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KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY-KNUST

GREY WATER TREATMENT USING CONSTRUCTED WETLAND AT KNUST IN KUMASI

BY

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MSc. THESIS

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GREY WATER TREATMENT USING CONSTRUCTED WETLAND AT KNUST IN KUMASI

By

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In partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

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College of Engineering

July 2007

CERTIFICATION

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

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ABSTRACT

Constructed wetlands are current the most widely recognized wastewater treatment option, especially in developing countries where they have the potential for improving water quality and creating valuable wildlife habitat in ecosystem with treatment requirement relatively simple for operation and maintenance cost. Lack of grey water treatment facilities at Kwame Nkrumah University of Science and Technology (KNUST) Kumasi, Ghana, causes pollution in the main drainage Wiwi stream. In order to assess the potential of constructed wetlands in treatment of grey water at KNUST; a Horizontal Sub-surface Flow pilot-scale constructed wetland was designed, constructed and operated on the KNUST campus in the flood plains of the Wiwi stream bridge on the left side of Duncanson road from Administration. The study was carried out in a sedimentation tank of 3.65 x 0.65 x 0.4 m deep and a Horizontal Sub-surface constructed wetland of 3.5m x 0.8m x 0.8m deep. The grey water flow rate of 0.48 m^3/d was flowed through vegetated wetland and sandy pilot plant. The filter media consisted of 0.6 to 2 mm of coarse sand, 368.78 cm^3/d of hydraulic conductivity and cattails (*Typha latifolia spp*) were used as plants species. The effluent flow rate of the plant was 0.327 m^3/ day and the retention time was 15hrs. 72% to 79% of BOD, COD, SS, Grease, and Faecal Coliform removal were achieved, while the nutrients (Nitrogen and Phosphate) removal was the range of 34% to 53%. There was no significant difference between the morning and evening results ($P > 0.05$). The effluent characteristics did not meet the EPA (Ghana) guidelines primarily because the organic load of the waste water discharged into the wetland was much than anticipated.

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DO	Dissolved oxygen
EPA	Environmental Protection Agency
EQE	Environment Quality Engineering Laboratory
FAS	Ferrous Ammonium Sulphate
FC	Faecal Coliforms
FWS	Free water surface systems
GW	Grey Water.
HSSF	Horizontal Sub-Surface Flow
KMA	Kumasi Metropolitan Assembly
KNUST	Kwame Nkrumah University of Science and Technology
N	Nitrogen
NO_2^- - N	Nitrite Nitrogen
NO_3^- - N	Nitrate Nitrogen
PO_4^{3-} - P	Phosphate Phosphorous
SF	Subsurface flow
SFS	Subsurface flow systems
SS	Suspended Solids
TDS	Total Dissolved Solids
TP	Treatment Plant
UNESCO	United Nations Educational, Scientific and Cultural Organization
VSB	Vegetated submerged bed systems

1 INTRODUCTION

1.1 Background Information

Grey water is defined differently by writers as all no-toilet waste water from sinks of kitchen or dishwasher, bathroom or laundry machines and general use in various homes and institutions (Hammer, 1988). The same definition is used in New Mexico of USA except that grey water does not include wastewater from kitchen sinks or dishwashers or laundry water from the washing of material soiled with human excreta, such as diapers (NMED, 2005). Generally in the World, over two-thirds of used water is grey water and can be used safely after treated in irrigation, small commercial garden, landscape or groundwater recharge so that it can substitute water fresh (Kaufman, 2005). Grey water as a domestic waste water contains macronutrient concentration and pathogenic microorganisms that can endanger human health (Fong et al, 2004).

Grey water can be successfully treated by the microorganisms and earthworms in healthy porous topsoil or active compost. In the biologically topsoil layer of soil, there is a complex community of soil microbes that metabolize, cleanse and purify water. The diverse microorganisms living in the manure of earthworms destroy disease-causing pathogens. Heavy clay or very sandy soil can lack the organic matter that nourishes soil life for a fundamental soil ecosystem. Addition of compost to typically clay or sandy soil increases aeration, drainage and decomposition activity significantly so any soil can become a living treatment system

as nature intended (Kaufman, 2005). Also the potential of plants for waste water treatment has been intensively studied and is highly been all over the world, (Vymazal 2000; Vacca et al, 2005). One of the treatment techniques which has been deeply examined is the Constructed Wetland. It is considered to be relatively inexpensive in developing countries (Kimwaga et al, 2004; Vacca, et al, 2005).

