prefer agricultural reuse of wastewater.

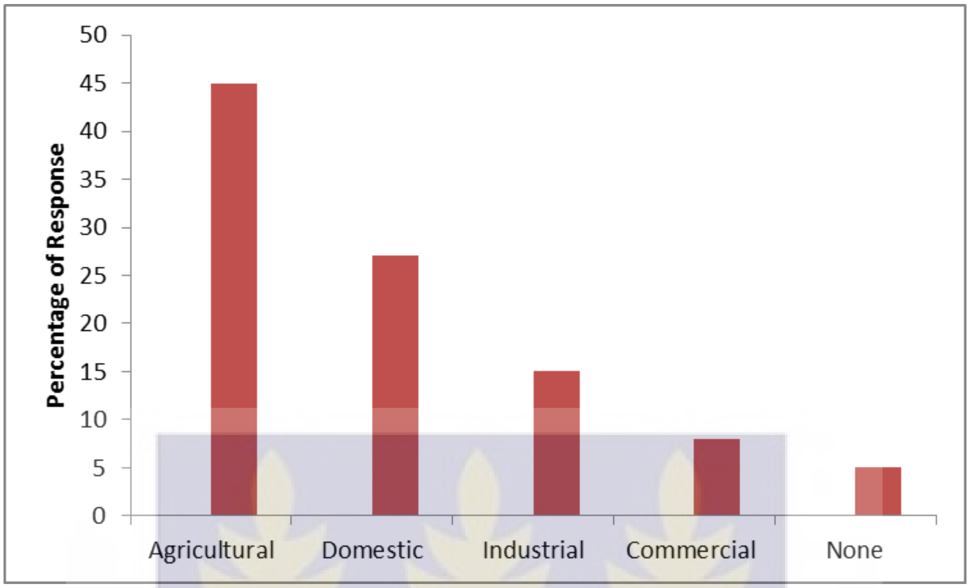


Figure 4. 25 Types of preferred wastewater for reuse applications.

CHAPTHER FIVE

DISCUSSION

5.1 Introduction

The quality of sewage effluent from the VVU biogas facility and the phytoremediation potential of the selected aquatic plants for this study shall be discussed based on physical parameters, organic load, nutrients content, heavy metal concentration and microbial quality. The public's knowledge and acceptability of treated sewage effluent for both essential and non-essential purposes from the social survey conducted is also discussed in this section. They are as follows:

5.2 Physical Parameters

The physical parameters discussed in this study include: temperature, pH, electrical conductivity, turbidity, TSS and TDS.

5.2.1. Temperature

Generally, the temperature of the effluent from the biogas plant was within the EPA effluent quality standard for discharge into natural water bodies which is not greater than 30^{o}C above ambient temperature. The low temperature may be due to the non- exposure of the sewage to the bare sun in the filtration chamber and the cooling effect exerted on the pipeline by the soil into which it is buried. The temperature value recorded for the final effluent remains in the temperature range for the growth and activeness of most micro-organisms (Pearson *et al.*, 1987).

Hence the temperature found is conformity with EPA recommended range and is therefore likely not to damage aquatic life when released into nearby water bodies.

5.2.2 Hydrogen Ion Concentration (pH)

The pH of 7.47 for the sewage effluent from the biogas plant according to Tchobanogolous *et al*., 2003, is in the pH concentration range suitable for the existence of most biological life. Hence both chemical and biological activities would not be affected negatively since pH is in the desired range of 6-9 given by EPA Ghana for discharge. The alkalinity of the effluent may be due to the presence of chemicals in soaps and detergents used for bathing, cleaning and washing on campus. This agrees with observations made by Awuah and Abrokwah, (2008). Colmenarejoa *et al*., 2006 also argued that an increase in effluent pH compared to influent pH may be attributed to the decrease in dissolved CO_2 concentration through a reduction in the concentration of organic matter due to oxidation during the treatment. Mahmood *et al*., 2005 also argued that reduction in pH may be due to absorption of nutrients or by simultaneous release of H+ ions with the uptake of metal ions.

5.2.3 Electrical Conductivity

Generally, conductivity of wastewater is measured to obtain the ability of the water to conduct electrical current. The recorded sewage effluent conductivity of 6613 µS/cm is unsatisfactory compared to the Ghana EPA guideline value (1500 µS/cm). The high value may be attributed to high concentrations of dissolved ions present in the raw sewage. However, in a study by Hodgson, 2007, low mean conductivity values were recorded. Research has found that there is a positive correlation between conductivity and total dissolved solids (TDS) and the later may be obtained by multiplying conductivity by a factor between the ranges of 0.55-0.75 (Chapman, 1992).

Phytoremediation treatment performed even though effective, could not reduce conductivity below the EPA guideline. The high conductivity of the waste effluents can increase the salinity of the receiving water which may result in adverse ecological effects on aquatic biota (Fried, 1991).

5.2.4 Turbidity

Turbidity, a measure of the light transmitting property, is a test used to indicate the quality of wastewater discharges with respect to colloidal and residual suspended matter. It is affected by the presence of colloidal particles. The raw sewage had considerable quantities of suspended solids in the form of organic matter and micro-organisms as well as other solid particles. The high total suspended solids removal and the significantly high micro organisms' removal (Table 4.1), might have influenced the results. The reduction in turbidity values is directly linked with that of TSS and Total coliform (Awuah and Abrokwa, 2008). The effluent turbidity of 48 NTU was below the limit; hence satisfactory compared to the Ghana EPA guideline value of 75 NTU.

5.2.6 Total Suspended Solids (TSS)

TSS is a very important quality parameter in wastewater treatment. High concentrations of suspended solids can cause many problems for stream health and aquatic life. The discharging of effluents with high levels of Suspended Solids can cause sludge deposition and create anaerobic conditions in the receiving water body (Hodgson, 2000). High TSS can also cause an increase in surface water temperature and cause dissolved oxygen levels to fall, which can lead to death of aquatic lives (Mitchell and Stapp, 1992).

A mean value of 233.83 mg/l of effluent was recorded from the biogas plant. The concentration measured is unsatisfactory compared to the Ghana EPA guideline value of 50 mg/l. The high TSS concentration could be attributed to dead matter from aquatic plants when maturation stage was reached. This could have also led to increased mineralization of the organic matter and thereby increasing suspended matter. High TSS causes reduction in sunlight intensity in water bodies and reduces primary productivity especially on green algae. This disturbs the aquatic food chain. Less light also affects temperature in the aquatic environment impacting negatively on primary and secondary productivity of aquatic life and temperature stratification of the system. TSS is also a source of organic decay that releases nauseating odours (Mitchell and Stapp, 1992).

5.2.6 Total Dissolved Solids (TDS)

TDS is a measurement of inorganic salts, organic matter and other dissolved materials in water. The toxicity of TDS is influenced by increases in salinity, changes in the ionic composition of the water, and toxicity of individual ions. The mean concentration of the effluent was 3310 mg/l and this could suggest high concentrations of dissolved inorganic and organic molecules and ions present in the sewage effluent. The measured concentration was above EPA guideline of 1000 mg/l and hence not satisfactory. Kagya, (2011) in his study on effluent quality of two wastewater treatment systems, also reported a high value of 329.0 mg/l in the final effluent discharged in to water bodies.

5.3 Removal of Organic Load

The parameters used to assess organic load included Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

5.3.1 Biochemical Oxygen Demand

A low BOD below the EPA guidelines of 50 mg/l is an indication of the satisfactory nature of the biogas facility. Effluents with high concentrations of BOD can cause depletion of natural oxygen resources which may lead to the development of septic conditions (Hodgson, 2000).

Kagya (2011) also reported a low mean load of 17.58 mg/l in the effluent and argued that it is the result of considerably, small amounts of organic materials available for biodegradation because BOD/COD ratio of the raw influent was 0.28.

However, the effect of phytoremediation in removing BOD was evident after treatment of effluent with selected aquatic plants. A removal of 93 % for Lemna is remarkably. The ability of all four plants to remove BOD was shown with concentrations far below the EPA, Ghana guideline of 50 mg/l. Zimmo *et al.*, 2005 found that BOD removal efficiency was higher in duckweed based ponds than in algae based ponds. The removal of BOD is this study is in the ranking order of Lemna > Ceratophyllum > Water hyacinth > Mimosa. The fast rate of BOD removal in the first two weeks can be due to plant uptake being higher.

5.3.2 Chemical Oxygen Demand

The concentration of the effluent discharged from the facility did not satisfy the limit set by Ghana EPA. COD test measures the oxygen demand of oxidizable pollutants both organic and inorganic materials. The higher levels of COD observed at the discharge point is undesirable. Continuous discharge of effluent will greatly impact receiving water body to some extent and this may have negative effects on the quality of the freshwater and subsequently cause harm to the aquatic life especially fish (Morrison *et al.*, 2001).

Phytoremediation treatments with Water hyacinth and Water mimosa however could meet the EPA, guidelines for discharge into the environment in this study. The high performance could be attributed to the observations made by Shah *et al.*, (n.d) in a similar study. Their result showed high performance to remove COD and was mainly attributed to the well-developed root system of Water hyacinth. Further observations also revealed that a major part of the degradation of COD in the wastewater is attributed to micro-organisms which may have established a symbiotic relationship with the plants.

5.4. Nutrients Removal

Effluent with high concentrations of nutrients can cause undesirable phytoplankton growth in receiving water bodies. The nutrients type assessed under this work are phosphate, nitrate, nitrite, and ammonia.

5.4.1 Nitrate-Nitrogen (NO_3-N)

Nitrate in water is the end product of the aerobic stabilization of organic nitrogen and may enter the environment via run offs from agricultural lands or in treated effluents from wastewater plants. The study showed that nitrate concentration (17.8 mg/l) of the final effluent was unsatisfactory compared to the Ghana EPA guideline value of 0.1 mg/l. Work by Fosu (2009) on KNUST treatment plant also recorded a high concentration of nitrate in the final effluent (10.83 mg/l) above the acceptable limit. According to Nkegbe *et al*., 2005, the high nitrate concentration may be due to the fact that more organic matter was broken down to oxides and nitrate.

However, effluent treatment with the selected aquatic plants showed significant nitrate removal efficiency of 87.4%, 91%, 91.6% and 98.9% for Water Hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendix A, B, C, and D). The high average % removal values indicate the usefulness of Water Hyacinth, Mimosa, *Lemna* and *Ceratophyllum* plants for reducing the level of nitrate in contaminated water.

Nitrogen is a critical nutrient assimilated by plants (Rogers *et. al*., 1991) either as ammonia or nitrates and used in the production of biological macromolecules such as amino acids and nucleotide bases. The selected plants are not so different from other plants taking up nitrogen as either ammonia or nitrates. The observed decreases in the concentration of nitrates in Fig 4.10 may be attributed to assimilation by the plants or could also be due to the process of denitrification in which nitrates are reduced to molecular nitrogen gas (N_2) Sooknah, (2000). This observation pattern is similar to that presented in other studies (Kutty *et al*., 2009), (Dar *et al*., 2011), (Akinbile and Yusoff, 2012).

The potential of *Eichhornia crassipes* to remove nitrogen and phosphorus from wastewater of a textile mill (Gamage and Yapa 2001), from upgraded facultative lagoon (Wolverton and McDonald 1979), and a lake (Sangeeta 2007) also have been reported. However, according to Alade and Ojoawo (2009), nitrogen and phosphorus content of wastewater treated with

Eichhornia crassipes was increased by 77.5% and 66.3% respectively. The increased nitrate and phosphate ion concentration would have been due to the mineralization of the organic matter found in waste water. The potential of duck weed (*Lemna minor*) in the removal of pollutants from refinery wastewater was studied by Azeez and Sabbar, (2012) and reported removal efficiency of 57.1%.

5.4.2 Nitrite-Nitrogen (NO_2-N)

The mean nitrite concentration of the effluent was 9.5 mg/l discharged into the environment. This high effluent nitrite concentration indicates that the biogas system was not efficient in treating nitrite. It is also not satisfactory compared to Switzerland official maximum concentration of 0.3 mg NO_2-N/l. Increased concentrations are usually an indication of a disturbance of microbiological processes, of an overloaded plant or insufficient aeration capacity. Microbiological inhibition can be caused by toxic substances, seasonal variations in temperature or generally unfavourable conditions for Nitrite Oxidizing Bacteria (Eawag, 2003).

The Ghana EPA guideline value for nitrite could not be established. Nitrite is a strong fish poison and is considered as a possible cause of fishes populations decrease in Swiss waters (Fischnetz, 2004).

The effect of phytoremediation was evident in the cleaning processes performed by the selected plants. An efficiency of 99.9 % in reducing the nitrite content of sewage effluent to 0.005 mg/l (Appendix D) which is below the EPA discharge limit by *Ceratophyllum demersum* is very satisfactory. Significant reductions of 99.2 %, 99.8 % and 99.7 % for Water Hyacinth, Mimosa, and *Lemna* respectively below EPA standard is indicative of the high phytoremediating ability of the selected plants in reducing nitrite concentration in sewage effluent. Based on this study, the order of removability of nitrite can be given as: *Ceratophyllum* > Mimosa > *Lemna* > Water Hyacinth.

The increasingly reduction in nitrite concentration could be due to the nitrification process in which nitrites were being converted to nitrates by a microbial mediated process for assimilation Sooknah, (2000).

5.4.3 Ammonia- Nitrogen (NH_3-N)

Free ammonia is formed as an initial product due to the decomposition of nitrogenous organic matter. The ammonia concentration obtained for the effluent (8.2 mg/l) was above the Ghana EPA guideline value of 1.0 mg/l as shown in figure 4.12. The increased value could be due to the anaerobic decomposition with the liberation of ammonia, Okoh (2010). The obtained value is comparably favourable to other waste treatment plants such as one at Santa Rosa Laguna district with the discharge of ammonia concentration of 10 mg/l. It is however not in agreement with a discharge of 1.4 mg/l by plant at the Montecito Sanitary District, California, USA (Asano and Tchobanoglous, 1987).

The mean ammonia removal efficiency after phytoremediation was 89 %, 76.2 %, 75.9 and 98.2 % for Water Hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendix A, B, C, and D). Kulasekaran *et al*., 2014, reported high percentage reduction of 97.2-99.2% in ammonia after phytoremediation of sewage with *Ceratophyllum demersum*. In comparison with reported work by Sangeetha (2007), in which macrophytes such as *Hydrilla verticillata*, *Eichhornia crassipes*, Solms-Laub. (Water hyacinth), *Pistia stratiotes* L. (Water lettuce) and *Lemna minor* L. (Duckweed) were used, this work proves to be very significant and the aquatic plants showed excellent activity. Hence, the phytoremediation potential of the selected plants with regards to ammonia-nitrogen can be reported in a decreasing order as follows: *Ceratophyllum* > Water Hyacinth > Mimosa > *Lemna*.

5.4.4 Phosphate-Phosphorus (PO_4-P)

The recorded mean effluent concentration discharged was 14.5 mg/l. This was found to be higher than Ghana EPA guideline value of 2.0 mg/l and hence final effluent was found to be unsatisfactory.

A study by Fosu (2009), on the KNUST Sewage Treatment Plant showed a similar high concentration of phosphate (ie 12.20 mg/l) in effluent. It was also observed that the plant was fed with sewage above its capacity. The plant was designed to receive about 500m^3 of sewage daily but received over 800 m^3 of sewage daily due to the increase in student populations on campus.

Phosphorus is the only plant nutrient that can trigger plant growth when introduced into an aquatic environment (Nkegbe *et al*., 2005). Nitrogen and phosphorus interact to produce large standing crops of algae (Mason, 1996). When added singly, phosphorus caused increase in standing crops of algae, whereas nitrogen alone did not elicit a response (Mason, 1996). This showed that phosphorus controls the growth of phytoplankton hence its limitation reduces the problem of eutrophication. A concentration of 0.01 mg/L phosphorus can result in eutrophication (Nkegbe *et al*., 2005). Hence the high phosphate concentration in the final effluent would promote the growth of algae in water bodies.

The process of phytoremediation yielded removal efficiencies of 57.5 %, 62.8 %, 53.4 % and 61.7 % for Water Hyacinth, Mimosa, *Lemna* and *Ceratophyllum* respectively (Appendix A, B, C, and D) which is indicative of ability to remove phosphates from sewage effluent. The removal efficiency in decreasing order as shown in this work is as follows: Mimosa > *Ceratophyllum* >Water Hyacinth > *Lemna*.

5.5 Removal of Heavy Metals

The general decrease in the heavy metal concentrations shows that all the aquatic plants (Water hyacinth, *Ceratophyllum*, *Lemna* and Mimosa) were effective at phytoremediating all the metals investigated, even though there were differences in their removal efficiencies. This is consistent with other works done by Keskinkan *et al*., (2004) in Turkey which indicated that *C. demersum* was capable of removing lead, zinc, and copper from solution. Similarly, Mishra and Tripathi, (2008) also reported that *E. crassipes* was the most efficient among other two aquatic plants (*P. stratiotes* and *S. polyrrhiza*.) for the removal of selected heavy metals (Fe, Zn, Cu, Cr and Cd).

Whiles lead, nickel and iron were highest removed by *C. demersum*, zinc and copper were highest removed by *Lemna* and Cadmium was best removed by water hyacinth. The differences could be associated with the differences in individual plant affinity to these metals.

Nonetheless the water hyacinth and mimosa showed some signs of wilting indicating intoxication. This could be attributed to the high concentration of the metals in the effluent. High concentrations of zinc often result in inhibited photosynthesis and have been shown for plants cultivated at enhanced concentrations (Mishra and Tripathi, 2008). Similarly Cd^{2+}

ions are readily taken up by roots and translocated into the leaves in many plants, and could depress growth in high concentrations by affecting photosynthesis, chlorophyll fluorescence and nutrient uptake by plants. Copper is also reported to inhibit the biological processes of aquatic macrophytes (Satyakala and Jamil, 1992).

5.6 Microbial Quality

Most pathogenic microorganisms remain in sewage sludge; however, some of them together with the resultant effluent can reach the environment. A decreased value in the microbial population density was observed in the effluent from the biogas facility and it was slightly above the limit set by the EPA (100 cfu/100ml) for FC and therefore unsatisfactory for discharge into natural water bodies. The facility, however, recorded lower values for TC and THB. These reductions are best accomplished by adhesion; microbes attach themselves to suspended solids to either be filtered or separated through sedimentation, adsorption and predatory activities of predator micro-organisms such as explained by the nematodes and protozoas which attach themselves to the filter media within the trickling filters (Kawamura and Kaneko, 1986). Those micro-organisms act on other microbes and other organic constituents of sewage to reduce their pollution levels.

The ability of phytoremediation to reduce microbial load in sewage effluent tested in this study is generally of high removal efficiencies (Appendix A, B, C, D). Phytoremediation removal efficiencies of microbes from sewage effluent based on this study for FC, TC and THB is *Ceratophyllum* > *Lemna* > Water Hyacinth > Mimosa. This is could be explained in line with Mandi *et al*., (1993). According to them macrophyte populations (such as water hyacinths) in wetlands, sedimentation, predation and death play an important role in the reduction in micro-organisms. Molleda *et al*., (2008) in their work also confirmed the idea by saying that the reduction in the indicator micro-organisms TC and *E. coli* in treatment system may be a consequence of biological factors such as nematode and protozoan predation, bacterial lysis caused by bacteriophages, chemical factors such as oxidation reactions, absorption, or exposure to plant and microbial toxins.

5.7 Socio-Economic Survey

The success of the reuse projects is directly related to public knowledge and acceptance (Po et al., 2003). The public's opinion is important in the planning, constructing, and operating stages for wastewater reclamation and reuse facilities.

Robinson *et al*., (2005), reported that both men and women view the use of wastewater for possible consumption or applications involving close, personal contact unfavorably. This has been confirmed in this work where both genders felt that wastewater reuse for applications not involving close personal contact was acceptable.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Based on the study conducted to determine the quality of the sewage effluent, assess the phytoremediation potential of some selected aquatic plants in treating it and assess public acceptability of the treated sewage effluent for reuse, the following conclusions have been made:

- The treated effluent from the biogas plant did not meet most of the criteria set by EPA of Ghana. Values for parameters such as EC, TSS, TDS, COD, Phosphate, Nitrate, Nitrite, Ammonia, Faecal coliform, THB and the heavy metals used to assess the quality of the effluent were higher than the Ghana EPA standard. However parameters such as temperature, pH, BOD and Total coliform were satisfactory.
- All aquatic plants studied namely *Eichhornia crassipes* (Water hyacinth), *Lemna minor* (Duckweeds), *Neptunia* oleracea (Water mimosa) and *Ceratophyllum demersum* (Coontail) showed remarkably removal efficiencies for all the parameters studied.
- The ability to remove contaminants were shown in a decreasing order by plants as *Ceratophyllum demersum* (Coontail) > *Eichhornia crassipes* (Water hyacinth) > *Lemna minor* (Duckweeds) > *Neptunia* oleracea (Water mimosa).
- Even though removal efficiencies were generally high for the all the plants, the sewage effluent under such treatment as phytoremediation could still not meet EPA guidelines for discharged into the environment with respect to parameters such as EC, TDS, Nutrients (phosphates, nitrates, ammonia), Coliform (especially faecal

coliforms) and Heavy metals (Cd, Pb, Ni). Hence treated effluent was not satisfactory.

- In determining the public's opinion regarding water reuse applications, it can be concluded that the public is most concerned about the health risks of recycled water. In addition, the public want to know about the health implications and food safety implications of recycled water when it is used for irrigating food crops. The most alarming subject for public opinion concerned the presence of pathogen and harmful microorganisms in water even after the treatment process.
- Both genders felt that wastewater reuse for applications not involving close personal contact (such as firefighting, car washing, lawn irrigation and agricultural uses) was acceptable.

6.2 Recommendations

- Further treatment is required for effluent from the Valley View University biogas facility to meet EPA guidelines for discharge into the environment
- Further studies could be performed to determine effect of having different combination of plants working together to effect phytoremediation as a means of making the plants more effective in cleaning to the point where the treated sewage effluent could be considered suitable for discharge or reuses purposes.
- Phytoremediation of sewage effluent should not necessarily be done for very long period of time since most of the contaminants were mostly removed in the first three weeks as this study has shown.

- More extensive survey work using large sample size should be done to achieve more accurate results to aid in-depth quantitative analyses of public acceptance of treated wastewater for reuse.
- Both Government institutions and Non-governmental organizations should increase effort to raise awareness for the public and effective policy initiatives should be implemented.
- Since the media (television, radio, newspaper, etc.) is the most dominant method of informing communities, more informative programs should be conducted using the media outlets especially radio and television.

REFERENCES

Abbasi, S. A., (1987). Aquatic Plant Based Water Treatment Systems in Asia, Aquatic Plants for Water Treatment and Resource Recovery, K. R. Reddy (Ed.), Magnolia Publishers Inc., Orlando, FL., USA

Abou-Shenab, R.; Ghanem, N.; Ghanem, K.; Al-kolaibe, A. (2007). Phytoremediation potential of crop & wild plants for multi-metal contaminated soils Res. J. Agric. Bioll. Sci, 3 (5): 370-376

Accra Millennium City: Summary Profile, April 2011: Policy Initiatives and Projects and Achievements: and Investment Opportunities.

Adewumi J.R., Ilemobade A.A., Van Zyl J.E. (2010). Treated wastewater reuse in South Africa: Overview, potential and challenges Resources, Conservation and Recycling *55 (2010) 221–231*

Agbozo, S. K., Huibers, F.P., Chenini, F, Van Lier, J.B., Duran, A. (2003), "Use of wastewater in irrigated agriculture, country studies from Bolivia, Ghana and Tunisia", Volume 2: Ghana, Wageningen, WUR (W4F-wastwater).