According to Kaufman (2005), a natural wetland is nature's kidney, a water-saturated soil ecosystem, packed cleansing microbial activity due to its performance in sieving or absorption of sediments, pollutants and nutrients into plant biomass. The roots of wetland plants are oxygen-rich habitats for aerobic microbes that metabolize waste. Where oxygen does not achieve, anaerobic microbes provided with plenty carbon to convert nitrate from waste products into nitrogen gas so as to return safely to the atmosphere “denitrification process”. Microbes living on media filter or on plant roots absorb the phosphorous taken by plants.

A constructed wetland can be considered as a soil box created with a restored natural habitat for beauty and renewal of water and landscape. The walls of the constructed wetland can be earth, mixed with clay powder, manure and leaves to form a watertight layer. Constructed Wetland is also used as polishing step following conventional treatment and there are several limitations to the use of it which have to be considered in constructed wetland design (weather, hydrologic conditions, etc.)

In urban centers of Ghana, the grey water is not treated, it is discharged into gutters or sometime it is sprayed on the ground. Presence of some nutrients and organic matter result in aesthetically displeasing odour when discharged into the

environment which happens at Kwame Nkrumah University of Science and Technology. In developing countries like Ghana, many people are not aware of dangers of grey water in contact with human body or in discharging into the environment. Until now, the existing legal regulations are inadequate to prevent direct discharge of grey water. For example at KNUST campus, the grey water from the halls, staff houses, faculty area is discharged directly into Wiwi stream, meanwhile the stream is used by the farmers to cultivate vegetables, while others do fishing in it. Previous researches done from 1999 to 2007 on Wiwi stream showed that there were increased pollution and the stream water quality is deteriorating from 64 to 192 mg/l and from 2.5 to 12.4 mg/l respectively for COD and Phosphates (Awuah et al, 1999; Environmental Quality Engineering laboratory unpublished data, 2005 & 2007). Consequently, water borne diseases are occurrence in the environment and the pollution of surface or ground water are unavoidable.

The treatment of grey water is needed because untreated waste water can contaminate waters for irrigation, fish production, recreation, or by human consumption, etc. (US EPA, 1993). The treatment of waste water is required before being discharged into receiving water bodies to reduce odour, prevent the breeding of flies and mosquitoes or control infectious diseases caused by pathogens through feacal matter or urine (Navaraj, 2005). Constructed wetland has capacity to remove BOD, COD, SS, and bacteriological at 90% and N and P at 50%. This removal levels may be the contribution of the dominant plant species in the wetland, characteristics of grey water, retention period.

1.2 Problem Statement

Lack of grey water treatment facilities at Kwame Nkrumah University of Science and Technology in Kumasi causes pollution in the Wiwi stream which receives most of the grey water generated on campus. During flooding, the wetland can be contaminated by the polluted stream water. However, some inhabitants or farmers are using the wetland around the stream for growing vegetables and arable crops. Dry season farming on the wetland around the Wiwi stream is a common practice where polluted water from the stream is used to water the crops including fresh eating vegetables. If the grey water is treated before discharge it will prevent the stream from getting polluted together with the wetland and subsequently improve the wetland ecosystem and the quality of vegetables produced.

1.3 Purpose of the Study

The main purpose of the research was to assess the potential of a constructed wetland in the treatment of grey water at Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. The study looked at literature on constructed wetlands and carried out studies on pollutants removal in designed constructed wetland on a pilot scale.

1.4 Objective of the Study

The main objective of this study was to determine the efficiency of constructed wetland system in grey water treatment at KNUST.