Agriculture and Agri-food Canada (2000). The Health of our Water towards Sustainable Agriculture in Canada. Agriculture and Agri-Food Canada, Ottawa, Canada.

Ahmed, A. and Sorensen, D.L., (1995). Kinetics of pathogen destruction during storage of Biosolids. Water Env. Res. 67 (2) 143-150.

Akinbile C.O., Yusoff S.M., (2012). Int. J. of Phyto., 2012, 14, 201 – 211.

Alade G.A., Ojoawo S.O., (2009). Purification of Domestic Sewage by Water-Hyacinth (*Eichhornia Crassipes*). Int J of Environ Tech Manage 10 (3/4):286–294.

Alkorta, I., Hernandez-Allica, J., Becerril, J., Amezaga, I., Albizu, I., Garbisu, C., (2004). Recent findings on the phytoremediation of soils contaminated with environmentally toxic heavy metals and metalloids such as zinc, cadmium, lead, and arsenic. Rev. Environ. Sci. Biotechnol. 3, 71–90

Amoah, P., (2008). An Analysis of the Quality of Wastewater Used to Irrigate Vegetables in Accra , Kumasi and Tamale, Ghana. Chapter 6. Agriculture in Urban Planning. Generating Livelihoods and Food Security. Published by Earthscan & International Development Research Centre (IDRC), 2009 | ISBN 978-184407668

Annang E.A. (2000). Assessment of Water Quality of Two Wetlands- Chemu and Laloi Lagoons- in the Tema Export Processing Zone. KNUST, Kumasi. MSc. Thesis, pp 17-60.

APHA (1998). Standard Methods for Examination of Water and Wastewater. 20th ed. American Public Health Association, Washington, DC, USA

APHA, AWWA, WEF (1995). Standard Methods for the Examination of Water and Wastewater. 19th edition, pp 2.1-2.3, 2-56.

American Public Health Association (APHA), (1995). Standard Methods for the Examination of Water and Wastewater. 19th Edition. Prepared and Publushed jointly by American Public Health Association, American Water Works Association and Water Environment Federation Washington DC USA. Pg 4 -91

American Public Health Association (1989). Standard Methods for the Examination of Water and Wastewater. APHA, Washington, USA.17th Edition American Public Health Association, Washington DC. 1,268 pp.

Asano, T. and Tchobanoglous G. (1987). Municipal wastewater treatment and effluent utilization for irrigation. Paper prepared for the Land and Water...

Asano, T., Maeda, M. and Takaki, M., (1996). Wastewater reclaimation and reuse in Japan: Overview and implementation examples. Wat.Sce. Tech. 34(11), 219-226.

Awuah, E. and Abrokwah, K. A., (2008). Performance Evaluation of the UASB treatment plant at James Town (Mudor), Accra. A paper presented at the 33rd WEDC Conference, Accra, Ghana.

Azeez N.M., and Sabbar A.A., (2012). Efficiency of Duckweed (Lemna minor L.) in Phytotreatment of Wastewater Pollutants from Basrah Oil Refinery. Journal of Applied Phytotechnology in Environmental Sanitation, 1 (4): 163-172.

Bahri.A, Basset C., Oueslati F., (2001). Reuse of reclaimed wastewater for golf course irrigation in Tunisia. Wat.Sci.Tech. 43(10):117-124

Baran E.M.R., (2008). Treatment of Reject Water, Thesis Submitted to the Graduate School of Natural and Applied Sciences of Dokuz Eylül University, In Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Engineering, Environmental Technology Program.

Barcelo, J., Poschenrieder, C., (2003). Phytoremediation: principles and perspectives. Contrib. Sci. 2, 333–344.

Beychok, M.R. (1971). "Performance of surface-aerated basins". Chemical Engineering Progress Symposium Series **67** (107): 322–339. CSA

Brown, D.H., D. Mountain.(1998). Wastewater reuse as cooling tower makeup- a poineering case study in Maryland. Proceedings of the 1998 91st Annual meeting and exposition of the Air and waste Management Association. San Diego, CA.

Chapman D. and Kimstach V. (1992). The Selection of Water Quality Variables. In: Water Quality Assessment- A Guide to the use of Biota, Sediment and Water in Environmental Monitoring. D. Chapman (Ed) published on behalf of UNESCO, WHO and UNEP, pp 60-116

Chapman, D. (1992). “Water Quality Assessment: A Guide of the use of Biota, Sediments and Water in Environmental Monitoring”. University Press, Cambridge, pp: 585.

Cheng J.; Landesman, L.; Bergmann, B.A.; Classen, J.J.; Howard, J.W.; Yamamoto, V.T. (2002). Nutrient removal from swine lagoon liquid by Lemna minor 8627. Transctions of the ASAE 45, 1003-1010.

CISRO, (2006). Literature review: Sources of critical contaminants in domestic wastewater. 55pp. (http//www.cisro.au). Accessed 4th January, 2011.

Clark, T. Stephenson, T. Pearce, P. A., (1997). Phosphorus removal by chemical precipitation in a biological aerated filter. Water Res., 31(10), 2557-63.

Colmenarejoa, M.F., Rubioa, A., Sancheza, E., Vicenteb, J., Garcıa M.G. and Borja, R. (2006). Evaluation of municipal wastewater treatment plants with different technologies at Las Rozas, Madrid (Spain). J. Environ. Manage., 81: 399-404.

Cornish, G.A., Aidoo, J.B., and Ayamba, I., (2001). Informal Irrigation in the Peri-urban zone of Kumasi, Ghana. An Analysis of Farmer Activities and Productivity. Report OD/TN 103, February 2001. DFID's Water KAR Project R7132, HR Wallingford, UK, 39 pp.

Crook, J. (1999). Indirect potable reuse. Water Environmental &Technology. May, 1999,71-75.

Dar S.H., Kumawat D.M., Singh N., Wani K.A., (2011). Res. J. of Env. Sci., 2011, 5, 377 – 385.

Doty, S.L., Shang, Q.T., Wilson, A.M., Moore, A.L., Newman, L.A., Strand, S.E., (2007). Enhanced metabolism of halogenated hydrocarbons in transgenic plants containing mammalian P450 2E1. Proc. Natl. Acad. Sci. USA 97, 6287–6291.

Drinan & Whiting, (2001). Water & Wastewater Treatment: A Guide for the Nonengineering Professional, Technomic Pub Co, 240p

Environment Canada (2006). 'Municipal wastewater sources and characteristics', www.atl.ec.gc.ca/epb/issues/wstewtr.html. (Accessed 14/01/2011)

Environmental Guidelines, October (2004). Use of effluent by irrigation, Department of Environment and Conservation (NSW), Sydney.

Erakhrumen, A. A., (2007). Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries. Edu. Res. Rev. 2, 151–156.

Federal Water Pollution Control Administration (FWPCA), (1968). Water Quality Criteria. Report of the National Technical Advisory Committee to the Secretary of the Interior. U.S. Government Printing Office.

Fischnetz, (2004). On the trail of declining fish stock EAWAG/SAEFL. Dubendorf, Berne 25pp

Flathman, P.E. and Lanza, G.R., (1998). Phytoremediation: current views on an Emerging Green Technology, Journal of Soil Contamination, vol. 7, No. 4, 415-432.

Food and Agricultural Organization (FAO), (1992). Wastewater Treatment and Use in Agriculture; Irrigation and Drainage Paper 47.

Forni C, Chen J, Tancioni L, Grilli C.M. (2001a). Evaluation of the fern Azolla for growth, nitrogen and phosphorus removal from wastewater. Water Res 35: 1592–1598.

Forni C, Nicolai MA, D'Egidio M.G. (2001b). Potential of the small aquatic plants Azolla and Lemna for nitrogenous compounds removal from wastewater. In: Brebbia CA, editors. Water pollution. Vol. VI: Modeling, measuring and prediction. Southampton, Boston: WIT Press. pp. 315–324.

Fosu A., (2009). Assessing the Efficiency of KNUST Sewage Treatment Plant, MSc Thesis submitted to the Department of Theoretical and Applied Biology, KNUST.

Freid, J. J. (1991). Nitrates and their control in the EEC aquatic environment. In: *Nitrate Contamination, Exposure, Consequences and Control*, Borgadi, I., and Kuzelka, D. (eds.), NATO ASI Series G30, Ecological Sciences. Springer-Verlag, Berlin.

Gamage N.S., Yapa P.A., (2001). Use of water hyacinth (*Eichhornia crassipes (Mart) solms*) in treatment systems for textile mill effluents. A case study. J Natn Sci Foundation Sri Lanka 29(1&2):15–28.

Gerard, M.; Jean-Luc, P.; Thierry, L. (2002). Performances of constructed wetlands for municipal wastewater treatment in rural mountainous area. Hydrobiologia 469, 87-98.

Ghana Statistical Service (2012), "2012 Population and Housing Census", Summary report of provisional results, Accra, Ghana.

Ghosh, M., Singh, S.P., (2005). A review on phytoremediation of heavy metals and utilization of it's by products. Appl. Ecol. Environ. Res. 3, 1−18.

Greenberg, Arnold E. (Ed), Lenore Clesceri, E. (Ed), Andrew Eaton, D. (Ed) (1992). Standard Methods for the Examination of Water and Wastewater, 18TH Edition, American Public Health Association Washington, America Water Works Association and Water Environment Federation. Victor Graphics, Inc., Baltimore, Maryland. pp 170-290.

Gunnarsson, C.C.; Petersen, C.M. (2007). Water hyacinths as a resource in agriculture and energy production: A literature review. Waste Management, 27 (1): 117-129.

Henry, J.R. (2000). In An Overview of Phytoremediation of Lead and Mercury. NNEMS Report. Washington, D.C., 3-9.

Hodgson O. A. Isaac, (2000). Treatment of domestic sewage at Akuse (Ghana). Water S A Vol. 26 No. 3

Horne, A. J. (1995). Nitrogen Removal from Waste Treatment Pond or Activated Sludge Plant Effluents with Free Surface Wetlands. Water Science and Technology 31(12):341-351.

Huang, J.W. and Cunningham, S.D., (1996). Lead phytoextraction: Species variation in lead uptake and translocation. New Phytologists, vol. 134, p. 75-84.

Huang, J.W.; Chen, J.; Berti, W.R. and Cunningham, S.D., (1997). Phytoremediation of lead contaminated soil: role of synthetic chelates in lead phytoextraction. Environmental Science and Technology, vol. 31, no. 3, 800-805.

Integrated Urban Water Management in Accra, Institutional arrangements and Map, August 2010.

Jain, D.K. (2000). Water hyacinth-A Potential Provider In: Srivastava, P: ed. Environmental Pollution and its Managament. New Delhi, India. A.P.H. Publishing Corporation. 120-127.

Juanico, M., Friedler, E., (1999). Wastewater reuse for river recovery in semi-arid Isreal. Wat. Sci.Tech. 40(4-5):43-50.

Kagya, A. W., (2011). Determination of Effluent Quality of two Wastewater Treatment Systems: An Activated Sludge Sewage Treatment Plant And Waste Stabilization Ponds at Juapong, KNUST MSc Thesis.

Kawamura K. and Kaneko M., (1986). Microbial quality of human wastes and treatment plant effluent. Water Science Technology. Vol. 18, pp: 257.

Keskinkan, O., Goksu, M.Z.L., Basibuyuk, M. & Forster, C.F., (2004). Heavy metal adsorption properties of a submerged aquatic plant (*Ceratophyllum demersum*). *Bioresource Technology* (92) 197–200

Knasmuller, S., Gottmann, E., Steinkellner, H., Fomin, A., Pickl, C., Paschke, A., God, R., and Kundi, M. (1998). Detection of genotoxic effects of heavy metal contaminated soils with plant bioassay. *Mutat Res.,* 420, 37– 48.

Korner, S.; Lyatuu, G.B. and Vermaat, J.E. (1998). The influence of Lemna gibba L. on the degradation of organic material in duckweed covered domestic wastewater. Water Res., 32, 3092-3098.

Korner, S. and Vermaat J.E. (1998). The relative importance of Lemna gibba L. bacteria and algae for the nitrogen and phosphorus removal in duckweed covered domestic wastewater. Water Res., 32, 3651-3661.

Korner, S.; Vermaat J.E. and Veenstra, S. (2003). The capacity of duckweed to treat wastewater. J. Environ. Qual., 32 1583-1590

Kuiper, I., Lagendijk, E.L., Bloemberg, G.V., Lugtenberg, B.J.J., (2004). Rhizoremediation: a beneficial plant-microbe interaction. Mol. Plant-Microbe Interact. 17, 6−15.

Kulasekaran A., Andal G., John A. J., (2014). A study on the removal efficiency of organic load and some nutrients from sewage by *Ceratophyllum Demersum*-L. J. Mater. Environ. Sci. 5 (3) (2014) 859-864.

Kumar G.P and Prasad M.N.V., (2004). Cadmium-inducible proteins in Ceratophyllum demersum L. (a fresh water macrophyte): toxicity bioassays and relevance to cadmium detoxification. Bull. Environ. Contam. Toxicol. 73:174-181.

Kutty R.M.S, Ngatenah N.I.B.S., Mohamed H.I., Amirhossein M., (2009). Wor. Aca. of Sci. Eng. Tec., 2009, 60, 1115 – 1123.

Lasat, M. M., Fuhrmann, M., Ebbs, S. D., Cornish, J. E. & Kochian, L.V., (1998). Phytoremediation of a radio cesium contaminated soil: evaluation of cesium-137 bioaccumulation in the shoots of three plant species. Journal of Environmental Quality, vol. 27, no. 1, 165-168.

Lorber, M.N.; Mishoe, J.W.; Reddy, P.R. (1984). Modelling and analysis of water hyacinth biomass. Ecol. Model. 24, 61-77.

Mason C. F., (1996). Biology of Freshwater Pollution. 3rd edition, Longman, England, pp: 119

Mahmood, Q., Zheng, P., Islam, E., Hayat, Y., Hassan, M.J., Jilani, G. and Jin, R.C., (2005). Lab scale studies on water hyacinth (Eichhornia crassipes marts solms) for biotreatment of textile wastewater. Caspian J. Env. Sci., 3(2), 83-88.

Mahmut, O. Ayhan, S., (2003). Effect of tannins on phosphate removal using alum. Turkish J. Eng. Environ. Sci., 27, 227-236.

Mandi, L., Ouazzani, N., Bouhoum, K., Boussaid, A., (1993). Wastewater treatment by stabilization ponds with and without macrophytes under arid climate. Water Sci. Technol. 28 (10), 177–181.

Manousaki, E., Kalogerakis, N., (2011). Halophytes present new opportunities in phytoremediation of heavy metals and saline soils. Ind. Eng. Chem. Res. 50, 656–660.

Mesjasz-Przybylowicz, J., Nakonieczny, M., Migula, P., Augustyniak, M., Tarnawska, M., Reimold, W.U., Koeberl, C., Przybylowicz, W., Glowacka, E., (2004). Uptake of cadmium, lead, nickel and zinc from soil and water solutions by the nickel hyperaccumulator Berkheya coddii. Acta Biol. Cracov. Bot. 46, 75–85.

Metcalf and Eddy Inc. (1991). Wastewater Engineering: Treatment, Disposal, Reuse. 3rd Edition. McGraw-Hill, New York.

Mezrioui, N. and B. Baleux (1994). Resistance patterns of E. Coli strains isolated from domestic sewage before and after treatment in both aerobic lagoon and activated sludge. Water Research 28, 2394-2406

Mishra, V. K. & Tripathi, B.D., (2008). Concurrent removal and accumulation of heavy metals by the three aquatic macrophytes. Bioresource Technology (99) 7091–7097.

Mitchell, M. K. and Stapp W. B. (1992). Field Manual for Water Quality Monitoring.

Molleda P., Blanco I., Ansola G., De Luis E., (2008). Removal of wastewater pathogen indicators in a constructed wetland in Leon, Spain. Ecological Engineering 33 (2008) 252–257.

Morrison, G.; Fatoki, O. S.; Persson, L.; Ekberg, A., (2001). Assessment of the impact of point source pollution from the Keiskammahoek Sewage Treatment Plant on the Keiskamma River–pH, electrical conductivity, oxygen demanding substance (COD) and nutrients. Water SA., 27 (4), 475-480 (6 pages).

Middlebrooks, E.J. Reed, S.C. and Crites, R.W. (1988). Natural Systems for Waste Management and Treatment. McGraw HillBook Co., New York.

Mukhopadhyay, S., Maiti, S.K., (2010). Phytoremediation of metal enriched mine waste: a review. Global J. Environ. Res. 4, 135–150.

Newman, L.; Strand, S.; Choe, N.; Duffy, J.; Ekuan, G.; Ruszaj, M.; Shurtleff, B.; Wilmoth, J.; Heilman, P. and Gordon, M. (1997). Uptake and biotransformation of trichloroethylene by hybrid poplars. Environ Sci Tech., 31, 1062-1067.

Nkegbe E., Emongor V and Koorapetsi I (2005). Assessment of Effluent Quality at Glen Wastewater Treatment Plant. Journal of Applied Sciences 5 (4): 647 – 650.

Obuobie E, Keraita B., Danso G., Amoah P., Cofie O., Raschid-Sally L. and Drechsel P., (2006). Irrigated Urban Vegetable Production in Ghana: Characteristics, Benefits and Risks. IWMI - RUAF – CPWF

Okoh, A. E. (2010). Water Auditing of a Ghanaian Beverage plant, pp 115

Okun, D. A. (1997).Distributing reclaimed water through dual systems.AWWA,89:11:52.

Padmavathiamma, P.K., Li, L.Y., (2007). Phytoremediation technology: hyperaccumulation metals in plants. Water Air Soil Pollut. 184, 105–126.

Pearson, H.W., Mara, D.D., Mill, S.W. and Smallman, D.J. (1992). Physicochemical Parameters influencing Faecal Bacteria Survival in Waste Stabilization Ponds. Wat. Sci. Tech. 19(12) 145-152. Great Britain.

Pearson, H.W., Mara, D.D. and Bartone, C.R., (1987). Guidelines for the minimum evaluation of the performance of full-scale waste stabilization ponds. *Water Research* 21 (9), 1067−1075.

Pilon-Smits, E., (2005). Phytoremediation. Annu. Rev. Plant Biol. 56, 15–39.

Pivertz E, Bruce (2001). Phytoremediation of Contaminated Soil and Ground Water at Hazardous Waste Sites. Environmental Research Services Corporation. EPA/540/S-01/500.

Po M., Kaercher J.D., Nancarrow B.E., (2003). Literature Review of Factors Influencing Public Perceptions of Water Reuse. Australia: CSIRO Land and Water; 2003, Technical Report 54/03.

Polprasert, C.; Khatiwada, N.R., (1998). An integrated kinetic model for water hyacinth ponds used for wastewater treatment. Water Res. 32, 179-185.

Pankratz, T. M. (2000). Environmental Engineering Dictionary and Directory, Lewis Publishers, Boca Raton, London, New York Washington D.C.

Prasad, M.N.V. (2004). Phytoremediation of metals and radionuclide in the environment: To ecosystem (2nd edn.). Springer-Verlag, Heidel Berg. 345-392.

Rafati, M., Khorasani, N., Moattar, F., Shirvany, A., Moraghebi, F., Hosseinzadeh, S., (2011). Phytoremediation potential of Populus alba and Morus alba for cadmium, chromuim and nickel absorption from polluted soil. Int. J. Environ. Res. 5, 961– 970.

Raschid-Sally, L. and Jayakody, P. (2008) 'Drivers and characteristics of wastewater agriculture in developing countries: Results from a global assessment, Colombo, Sri Lanka', IWMI Research Report 127, International Water Management Institute, Colombo).

Ravindran, K.C., Venkatesan, K., Balakrishnan, V., Chellappan, K.P., Balasubramanian, T., (2007). Restoration of saline land by halophytes for Indian soils. Soil Biol. Biochem. 39, 2661–2664.

Reed, S.C. and Brown, D.S. (1995). Subsurface flow wetlands-A performance evaluation. Water Environment Research, 67, 244-248.

Robinson K, Robinson C, Hawkins S., (2005). Assessment of public perception regarding wastewater reuse. Water Sci Technol 2005;5(1):59–66.

Rogers K.H., Breen P.F., Chick A.J., (1991). *J. of Wat. Pol. Con. Fed.*, 1991, 63, 934 – 941.

Rose, A.E.S.; (2000). Studies on waste water treatment by Lemna minor, J Environ Biol, 21, 43.

Rugh, C.L.; Bizily, S.P. and Meagher, R.B. (2000). Phytoremediation of environmental mercury pollution. In: Raskin, I. and Ensley, B.D., eds. Phytoremediation of toxic metals: using plantsto clean-up the environment. New York, John Wiley and Sons, 151-170.

Runion, R. (2010). Wastewater Color - How to Use Color to Test Wastewater: (http://ezinearticles.com/?Wastewater-Color---How-to-Use-Color-to-Test-Wastewater&id=3718174 - Feb 08, 2010). Accessed 1st March, 2011

Russell D.L. (2006). Practical Wastewater Treatment. John Wiley & Sons, Inc., Hoboken, New Jersey. Pp 39-88

Sakai, Y., Ma, Y., Xu, C., Wu, H., Zhu, W., Yang, J., (2012). Phytodesalination of a salt affected soil with four halophytes in China. J. Arid Land Stud. 22, 17–20.

Salt D.E.; Smith R.D. & Raskin I.; (1998). Phytoremediation, Annu. Rev. Plant Physiol Plant Mol Biol, 49 643.

Samuelsson P., (2005). Control of Nitrogen Removal in Activated Sludge Process. PhD Dissertation from the Sicence and Technology Faculty of Uppsala University, Sweden. 64-156pp. ISBN 91-554-6311-8.

Sangeeta D., (2007). Role of Macrophytes in improving water quality of an aquatic eco-system. J Appl Sci Environ Manage 11(4):133–135.

Satyakala, G., Jamil, K., (1992). Chromium induced biochemical changes in Eichhornia crassipes (Mart) Solms.and Pistia stratiotes L.. Bull. Environ. Contam. Toxicol. 48, 921–928.

Sedlak, R., (1991). Phosphorus and nitrogen removal from municipal wastewater: Principles and practice. Lewis publishers, USA.

Sekara, A., Poniedzialeek, M., Ciura, J., Jedrszczyk, E., (2005). Cadmium and lead accumulation and distribution in the organs of nine crops: implications for phytoremediation. Pol. J. Environ. Stud. 14, 509–516.

Singh, S., (2012). Phytoremediation: a sustainable alternative for environmental challenges. Int. J. Gr. Herb. Chem. 1, 133–139.

Sinton, L.W. and Donnison A. M., (1994). Characteristics of faecal streptococci from some New Zealand effluents and receiving water. New Zealand Journal of Marine Freshwater Research 28, 145-158.

Shah M., Hashmi H. N., Ali A., Ghumman A. R., (n.d). Performance assessment of aquatic macrophytes for treatment of municipal wastewater

Shaw, B., Mechenich C., and Klessig L., (2000). Understanding Lake Data. Board of Regents of the University of Wisconsin System doing business as the division of Cooperative Extension of the University of Wisconsin – Extension. Retrieved 03/03/11 (www.casonassociates.com/downloads/impacts.pdf) Impacts of Aeration on Effluents TSS in Stormwater Ponds.

Slaats, L.P.M., Rosenthal, W.G., Siegers, M., Van Den Boomen, Beuken, R.H.S and Vreeburg, J.H.G. (2003). AWWARF Report no.90966F Processes involved in the generation of Discolored Water, AWWARF.

Sooknah H, (2000) *Sci. Tech. – Res. J.* 2000, 6, 49 – 57.