Specific Objectives

The study seeks to:

- Design and construct a pilot constructed wetland with respect to:
    - Determine the soil that could be used in the constructed wetland.
    - Identify the plant species that could be used in the constructed wetland,
- Evaluate the performance of the pilot plant with respect to:
    - Flow rate measurement
    - Retention time based on BOD
    - Efficiencies of pilot plant
    - Effluent water quality of pilot plant
- Characterize the grey water generated from Kwame Nkrumah University of Science and Technology.
- Make recommendations on constructed wetland based on the outcome.

1.5 Justification of the study

KNUST, a tertiary educational institution in Kumasi Metropolis produce a large volume of waste water from the students, staffs and neighbourhoods. The grey water is discharged directly into the Wiwi stream on KNUST Campus. Untreated wastewater contains pathogens and other organisms that may cause water related diseases. Nutrients and other organics in the waste water may degrade the quality of the water thereby affecting other flora and fauna. There has not been any studies on grey water treatment using constructed wetland in Ghana. The Government of Ghana, has stated in its objectives in Millennium Development Goals, to ensure sustainable environment for improved public health in order to offer opportunities for economic growth and poverty reduction. According to the National Development Planning Commission of Ghana (NDPC), Ghana could meet the target of safe water by the year 2015 (Gyau-Orhin, 2005). Beside this, another objective of the Government in establishing the high institutions of learning is to be able to attend to the public problems. One the current and overreaching problem in our society is environmental sanitation. The university in particular should be able to handle its problems. KNUST discharges grey water from four halls of residences on the campus direct into Wiwi stream, which is therefore polluted. Information from this study should be very important in the promotion of social, economic and physical well-being of the KNUST community and the adjoining communities.

1.6 The Scope and Limitation of Work

The performance of the constructed wetlands was assessed for the first ten weeks after construction, including the first three weeks which allowed the roots of the plants and microorganisms to establish. The time allowed to this study was not enough to the laboratory facilities and number of the students (undergraduate and graduate). Intermittent power failure, water flow and lack of some materials became obstacle.

1.7 Organization of Report

The report is subdivided into five chapters. Chapter one started with introduction which talks about the background of the study, justification of the study, objectives of the study, scope and limitation of work and research methodology and organization of report. Then chapter two is consisted of a review of literature grey water treatment using constructed wetlands. After that, chapter three looks at materials and methods in which details of the actual situation and the methodology used to carry out the solution of environmental sanitation problem is outlined. The fourth chapter presents the results obtained and their discussion, and the final chapter is the conclusion and recommendations of the research.

2 LITERATURE REVIEW

2.1 Overview of Grey Water

There are significant distinctions between grey water and toilet wastewater (called "blackwater"). These distinctions tell us how these wastewaters should be treated, managed and why, in the interests of public health and environmental protection, they should not be mixed together.

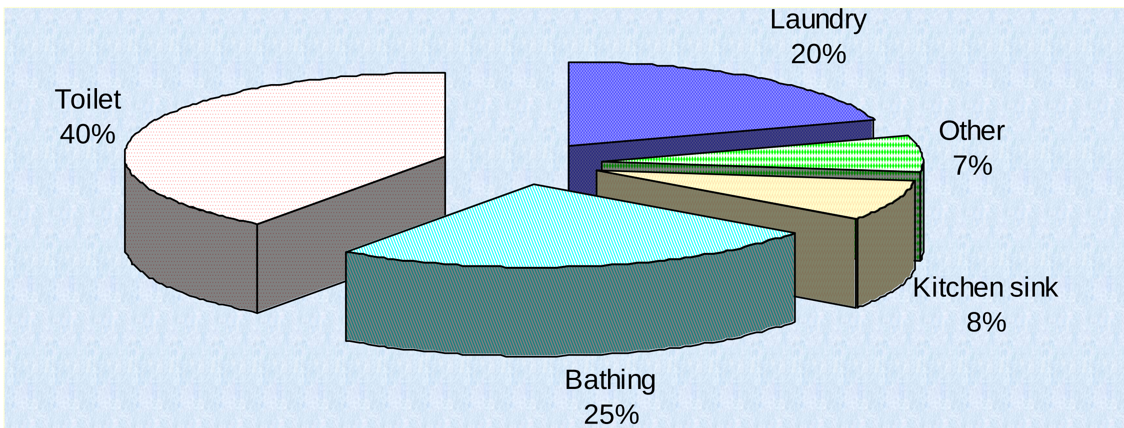


Figure 2.1: Combined Wastewater (Source from Lindstrom, 2000)

As confirmed by (Lindstrom, 2000 and Bizuszek, 2006), Grey water usually contains less nitrogen, few pathogens and breaks down in the environment faster than blackwater. Normally, nitrogen is difficult to remove and is one pollutant affecting drinking water supply, streams or rivers. Some countries developed grey water irrigation guidelines due to its huge quantity per day and its importance (NMED, 2005).

2.2 Grey Water Used and its Characteristics

Grey water may contain the pathogenic microorganisms, suspended solids and substances such as oil, fat, soaps, detergents, and other household chemicals (Morel *et al*, 2006). The main sources of grey water are waste water from baths, showers, hand basins, washing machines, dishwashers and kitchen sinks. On a small scale this tends to exclude kitchen and clothes washing as they represent more heavily polluted sources but at larger scale all non toilet sources tend to be included to maximise water savings.

The most commonly described application for grey water reuse is toilet, and urinal flushing which can reduce water demand within dwelling by up to 30% (Martin *et al*, 1997; Jefferson *et al*, 2004).

However, grey water has been considered for many other applications including irrigation of lawns at cemeteries, golf courses and college campuses, vehicle washing, fire protection, boiler feed water, concrete production and reservation of wetlands. The water quality requirements for each application contain criteria based on organic, solids and microbiological content of the water (Jefferson *et al*, 2004).

2.3 The need for grey water treatment

Removal of nitrogen is needed in grey water to prevent eutrophication in receiving water bodies (Patrick *et al*, 2003). In their research on denitrification in Constructed Wetlands used for treatment of swine wastewater, Patrick *et al* 2003

realized that Denitrification Enzymes Activity "DEA" were significant. The plants species used were bulrushes and cattails.

The need for use of constructed wetlands in grey water treatment may provide a simple and inexpensive solution for controlling many water pollution problems facing small communities, industries, and agricultural operations.

Adoption of this technology has been inhibited by a lack of guidelines and instructions supported by adequate information on important components of wetland ecology , designs and basic equipment (Hammer, 1988).

2.3.1 Regeneration

In nature there is no waste and there is no pollution (Kaufman, 2005). The output of one organism is the food for another in an ever-renewing cycle of life. Regeneration is at the heart of a healthy living system. Living creatures and natural ecosystems maintain themselves by renewal. However, today, many communities are not working with nature, but unconsciously develop one-way flows that create waste. Lack of nutrient recycling to the land causes hungry soil. By recycling, a high quality fertilized soil and a well watered garden can be obtained.

2.4 Grey water pollution

2.4.1 Primary pollution

A few decades ago, the lakes, rivers and coastal waters were clean and supported a balanced aquatic plant and animal life. As rivers and lakes started to

receive organic pollution from industry, sewers, septic systems, and present-day agricultural and livestock-raising practices, these organics decomposed in the water, consuming the oxygen dissolved in it, oxygen crucial for fish and other aquatic animals. This process is known as primary pollution. The commonly used measurement of primary pollution is BOD_5 (five-day Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand), the amount of oxygen extracted from water by bacteria when pollutants decompose. The more organic material there is in sewage, the greater the amount of oxygen needed to decompose these pollutants and, consequently, the greater the primary pollution (Lindstrom, 2000).

2.4.2 Secondary pollution

Concomitant with the primary pollution, algae and other "out -of- balance" plant species start to grow as the result of being fertilized by the surge of nutrients from the above-mentioned sources. These fertilized plants, in turn, die and decompose, further robbing the water of its naturally dissolved oxygen. This phase is called secondary pollution "eutrophication", and is considerably more damaging to the oxygen level than primary pollution. The principal nutrients causing secondary pollution are nitrogen, phosphorus and potassium. Secondary pollution is caused by fertilizer run off from agriculture practices and nutrients from domestic wastewater especially from homes using phosphates based detergents (Lindstrom, 2000).