Tel-Or E., Sela M., Ravid S., (1997). Biofiltration of heavy metals by the aquatic fern Azolla. In: Rosen D, Tel-Or E, Hadar I, Chen Y, editors. Modern agriculture and the environment. London: Kluwer Academic Publisher. pp. 431–442.

Tchobanologous, G., Burton, F.L. and Stensel, H. D. (2003). Wastewater Engineering Treatment and Reuse, 4th Edition, Mc Graw Hill, Boston, U.S.A. pp 47-111.

UN-EASCWA, (2003). United Nations-Economic and Social Commission for Western Asia. Waste-water treatment technologies: A general review pp 122

Upadhyay, A.R.; Mishra, V.K.; Pandey, S.K.; Tripathi, B.D. (2007). Biofilteration of secondary treated municipal wastewater in a tropical city. Ecological Engineering 30, 9-15.

Vangronsveld, J., Herzig, R., Weyens, N., Boulet, J., Adriaensen, K., Ruttens, A., Thewys, T., Vassilev, A., Meers, E., Nehnevajova, E., Van der Lelie, D., Mench, M., 2009. Phytoremediation of contaminated soils and groundwater: lessons from the field. Environ. Sci. Pollut. Res. 16, 765–794.

Vishnoi, S.R., Srivastava, P.N., (2008). Phytoremediation-green for environmental clean. In: The 12th World Lake Conference, pp. 1016–1021.

Weis, J.S.; and Weis, P., (2004). Metal uptake, transport and release by wetland plants: implications for phytoremediation and restoration. Environ. Intl. 685-700.

WHO, (1985). Guidelines for Drinking-water quality Vol 3. Drinking –water quality Control in small – community supplies. Geneva WHO 121p ISBN 92 – 154170-9.

Wolverton BC, McDonald RC. (1979). Water hyacinth (*Eichhornia crassipes*) productivity and harvesting studies. Econ Bot 33:1–10.

Wuana, R.A., Okieimen, F.E., (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. ISRN Ecology 2011, 1–20.

Yadav, R., Arora, P., Kumar, S., Chaudhury, A., (2010). Perspectives for genetic engineering of poplars for enhanced phytoremediation abilities. Ecotoxicology 19, 1574–1588.

Yang, D.Q.; Jing, Y.X.; Chen, Z.P.; Cheng, H.Q. (2001). Study on the removal effect and regulation of Cleistocalyx operculatus to N and P in a eutrophic water body. Acta Scientiae Circumstantiae, 21 (5): 637-639.

Yoon, J., Cao, X., Zhou, Q., Ma, L.Q., (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Sci. Total Environ. 368, 456–464.

Zimmels Y, Kirzhner, F Malkovskaja A. 2006. Application of Eichhornia crassipes and Pistia stratiotes for treatment of urban sewage in Israel. J Environ Manage 81(4):420–428.

Zimmo, O.R., VanDerSteen, N.P., and Gijzen, H.J., (2005). Effect of Organic Surface Load on Process Performance of Pilot Scale Algae and Duckweed Based Waste Stabilization Ponds. J. Environ. Engg. 131: 94- 587.

Zorrig, W., Rabhi, M., Ferchichi, S., Smaoui, A., Abdelly, C., (2012). Phytodesalination: a solution for salt-affected soils in arid and semi-arid regions. J. Arid Land Stud. 22, 299–302.

APPENDDICES

APPENDIX A

PHYTOREMEDIATION OF SEWAGE EFFLUENT USING *EICHHORNIA CRASSIPES* (WATER HYACINTH)

		WEEKS							
Parameter	**Before**	**1**	**2**	**3**	**4**	**5**	**6 (After)**	**EPA Guidelines, 2000**	**% Reduction**
Ph	7.47	7.45	5.5	6.86	6.6	6.5	6.57	6-9	12
Temperature (°C)	27.3	27.4	29.6	25.3	28.2	26.7	29.2	<30 (Above ambient)	
Conductivity (µS/cm)	6613	2337	3410	6468	6023	5244	4600	1500	30.4
DO (mg/l)	3.8	4.5	5.1	5.9	6.1	6.5	6.7	<1	
BOD (mg/l)	38	29	24	19	14	10	6	50	84.2
COD (mg/l)	640	580	420	310	215	195	150	250	76.6
TDS (ppm)	3310	1075	1705	3234	3012	2122	2300	1000	30.5
TSS (mg/l)	92	35	18	210	220	242	258	50	
Colour (PtCo)	576	18	377	392	422	645	742	-	
Turbidity (NTU)	48	5.3	8.4	13.6	23.6	38.4	55.3	75	
PO4 (mg/l)	14.5	5.98	5.38	5.28	5.21	4.82	4.16	2	57.5
NO_3-N (mg/l)	17.8	12.5	11	10.5	7.5	5.2	2.24	0.1	87.4
NO_2-N (mg/l)	9.5	6.3	5.1	4.2	2.1	1.4	0.076	3	99.2
NH_3-N (mg/l)	8.2	6.8	3.6	3.2	2.4	1.2	0.9	1.5	89
Total Coliform (cfu/100ml)	348	234	209	175	100	69	22	400	93.4
Faecal Coliform	101	65	45	30	21	12	8	0	92.1
THB (cfu/100ml)	1124	854	724	605	480	400	376		66.5
Ni (mg/l)	0.943	0.862	0.745	0.538	0.431	0.322	0.311	0.02	67
Cd (mg/l)	0.273	0.161	0.089	0.069	0.057	0.046	0.045	0.003	83.5
Fe (mg/l)	0.722	0.508	0.503	0.499	0.342	0.231	0.225	0.3	68.8
Zn (mg/l)	0.632	0.601	0.584	0.532	0.504	0.497	0.45	3	28.8
Cr (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.05	
Cu (mg/l)	2.24	1.93	1.88	1.85	1.81	1.77	1.75	2	21.9
Pb (mg/l)	1.122	0.862	0.664	0.364	0.221	0.18	0.12	0.01	89.3

APPENDIX B

PHYTOREMEDIATION OF FINAL SEWAGE EFFLUENT USING *NEPTUNIA OLERACEA* (WATER MIMOSA)

		WEEKS							
Parameter	**Before**	**1**	**2**	**3**	**4**	**5**	**6 (After)**	**EPA Guidelines, 2000**	**% Reduction**
pH	7.47	7.35	6.35	7.18	7.21	7.26	7.31	6-9	2.14
Temperature (°C)	27.3	26.7	29.6	25.2	27.4	29.2	29.9	<30 (above ambient)	
Conductivity (µS/cm)	6613	6180	5956	5576	4690	4480	4370	1500	33.9
DO (mg/l)	3.8	4.2	4.7	5.3	6.0	6.3	6.5	<1	
BOD (mg/l)	38	32	25	18	16	12	9	50	76.3
COD (mg/l)	640	608	576	425	386	320	200	250	68.8
TDS (ppm)	3310	3090	2978	2788	2345	2240	2685	1000	18.9
TSS (mg/l)	92	40	39	35	31	28	27	50	70.7
Colour (PtCo)	576	466	302	385	422	502	754	-	
Turbidity (NTU)	48	5.9	10.1	15.1	25.8	38.6	54.0	1000	
PO4 (mg/l)	14.5	9.88	7.22	6.21	5.88	5.36	5.4	2	62.8
NO3-N (mg/l)	17.8	13.7	10.8	8.4	5.2	3.6	1.6	0.1	91
NO2-N (mg/l)	9.5	5.208	3.022	1.129	0.982	0.521	0.023	3	99.8
NH3-N (mg/l)	8.2	6.74	5.22	4.63	3.35	2.66	1.95	1.5	76.2
Total Coliform (/100 ml)	348	307	215	194	160	95	65	400	81.3
Faecal Coliform (/100ml)	101	88	74	69	50	41	30	0	70.3
THB/ml	1124	995	902	945	889	860	844		24.9
Ni (mg/l)	0.943	0.843	0.782	0.664	0.601	0.588	0.547	0.02	41.9
Cd (mg/l)	0.273	0.201	0.189	0.164	0.137	0.116	0.105	0.003	61.5
Fe (mg/l)	0.722	0.689	0.602	0.595	0.583	0.412	0.333	0.3	53.9
Zn (mg/l)	0.632	0.611	0.584	0.502	0.486	0.431	0.382	3	39.6
Cr (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.05	
Cu (mg/l)	2.24	1.312	0.787	0.443	0.145	0.101	0.017	2	99.2
Pb (mg/l)	1.122	1.105	1.102	1.092	1.086	1.026	0.852	0.01	24.1

APPENDIX C

PHYTOREMEDIATION OF SEWAGE EFFLUENT USING *LEMNA MINOR* (DUCKWEED)

		WEEKS							
Parameter	**Before**	**1**	**2**	**3**	**4**	**5**	**6 (After)**	**EPA Guidelines, 2000**	**% Reduction**
Ph	7.47	7.71	6.84	6.39	6.45	6.8	6.64	6-9	11.1
Temperature (°C)	27.3	26.6	29.8	24.6	27.3	28.9	31.2	<30 (ABOVE AMBIENT)	
Conductivity (μS/cm)	6613	6596	5220	4321	3078	3624	3514	1500	46.9
DO (mg/l)	3.8	5.6	6.2	6.7	7.6	8.4	8.7	<1	
BOD (mg/l)	38	4.5	5.5	4.4	3.8	3	2.5	50	93.4
COD (mg/l)	640	624	619	614	501	512	480	250	25
TDS (ppm)	3310	3298	2610	2161	1539	1812	1757	1000	46.9
TSS (mg/l)	92	84	78	86	94	123	150	50	
Colour (PtCo)	576	294	682	534	431	388	366	-	36.5
Turbidity (NTU)	48	42	34	66.5	68.5	70.8	74.0	75	
PO4 (mg/l)	14.5	6.04	6.12	6.52	6.61	6.72	6.76	2	53.4
NO3-N (mg/l)	17.8	10.3	7.7	4.5	3.2	2.6	1.5	0.1	91.6
NO2-N (mg/l)	9.5	4.632	2.238	1.077	0.843	0.242	0.025	3	99.7
NH3-N (mg/l)	8.2	4.58	2.94	2.52	2.22	2.01	1.97	1.5	75.9
Total Coliform	348	30	54	35	28	20	12	400	96.6
Faecal Coliform	101	75	53	40	29	10	5	0	95
THB	1124	950	784	520	403	332	241		78.6
Ni (mg/l)	0.943	0.783	0.698	0.464	0.321	0.302	0.282	0.02	70.1
Cd (mg/l)	0.273	0.184	0.165	0.104	0.088	0.053	0.046	0.003	83.2
Fe (mg/l)	0.722	0.449	0.439	0.424	0.368	0.312	0.305	0.3	57.8
Zn (mg/l)	0.632	0.481	0.398	0.324	0.301	0.292	0.261	3	58.7
Cr (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.05	
Cu (mg/l)	2.24	1.252	0.963	0.096	0.048	0.04	0.001	2	99.9
Pb (mg/l)	1.122	1.118	1.109	1.085	1.045	0.943	0.528	0.01	52.9

APPENDIX D

PHYTOREMEDIATION OF SEWAGE EFFLUENT USING *CERATOPHYLLUM DESERNUM* (COONTAIL)