2.4.3 Pollution levels of the Wiwi stream.

Wiwi is a stream that runs through the KNUST campus from the north to

South West direction. Within its catchment area, resulting in discharge of different pollutants into it, in recent years. This is explained well by the following table.

Table 2. 2-1: Pollution levels of Wiwi stream

Wiwi Stream	Sampling point	PO4- (mg/L)	BOD (mg/L)	COD (mg/L)	E-Coli (No./100mL)	NO_3^- (mg/L)	NO_2^- (mg/L)	S.S (mg/L)
1999* Year	Inside campus	2.5	n.a	64	1.4x104	0.01	0.0	-
2005** Year	Inside campus	n.a	140 - 180	n.a	n.a	0.2-0.3	2.5	-
2007*** Year	Up stream	3.1	120	144	$1.2x10^5$	27	5.6	20
	Grey water discharge	21.7	720	832	$1.5x10^5$	58	30	360
	Down stream	12.4	160	192	$9x10^4$	36.5	7.35	35

n.a: not available

Source :* Awuah et al, 1999; ** Un published data from E.Q.E, 2005;*** Data from EQE, jan 2007

2.5 Legislative and Regulatory Aspects for Grey Water

According to (Forbes *et al*, 2004), New legislation from both the European Union (EU) and The United Kingdom (UK) parliaments is now in place, which will impose demanding restrictions on every aspect of storage, handling and disposal of grey water. Discharge from households to surface waters, ditches, streams, rivers and lakes and particularly to groundwater will be closely monitored and controlled.

In New Mexico, up to 0.96 m^3/d/family of residential grey water can be used for household gardening, composting or landscaping irrigation without a permit.

Consequently, New Mexico Environment Department issued Grey Water Irrigation Guidelines, and proposed amendments to the Liquid Waste Disposal Regulations (NMED, 2005) that are consistent with the Legislative.

2.6 Historic context of Constructed wetland

Constructed Wetland research has been ongoing for several decades, firstly in Europe with urban waste streams, principally sewage and domestic waste water and latterly globally, with industrial effluents (Hammer, 1988). Interest and research investigations spread to other countries and since the mid 80's, CW have been examined in greater detail (Forbes *et al*, 2004).

In 1991, the first subsurface flow constructed wetland for treatment of domestic wastewater was built in Norway. Today, this method is rapidly becoming popular for wastewater treatment in rural Norway. This is due to excellent performance even during winter and low maintenance requirements. The Norwegian concept for small constructed wetlands is based on the use of a septic tank followed by an aerobic vertical down-flow biofilter succeeded by a subsurface horizontal-flow constructed wetland. The aerobic biofilter, prior to the subsurface flow stage, is essential to remove BOD and achieve nitrification in a climate where the plants are dormant during the cold season. When the media is saturated with P, it can be used as soil conditioner and P-fertilizer. Nitrogen removal in the range of 40 to 60% is achieved. Removal of indicator bacteria is high and < 1000 thermotolerant coliforms/100 ml is normally achieved (Taylor, 2005).

2.7 Constructed wetland systems

As reported by (Keraita, 2005), Constructed wetlands consist of shallow reservoirs with water depths less than 0.6 m and plants are grown there. The constructed wetland is almost erected on a slope so that water flows through the bed media by gravity. Beside this they are shallow to permit a better removal of pollutants.

According to US EPA, (1988), Constructed wetlands can be constructed anywhere and they should perform well than a natural wetland having the same size. Constructed wetlands systems have capacity to produce effluent quality as conventional wastewater treatment systems at lower cost as well as the promotion of development for community responsibility (Mashauri *et al*, 2000). The constructed wetland system, a sand-gravel filter cultivated with emergent plants such as cattails, has already proven to be an efficient and low-cost technology for sludge and wastewater treatment (Metcalf & Eddy, 1991).