		WEEKS							
Parameter	**Before**	**1**	**2**	**3**	**4**	**5**	**6 (After)**	**EPA Guidelines, 2000**	**% Reduction**
Ph	7.47	7.81	7.61	7.51	7.91	7.85	7.84	6-9	
Temperature (°C)	27.3	27.4	29.8	25.1	28.4	29.6	30.1	<30 (ABOVE AMBIENT)	
Conductivity (μS/cm)	6613	5322	4106	3467	2230	1884	1755	1500	73.5
DO (mg/l)	3.8	8	8.9	10.5	11.6	12.1	12.6	<1	
BOD (mg/l)	38	28.7	15.3	12.6	10.4	8.8	4.2	50	88.9
COD (mg/l)	640	604	588	554	522	480	380	250	40.6
TDS (ppm)	3310	2608	2321	1735	1115	942	878	1000	73.5
TSS (mg/l)	92	66	52	49	44	28	7	50	92.4
Colour (PtCo)	576	419	387	350	223	150	142	-	75.3
Turbidity (NTU)	48	35.8	30.6	28.1	14.5	8.6	3.5	75	92.7
PO4 (mg/l)	14.5	7.96	6.64	5.94	5.72	5.6	5.56	2	61.7
NO3-N (mg/l)	17.8	2.3	1.8	1.1	0.8	0.4	0.2	0.1	98.9
NO2-N (mg/l)	9.5	4.928	2	1.013	0.93	0.02	0.005	3	99.9
NH3-N (mg/l)	8.2	6.24	4.73	2.44	1.73	1.2	0.15	1.5	98.2
Total Coliform	348	228	161	100	77	34	9	400	97.4
Faecal Coliform	101	86	66	45	30	15	4	0	96
THB	1124	900	709	550	345	209	84		92.5
Ni (mg/l)	0.943	0.671	0.42	0.311	0.31	0.305	0.023	0.02	97.6
Cd (mg/l)	0.273	0.196	0.14	0.081	0.07	0.062	0.056	0.003	79.5
Fe (mg/l)	0.722	0.491	0.25	0.107	0.01	0.002	0	0.3	100
Zn (mg/l)	0.632	0.487	0.45	0.334	0.3	0.295	0.286	3	54.7
Cr (mg/l)	ND	ND	ND	ND	ND	ND	ND	0.05	
Cu (mg/l)	2.24	1.96	1.43	0.62	0.49	0.11	0.008	2	99.6
Pb (mg/l)	1.122	0.118	0.12	0.112	0.11	0.101	0.09	0.01	92

APPENDIX E

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
HYDROGEN ION CONCENTRTION	Between Groups	10.419	3	3.473	10.446	.000
	Within Groups	6.650	20	.332		
	Total	17.069	23			
TEMPERATURE	Between Groups	1.353	3	.451	.117	.949
	Within Groups	76.907	20	3.845		
	Total	78.260	23			
ELECTRICAL CONDUCTIVITY	Between Groups	2.866E7	3	9553376.819	5.893	.005
	Within Groups	3.242E7	20	1621136.375		
	Total	6.108E7	23			
BIOLOGICAL OXYGEN DEMAND	Between Groups	779.395	3	259.798	4.731	.012
	Within Groups	1098.382	20	54.919		
	Total	1877.776	23			
CHEMICAL OXYGEN DEMAND	Between Groups	221302.792	3	73767.597	4.778	.011
	Within Groups	308780.833	20	15439.042		
	Total	530083.625	23			
TOTAL DISSOLVED SOLIDS	Between Groups	5265464.833	3	1755154.944	4.264	.018
	Within Groups	8232477.000	20	411623.850		
	Total	1.350E7	23			
TOTAL SUSPENDED SOLIDS	Between Groups	66757.667	3	22252.556	6.912	.002
	Within Groups	64389.667	20	3219.483		
	Total	131147.333	23			
COLOUR	Between Groups	138888.458	3	46296.153	1.522	.239
	Within Groups	608338.500	20	30416.925		
	Total	747226.958	23			
TURBIDITY	Between Groups	5984.668	3	1994.889	6.781	.002
	Within Groups	5883.817	20	294.191		
	Total	11868.485	23			
PHOSPHATE-PHOSPHORUS	Between Groups	8.303	3	2.768	2.581	.082
	Within Groups	21.447	20	1.072		
	Total	29.750	23			
NITRATE-NITROGEN	Between Groups	177.425	3	59.142	4.892	.010
	Within Groups	241.782	20	12.089		
	Total	419.207	23			
NITRITE-NITROGEN	Between Groups	11.837	3	3.946	.997	.415
	Within Groups	79.164	20	3.958		

	Total	91.001	23			
AMMONIA-NITROGEN	Between Groups	7.572	3	2.524	.722	.550
	Within Groups	69.874	20	3.494		
	Total	77.447	23			
FAECAL COLIFORMS	Between Groups	2767.458	3	922.486	1.409	.269
	Within Groups	13091.500	20	654.575		
	Total	15858.958	23			
TOTAL COLIFORMS	Between Groups	66254.458	3	22084.819	4.105	.020
	Within Groups	107590.500	20	5379.525		
	Total	173844.958	23			
TOTAL HETEROTROPHIC BACTERIA	Between Groups	685350.792	3	228450.264	4.325	.017
	Within Groups	1056407.833	20	52820.392		
	Total	1741758.625	23			
LEAD	Between Groups	3.762	3	1.254	33.110	.000
	Within Groups	.758	20	.038		
	Total	4.520	23			
ZINC	Between Groups	.162	3	.054	8.552	.001
	Within Groups	.126	20	.006		
	Total	.288	23			
COPPER	Between Groups	12.251	3	4.084	235.780	.000
	Within Groups	.346	20	.017		
	Total	12.597	23			
IRON	Between Groups	.476	3	.159	8.039	.001
	Within Groups	.395	20	.020		
	Total	.871	23			
NICKEL	Between Groups	.278	3	.093	2.481	.090
	Within Groups	.746	20	.037		
	Total	1.024	23			
CADMIUM	Between Groups	.017	3	.006	2.349	.103
	Within Groups	.049	20	.002		
	Total	.066	23			

APPENDIX F

Multiple comparism of the mean difference in plants using the Least Significant difference (LSD).

Dependent Variable	(I) PLANT	(J) PLANT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
pH	WATER HYACINTH	WATER MIMOSA	-.530000	.332905	.127	-1.22443	.16443
		LEMNA SP.	-.225000	.332905	.507	-.91943	.46943
		CERETOPHYLLUM	-1.710000*	.332905	.000	-2.40443	-1.01557
	WATER MIMOSA	WATER HYACINTH	.530000	.332905	.127	-.16443	1.22443
		LEMNA SP.	.305000	.332905	.370	-.38943	.99943
		CERETOPHYLLUM	-1.180000*	.332905	.002	-1.87443	-.48557
	LEMNA SP.	WATER HYACINTH	.225000	.332905	.507	-.46943	.91943
		WATER MIMOSA	-.305000	.332905	.370	-.99943	.38943
		CERETOPHYLLUM	-1.485000*	.332905	.000	-2.17943	-.79057
	CERATOPHYLLUM	WATER HYACINTH	1.710000*	.332905	.000	1.01557	2.40443
		WATER MIMOSA	1.180000*	.332905	.002	.48557	1.87443
		LEMNA SP.	1.485000*	.332905	.000	.79057	2.17943
TEMPERATURE	WATER HYACINTH	WATER MIMOSA	-.266667	1.132156	.816	-2.62830	2.09497
		LEMNA SP.	-.333333	1.132156	.771	-2.69497	2.02830
		CERETOPHYLLUM	-.666667	1.132156	.563	-3.02830	1.69497
	WATER MIMOSA	WATER HYACINTH	.266667	1.132156	.816	-2.09497	2.62830
		LEMNA SP.	-.066667	1.132156	.954	-2.42830	2.29497
		CERETOPHYLLUM	-.400000	1.132156	.728	-2.76164	1.96164
	LEMNA SP.	WATER HYACINTH	.333333	1.132156	.771	-2.02830	2.69497
		WATER MIMOSA	.066667	1.132156	.954	-2.29497	2.42830
		CERETOPHYLLUM	-.333333	1.132156	.771	-2.69497	2.02830
	CERATOPHYLLUM	WATER HYACINTH	.666667	1.132156	.563	-1.69497	3.02830
		WATER MIMOSA	.400000	1.132156	.728	-1.96164	2.76164
		LEMNA SP.	.333333	1.132156	.771	-2.02830	2.69497
ELECTRICAL	WATER	WATER MIMOSA	-528.333333	7.351046E2	.481	-2061.73469	1005.06802

CONDUCTIVITY	HYACINTH	LEMNA SP.	288.166667	7.351046E2	.699	-1245.23469	1821.56802
		CERETOPHYLLUM	2351.333333*	7.351046E2	.005	817.93198	3884.73469
	WATER MIMOSA	WATER HYACINTH	528.333333	7.351046E2	.481	-1005.06802	2061.73469
		LEMNA SP.	816.500000	7.351046E2	.280	-716.90135	2349.90135
		CERETOPHYLLUM	2879.666667*	7.351046E2	.001	1346.26531	4413.06802
	LEMNA SP.	WATER HYACINTH	-288.166667	7.351046E2	.699	-1821.56802	1245.23469
		WATER MIMOSA	-816.500000	7.351046E2	.280	-2349.90135	716.90135
		CERETOPHYLLUM	2063.166667*	7.351046E2	.011	529.76531	3596.56802
	CERATOPHYLLUM	WATER HYACINTH	-2.351333E3*	7.351046E2	.005	-3884.73469	-817.93198
		WATER MIMOSA	-2.879667E3*	7.351046E2	.001	-4413.06802	-1346.26531
		LEMNA SP.	-2.063167E3*	7.351046E2	.011	-3596.56802	-529.76531
BIOLOGICAL OXYGEN DEMAND	WATER HYACINTH	WATER MIMOSA	-1.666667	4.278593	.701	-10.59166	7.25832
		LEMNA SP.	13.050000*	4.278593	.006	4.12501	21.97499
		CERETOPHYLLUM	3.666667	4.278593	.402	-5.25832	12.59166
	WATER MIMOSA	WATER HYACINTH	1.666667	4.278593	.701	-7.25832	10.59166
		LEMNA SP.	14.716667*	4.278593	.003	5.79168	23.64166
		CERETOPHYLLUM	5.333333	4.278593	.227	-3.59166	14.25832
	LEMNA SP.	WATER HYACINTH	-13.050000*	4.278593	.006	-21.97499	-4.12501
		WATER MIMOSA	-14.716667*	4.278593	.003	-23.64166	-5.79168
		CERETOPHYLLUM	-9.383333*	4.278593	.040	-18.30832	-.45834
	CERATOPHYLLUM	WATER HYACINTH	-3.666667	4.278593	.402	-12.59166	5.25832
		WATER MIMOSA	-5.333333	4.278593	.227	-14.25832	3.59166
		LEMNA SP.	9.383333*	4.278593	.040	.45834	18.30832
CHEMICAL OXYGEN DEMAND	WATER HYACINTH	WATER MIMOSA	-107.500000	7.173805E1	.150	-257.14294	42.14294
		LEMNA SP.	-246.666667*	7.173805E1	.003	-396.30961	-97.02373
		CERETOPHYLLUM	-209.666667*	7.173805E1	.008	-359.30961	-60.02373
	WATER MIMOSA	WATER HYACINTH	107.500000	7.173805E1	.150	-42.14294	257.14294
		LEMNA SP.	-139.166667	7.173805E1	.067	-288.80961	10.47627
		CERETOPHYLLUM	-102.166667	7.173805E1	.170	-251.80961	47.47627
	LEMNA SP.	WATER HYACINTH	246.666667*	7.173805E1	.003	97.02373	396.30961
		WATER MIMOSA	139.166667	7.173805E1	.067	-10.47627	288.80961
		CERETOPHYLLUM	37.000000	7.173805E1	.612	-112.64294	186.64294

	CERATOPHYLLUM	WATER HYACINTH	209.666667*	7.173805E1	.008	60.02373	359.30961
		WATER MIMOSA	102.166667	7.173805E1	.170	-47.47627	251.80961
		LEMNA SP.	-37.000000	7.173805E1	.612	-186.64294	112.64294
TOTAL DISSOLVED SOLIDS	WATER HYACINTH	WATER MIMOSA	-446.333333	3.704159E2	.242	-1219.00739	326.34073
		LEMNA SP.	45.166667	3.704159E2	.904	-727.50739	817.84073
		CERETOPHYLLUM	852.833333*	3.704159E2	.032	80.15927	1625.50739
	WATER MIMOSA	WATER HYACINTH	446.333333	3.704159E2	.242	-326.34073	1219.00739
		LEMNA SP.	491.500000	3.704159E2	.199	-281.17406	1264.17406
		CERETOPHYLLUM	1299.166667*	3.704159E2	.002	526.49261	2071.84073
	LEMNA SP.	WATER HYACINTH	-45.166667	3.704159E2	.904	-817.84073	727.50739
		WATER MIMOSA	-491.500000	3.704159E2	.199	-1264.17406	281.17406
		CERETOPHYLLUM	807.666667*	3.704159E2	.041	34.99261	1580.34073
	CERATOPHYLLUM	WATER HYACINTH	-852.833333*	3.704159E2	.032	-1625.50739	-80.15927
		WATER MIMOSA	-1.299167E3*	3.704159E2	.002	-2071.84073	-526.49261
		LEMNA SP.	-807.666667*	3.704159E2	.041	-1580.34073	-34.99261
TOTAL SUSPENDED SOLIDS	WATER HYACINTH	WATER MIMOSA	130.500000*	3.275914E1	.001	62.16564	198.83436
		LEMNA SP.	61.333333	3.275914E1	.076	-7.00103	129.66770
		CERETOPHYLLUM	122.833333*	3.275914E1	.001	54.49897	191.16770
	WATER MIMOSA	WATER HYACINTH	-130.500000*	3.275914E1	.001	-198.83436	-62.16564
		LEMNA SP.	-69.166667*	3.275914E1	.048	-137.50103	-.83230
		CERETOPHYLLUM	-7.666667	3.275914E1	.817	-76.00103	60.66770
	LEMNA SP.	WATER HYACINTH	-61.333333	3.275914E1	.076	-129.66770	7.00103
		WATER MIMOSA	69.166667*	3.275914E1	.048	.83230	137.50103
		CERETOPHYLLUM	61.500000	3.275914E1	.075	-6.83436	129.83436
	CERATOPHYLLUM	WATER HYACINTH	-122.833333*	3.275914E1	.001	-191.16770	-54.49897
		WATER MIMOSA	7.666667	3.275914E1	.817	-60.66770	76.00103
		LEMNA SP.	-61.500000	3.275914E1	.075	-129.83436	6.83436
COLOUR	WATER HYACINTH	WATER MIMOSA	-39.166667	1.006925E2	.701	-249.20749	170.87416
		LEMNA SP.	-16.500000	1.006925E2	.871	-226.54083	193.54083
		CERETOPHYLLUM	154.166667	1.006925E2	.141	-55.87416	364.20749
	WATER MIMOSA	WATER HYACINTH	39.166667	1.006925E2	.701	-170.87416	249.20749
		LEMNA SP.	22.666667	1.006925E2	.824	-187.37416	232.70749

		CERETOPHYLLUM	193.333333	1.006925E2	.069	-16.70749	403.37416
	LEMNA SP.	WATER HYACINTH	16.500000	1.006925E2	.871	-193.54083	226.54083
		WATER MIMOSA	-22.666667	1.006925E2	.824	-232.70749	187.37416
		CERETOPHYLLUM	170.666667	1.006925E2	.106	-39.37416	380.70749
	CERATOPHYLLUM	WATER HYACINTH	-154.166667	1.006925E2	.141	-364.20749	55.87416
		WATER MIMOSA	-193.333333	1.006925E2	.069	-403.37416	16.70749
		LEMNA SP.	-170.666667	1.006925E2	.106	-380.70749	39.37416
TURBIDITY	WATER HYACINTH	WATER MIMOSA	-.816667	9.902707	.935	-21.47335	19.84002
		LEMNA SP.	-35.200000*	9.902707	.002	-55.85669	-14.54331
		CERETOPHYLLUM	3.916667	9.902707	.697	-16.74002	24.57335
	WATER MIMOSA	WATER HYACINTH	.816667	9.902707	.935	-19.84002	21.47335
		LEMNA SP.	-34.383333*	9.902707	.002	-55.04002	-13.72665
		CERETOPHYLLUM	4.733333	9.902707	.638	-15.92335	25.39002
	LEMNA SP.	WATER HYACINTH	35.200000*	9.902707	.002	14.54331	55.85669
		WATER MIMOSA	34.383333*	9.902707	.002	13.72665	55.04002
		CERETOPHYLLUM	39.116667*	9.902707	.001	18.45998	59.77335
	CERATOPHYLLUM	WATER HYACINTH	-3.916667	9.902707	.697	-24.57335	16.74002
		WATER MIMOSA	-4.733333	9.902707	.638	-25.39002	15.92335
		LEMNA SP.	-39.116667*	9.902707	.001	-59.77335	-18.45998
PHOSPHATE-PHOSPHORUS	WATER HYACINTH	WATER MIMOSA	-1.520000*	.597877	.019	-2.76715	-.27285
		LEMNA SP.	-1.323333*	.597877	.039	-2.57048	-.07618
		CERETOPHYLLUM	-1.098333	.597877	.081	-2.34548	.14882
	WATER MIMOSA	WATER HYACINTH	1.520000*	.597877	.019	.27285	2.76715
		LEMNA SP.	.196667	.597877	.746	-1.05048	1.44382
		CERETOPHYLLUM	.421667	.597877	.489	-.82548	1.66882
	LEMNA SP.	WATER HYACINTH	1.323333*	.597877	.039	.07618	2.57048
		WATER MIMOSA	-.196667	.597877	.746	-1.44382	1.05048
		CERETOPHYLLUM	.225000	.597877	.711	-1.02215	1.47215
	CERATOPHYLLUM	WATER HYACINTH	1.098333	.597877	.081	-.14882	2.34548
		WATER MIMOSA	-.421667	.597877	.489	-1.66882	.82548
		LEMNA SP.	-.225000	.597877	.711	-1.47215	1.02215
NITRATE-NITROGEN	WATER	WATER MIMOSA	.940000	2.007411	.645	-3.24739	5.12739

	HYACINTH	LEMNA SP.	3.190000	2.007411	.128	-.99739	7.37739
		CERETOPHYLLUM	7.056667*	2.007411	.002	2.86928	11.24405
	WATER MIMOSA	WATER HYACINTH	-.940000	2.007411	.645	-5.12739	3.24739
		LEMNA SP.	2.250000	2.007411	.276	-1.93739	6.43739
		CERETOPHYLLUM	6.116667*	2.007411	.006	1.92928	10.30405
	LEMNA SP.	WATER HYACINTH	-3.190000	2.007411	.128	-7.37739	.99739
		WATER MIMOSA	-2.250000	2.007411	.276	-6.43739	1.93739
		CERETOPHYLLUM	3.866667	2.007411	.068	-.32072	8.05405
	CERATOPHYLLUM	WATER HYACINTH	-7.056667*	2.007411	.002	-11.24405	-2.86928
		WATER MIMOSA	-6.116667*	2.007411	.006	-10.30405	-1.92928
		LEMNA SP.	-3.866667	2.007411	.068	-8.05405	.32072
NITRITE-NITROGEN	WATER HYACINTH	WATER MIMOSA	1.381833	1.148654	.243	-1.01422	3.77788
		LEMNA SP.	1.686500	1.148654	.158	-.70955	4.08255
		CERETOPHYLLUM	1.713000	1.148654	.151	-.68305	4.10905
	WATER MIMOSA	WATER HYACINTH	-1.381833	1.148654	.243	-3.77788	1.01422
		LEMNA SP.	.304667	1.148654	.794	-2.09138	2.70072
		CERETOPHYLLUM	.331167	1.148654	.776	-2.06488	2.72722
	LEMNA SP.	WATER HYACINTH	-1.686500	1.148654	.158	-4.08255	.70955
		WATER MIMOSA	-.304667	1.148654	.794	-2.70072	2.09138
		CERETOPHYLLUM	.026500	1.148654	.982	-2.36955	2.42255
	CERATOPHYLLUM	WATER HYACINTH	-1.713000	1.148654	.151	-4.10905	.68305
		WATER MIMOSA	-.331167	1.148654	.776	-2.72722	2.06488
		LEMNA SP.	-.026500	1.148654	.982	-2.42255	2.36955
AMMONIA-NITROGEN	WATER HYACINTH	WATER MIMOSA	-1.075000	1.079154	.331	-3.32608	1.17608
		LEMNA SP.	.310000	1.079154	.777	-1.94108	2.56108
		CERETOPHYLLUM	.268333	1.079154	.806	-1.98274	2.51941
	WATER MIMOSA	WATER HYACINTH	1.075000	1.079154	.331	-1.17608	3.32608
		LEMNA SP.	1.385000	1.079154	.214	-.86608	3.63608
		CERETOPHYLLUM	1.343333	1.079154	.228	-.90774	3.59441
	LEMNA SP.	WATER HYACINTH	-.310000	1.079154	.777	-2.56108	1.94108
		WATER MIMOSA	-1.385000	1.079154	.214	-3.63608	.86608
		CERETOPHYLLUM	-.041667	1.079154	.970	-2.29274	2.20941

	CERATOPHYLLUM	WATER HYACINTH	-.268333	1.079154	.806	-2.51941	1.98274
		WATER MIMOSA	-1.343333	1.079154	.228	-3.59441	.90774
		LEMNA SP.	.041667	1.079154	.970	-2.20941	2.29274
FAECAL COLIFORMS	WATER HYACINTH	WATER MIMOSA	-28.500000	1.477131E1	.068	-59.31242	2.31242
		LEMNA SP.	-5.166667	1.477131E1	.730	-35.97908	25.64575
		CERETOPHYLLUM	-10.833333	1.477131E1	.472	-41.64575	19.97908
	WATER MIMOSA	WATER HYACINTH	28.500000	1.477131E1	.068	-2.31242	59.31242
		LEMNA SP.	23.333333	1.477131E1	.130	-7.47908	54.14575
		CERETOPHYLLUM	17.666667	1.477131E1	.246	-13.14575	48.47908
	LEMNA SP.	WATER HYACINTH	5.166667	1.477131E1	.730	-25.64575	35.97908
		WATER MIMOSA	-23.333333	1.477131E1	.130	-54.14575	7.47908
		CERETOPHYLLUM	-5.666667	1.477131E1	.705	-36.47908	25.14575
	CERATOPHYLLUM	WATER HYACINTH	10.833333	1.477131E1	.472	-19.97908	41.64575
		WATER MIMOSA	-17.666667	1.477131E1	.246	-48.47908	13.14575
		LEMNA SP.	5.666667	1.477131E1	.705	-25.14575	36.47908
TOTAL COLIFORMS	WATER HYACINTH	WATER MIMOSA	-37.833333	4.234590E1	.382	-126.16533	50.49866
		LEMNA SP.	105.000000*	4.234590E1	.022	16.66801	193.33199
		CERETOPHYLLUM	33.333333	4.234590E1	.440	-54.99866	121.66533
	WATER MIMOSA	WATER HYACINTH	37.833333	4.234590E1	.382	-50.49866	126.16533
		LEMNA SP.	142.833333*	4.234590E1	.003	54.50134	231.16533
		CERETOPHYLLUM	71.166667	4.234590E1	.108	-17.16533	159.49866
	LEMNA SP.	WATER HYACINTH	-105.000000*	4.234590E1	.022	-193.33199	-16.66801
		WATER MIMOSA	-142.833333*	4.234590E1	.003	-231.16533	-54.50134
		CERETOPHYLLUM	-71.666667	4.234590E1	.106	-159.99866	16.66533
	CERATOPHYLLUM	WATER HYACINTH	-33.333333	4.234590E1	.440	-121.66533	54.99866
		WATER MIMOSA	-71.166667	4.234590E1	.108	-159.49866	17.16533
		LEMNA SP.	71.666667	4.234590E1	.106	-16.66533	159.99866
TOTAL HETEROTROPHIC BACTERIA	WATER HYACINTH	WATER MIMOSA	-332.666667*	1.326906E2	.021	-609.45442	-55.87891
		LEMNA SP.	34.833333	1.326906E2	.796	-241.95442	311.62109
		CERETOPHYLLUM	107.000000	1.326906E2	.430	-169.78776	383.78776
	WATER MIMOSA	WATER HYACINTH	332.666667*	1.326906E2	.021	55.87891	609.45442
		LEMNA SP.	367.500000*	1.326906E2	.012	90.71224	644.28776

		CERETOPHYLLUM	439.666667*	1.326906E2	.003	162.87891	716.45442
	LEMNA SP.	WATER HYACINTH	-34.833333	1.326906E2	.796	-311.62109	241.95442
		WATER MIMOSA	-367.500000*	1.326906E2	.012	-644.28776	-90.71224
		CERETOPHYLLUM	72.166667	1.326906E2	.593	-204.62109	348.95442
	CERATOPHYLLUM	WATER HYACINTH	-107.000000	1.326906E2	.430	-383.78776	169.78776
		WATER MIMOSA	-439.666667*	1.326906E2	.003	-716.45442	-162.87891
		LEMNA SP.	-72.166667	1.326906E2	.593	-348.95442	204.62109
LEAD	WATER HYACINTH	WATER MIMOSA	-.641833*	.112362	.000	-.87622	-.40745
		LEMNA SP.	-.569333*	.112362	.000	-.80372	-.33495
		CERETOPHYLLUM	.308000*	.112362	.013	.07362	.54238
	WATER MIMOSA	WATER HYACINTH	.641833*	.112362	.000	.40745	.87622
		LEMNA SP.	.072500	.112362	.526	-.16188	.30688
		CERETOPHYLLUM	.949833*	.112362	.000	.71545	1.18422
	LEMNA SP.	WATER HYACINTH	.569333*	.112362	.000	.33495	.80372
		WATER MIMOSA	-.072500	.112362	.526	-.30688	.16188
		CERETOPHYLLUM	.877333*	.112362	.000	.64295	1.11172
	CERATOPHYLLUM	WATER HYACINTH	-.308000*	.112362	.013	-.54238	-.07362
		WATER MIMOSA	-.949833*	.112362	.000	-1.18422	-.71545
		LEMNA SP.	-.877333*	.112362	.000	-1.11172	-.64295
ZINC	WATER HYACINTH	WATER MIMOSA	.028667	.045856	.539	-.06699	.12432
		LEMNA SP.	.185000*	.045856	.001	.08935	.28065
		CERETOPHYLLUM	.168833*	.045856	.001	.07318	.26449
	WATER MIMOSA	WATER HYACINTH	-.028667	.045856	.539	-.12432	.06699
		LEMNA SP.	.156333*	.045856	.003	.06068	.25199
		CERETOPHYLLUM	.140167*	.045856	.006	.04451	.23582
	LEMNA SP.	WATER HYACINTH	-.185000*	.045856	.001	-.28065	-.08935
		WATER MIMOSA	-.156333*	.045856	.003	-.25199	-.06068
		CERETOPHYLLUM	-.016167	.045856	.728	-.11182	.07949
	CERATOPHYLLUM	WATER HYACINTH	-.168833*	.045856	.001	-.26449	-.07318
		WATER MIMOSA	-.140167*	.045856	.006	-.23582	-.04451
		LEMNA SP.	.016167	.045856	.728	-.07949	.11182
COPPER	WATER	WATER MIMOSA	1.615833*	.075981	.000	1.45734	1.77433

	HYACINTH	LEMNA SP.	1.756667*	.075981	.000	1.59817	1.91516
		CERETOPHYLLUM	1.550333*	.075981	.000	1.39184	1.70883
	WATER MIMOSA	WATER HYACINTH	-1.615833*	.075981	.000	-1.77433	-1.45734
		LEMNA SP.	.140833	.075981	.079	-.01766	.29933
		CERETOPHYLLUM	-.065500	.075981	.399	-.22399	.09299
	LEMNA SP.	WATER HYACINTH	-1.756667*	.075981	.000	-1.91516	-1.59817
		WATER MIMOSA	-.140833	.075981	.079	-.29933	.01766
		CERETOPHYLLUM	-.206333*	.075981	.013	-.36483	-.04784
	CERATOPHYLLUM	WATER HYACINTH	-1.550333*	.075981	.000	-1.70883	-1.39184
		WATER MIMOSA	.065500	.075981	.399	-.09299	.22399
		LEMNA SP.	.206333*	.075981	.013	.04784	.36483
IRON	WATER HYACINTH	WATER MIMOSA	-.151000	.081124	.077	-.32022	.01822
		LEMNA SP.	.001833	.081124	.982	-.16739	.17105
		CERETOPHYLLUM	.242333*	.081124	.007	.07311	.41155
	WATER MIMOSA	WATER HYACINTH	.151000	.081124	.077	-.01822	.32022
		LEMNA SP.	.152833	.081124	.074	-.01639	.32205
		CERETOPHYLLUM	.393333*	.081124	.000	.22411	.56255
	LEMNA SP.	WATER HYACINTH	-.001833	.081124	.982	-.17105	.16739
		WATER MIMOSA	-.152833	.081124	.074	-.32205	.01639
		CERETOPHYLLUM	.240500*	.081124	.008	.07128	.40972
	CERATOPHYLLUM	WATER HYACINTH	-.242333*	.081124	.007	-.41155	-.07311
		WATER MIMOSA	-.393333*	.081124	.000	-.56255	-.22411
		LEMNA SP.	-.240500*	.081124	.008	-.40972	-.07128
NICKEL	WATER HYACINTH	WATER MIMOSA	-.102667	.111539	.368	-.33533	.13000
		LEMNA SP.	.059833	.111539	.598	-.17283	.29250
		CERETOPHYLLUM	.194833	.111539	.096	-.03783	.42750
	WATER MIMOSA	WATER HYACINTH	.102667	.111539	.368	-.13000	.33533
		LEMNA SP.	.162500	.111539	.161	-.07017	.39517
		CERETOPHYLLUM	.297500*	.111539	.015	.06483	.53017
	LEMNA SP.	WATER HYACINTH	-.059833	.111539	.598	-.29250	.17283
		WATER MIMOSA	-.162500	.111539	.161	-.39517	.07017
		CERETOPHYLLUM	.135000	.111539	.240	-.09767	.36767

	CERATOPHYLLUM	WATER HYACINTH	-.194833	.111539	.096	-.42750	.03783
		WATER MIMOSA	-.297500*	.111539	.015	-.53017	-.06483
		LEMNA SP.	-.135000	.111539	.240	-.36767	.09767
CADMIUM	WATER HYACINTH	WATER MIMOSA	-.074167*	.028584	.017	-.13379	-.01454
		LEMNA SP.	-.028833	.028584	.325	-.08846	.03079
		CERETOPHYLLUM	-.023833	.028584	.414	-.08346	.03579
	WATER MIMOSA	WATER HYACINTH	.074167*	.028584	.017	.01454	.13379
		LEMNA SP.	.045333	.028584	.128	-.01429	.10496
		CERETOPHYLLUM	.050333	.028584	.094	-.00929	.10996
	LEMNA SP.	WATER HYACINTH	.028833	.028584	.325	-.03079	.08846
		WATER MIMOSA	-.045333	.028584	.128	-.10496	.01429
		CERETOPHYLLUM	.005000	.028584	.863	-.05462	.06462
	CERATOPHYLLUM	WATER HYACINTH	.023833	.028584	.414	-.03579	.08346
		WATER MIMOSA	-.050333	.028584	.094	-.10996	.00929
		LEMNA SP.	-.005000	.028584	.863	-.06462	.05462

*. The mean difference is significant at the 0.05 level.

APPENDIX G
Questionnaires administered to respondents

UNIVERSITY OF GHANA

INSTITUTE OF ENVIRONMENT AND SANITATION STUDIES

M.PHIL ENVIRONMENTAL SCIENCE PROGRAMME

TOPIC: SOCIO-ECONOMIC SURVEY ON THE PUBLIC'S ACCEPTABILITY OF TREATED SEWAGE EFFLUENT FOR RE-USE

INTRODUCTION: The administration of this questionnaire is to solicit responses from individuals and community members in order to assist the establishment of facts about water quality and assessment of public acceptability of treated sewage effluent for reuse. All the information is strictly for academic purposes and will be highly treated with the greatest level of confidentiality.

PART A: DEMOGRAPHIC INFORMATION OF RESPONDENTS

1. Locality ……………………………………………………………………………………

2. Gender ☐ male ☐ female

3. Age ☐ <20yrs ☐ 20-29 yrs ☐ 30-39yrs ☐ 40-49yrs ☐ 50-59 yrs ☐ >60yrs

4. Marital status ☐ single ☐ married ☐ divorced ☐ widowed

5. Occupation ☐ Farming ☐ trading ☐ public service ☐ others, specify…………..

6. Level of Education

☐ None ☐ primary/JSS ☐ SSS/6th Form ☐ Tertiary ☐ Non Formal

7. Monthly Income < 500 ☐ 500-1000 ☐ 1000-1500 ☐ 1500-2000 ☐ >2000 ☐

PART B: PUBLIC AWARENESS AND ACCEPTABILITY OF WATER REUSE APPLICATIONS

	Strongly Disagree (1)	Disagree (2)	Not sure (3)	Agree (4)	Strongly agree (5)
8. I think water resources are being polluted and depleted quickly these days					
9a. I have taken measures to reduce water consumption in my daily life					

9b.What are some practices you can undertake to reduce water consumption in your daily lives

Please list

………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………
……………………………………………………………………………………

10. a. Are you aware of the wastewater reuse applications? Yes ☐ No ☐

b. If yes, what is your main source for obtaining information? Tick as many as applied to you.

Newspapers	Television	Radio	Internet	Municipal Authorities	Family/Friends	Environmental groups

11. Which water reuse alternatives are most applicable in your opinion?

Wastewater Reuse Alternatives	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
drinking water					
cooking in the home					
food preparation in restaurants					
preparation of canned vegetables					
Bathing					
swimming pool					
Laundry					
agricultural irrigation					
irrigation of golf course					
toilet flushing					
fire fighting					
Construction					
road washing					
Car washing					
irrigation of parks/gardens					
Industry for cooling					

12. If the quality of reclaimed water is certified as high quality, will you willingly accept this water as drinking water? Yes ☐ No ☐

13. In the case of treated wastewater reuse for grass irrigation is it appropriate that the children play on the grass? Yes ☐ No ☐

14. What types of reuse would you prefer for sewage effluent after following required wastewater treatment processes? Tick as many as applied to you.

Reuse Type	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
Domestic					
Industrial					
Commercial					
Agricultural purposes					
None of them					

15. For what reasons would you want wastewater treated for reuse. Tick as many as applicable

Environmental protection ☐ Scarcity of water resources ☐

Health Implications ☐ None of the above ☐

APPENDIX H

DRIED PLANT SAMPLE ANALYSIS BEFORE AND AFTER PHYTOREMEDIATION

	WATER HYACINTH		MIMOSA		LEMNA		CERATOPHYLUM	
PARAMETER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Ni (mg/Kg)	0.96	0.98	0.833	0.835	1.108	1.119	1.002	0.835
Cd (mg/Kg)	0.042	0.044	0.054	0.062	0.09	0.114	0.054	0.06
Fe (mg/Kg)	0.882	O.929	0.788	0.841	0.889	0.937	0.88	0.953
Zn (mg/Kg)	0.132	0.294	0.112	0.121	0.004	0.103	0.2	0.238
Cu (mg/Kg)	0.002	0.009	0.009	0.018	0.027	0.038	0.002	0.006
K (mg/Kg)	32.9	36.3	27.9	25.3	18.3	19.8	33.2	30.8
PO_4 (mg/Kg)	642	1243	885	1328	1122	1264	654	1080
NO_3-N (mg/Kg)	446.4	1584	777.6	846.8	748.8	1260	547.2	583.2
NO_2-N (mg/Kg)	984.6	1364	1121	1857	1854	2876	640	1230
NH_3-N (mg/Kg)	1281.6	1670.4	1353.6	2369	1216.8	2520	1742.4	1958.4