2.7.1 Advantages and disadvantages of Constructed Wetland System

Constructed wetlands offer several potential advantages as a wastewater treatment process. These advantages include site location flexibility, less rigorous preapplication treatment, no alteration of natural wetlands, process stability under varying environmental conditions, lower construction and operating costs, and in the case of free water surface systems, the possibility to create a wildlife habitat. The potential problems with Free Water Surface “FWS” constructed wetlands include mosquito, start-up problems in establishing the desired aquatic plant species with

FWS and Sub-surface Flow “SF” wetlands alike (US.EPA,1988 and McKenzie, 2004).

2.7.2 Types and functions of constructed wetlands

Two types of artificial or constructed wetlands have been carried out. The first is free water surface systems (FWS) and the second is subsurface flows systems (SFS), also called root zone, rock-reed filters or Vegetated submerged bed systems (VSB).

Free Water Surface Systems (FWS)

US EPA (1993), reported that Free water surface wetlands are the most common and they present of the following:

- basins or channels with natural or constructed subsurface barriers of clay or impervious material to avoid seepage;
- soil or another available medium to support the emerging vegetation; and
- wastewater flowing slowly over the soil surface at a shallow water depth.

Subsurface Flow Systems (SFS)

The second type is named a subsurface flow system. This system consists of a trench or bed, at the bottom of which is an impermeable layer of clay or a plastic liner. The bed contains rocks or other material that can support the growth of new vegetation. Wastewater flows about 6 to 12 inches below the bed surface. The local geology and soil conditions must be investigated before developing a design (US EPA, 1993).

Types and functions of vegetation

The important utility of plants in constructed wetlands is transfer of oxygen to the root zone. The roots penetrate into the soil and transport oxygen deeper than it would naturally travel by diffusion alone.

Another most important factor is the substrate for attached microbial growth. It is the responses of this attached biota that is believed responsible for much of the treatment that occurs.

The emergent plants most frequently found in wastewater wetlands include cattails, reeds, rushes, bulrushes and sedges. It is estimated that these plants transfer 5-45 g O_2 /day.m^2 depending on density and oxygen stress levels in the soil (US EPA, 1988). Table 2.1 below lists some of the major environmental requirements of some plants as well as their maximum depths of root penetration. According to (Koottatep et al, 1998) the cattail plants could be collected from the natural wetlands and transplanted to the pilot plants.

Emergent macrophytes have:

• well-developed mechanical tissues, fibres and thickened tissues to hold themselves erect and withstand wind action, and a well developed cuticle on stems and leaves to reduce water loss. Shoots may have epidermal hairs to reduce water loss further;

• numerous functional stomata (microscopic breathing pores) through which gas exchange and water loss can be regulated;

• an extensive rhizome system with roots and root hairs.

Table 2.1: Emergent Aquatic Plants for Wastewater Treatment

Common name	Scientific name	Temperature °C		Max.Salinity, tolerance, ppt	Root penetration , cm	pH range
		Desirable	Seed germination			
Cattail	*Typha spp*	10-30	12-24	30	30	4-10
Common reed	*Phragmites communis*	12-23	10-30	45	60	2-8
Rush	*Juncus spp*	16-26	-	20	-	5-7.5
Bulrush	*Scirpus spp*	16-27	-	20	76	4-9
Sedge	*Carex spp*	14-32	-	-	-	5-7.5
Ppt = parts per thousand						

Source: modified from U.S.EPA, 1988

2.7.3 Design methods

The dimension of constructed wetlands is not obtained haphazardly, the design made based on required surface area, filter media materials, and bed depth as well as plant species. Table 2.3 summarizes the rules of thumb design criteria.

Table 2.2: Rule of thumb design criteria for HSF

Criterion	Value range	
	Wood (1995)	Kadlec & Knight (1996)
Hydraulic retention time(days)	2 -7	2-4
Max. BOD loading rate (kg BOD/ ha/ day)	75	n.g
Hydraulic loading rate(cm day-1)	0.2-3.0	8-30
Areal requirement(ha m-3 day)	0.001-0.007	n.g
n.g.: not given		

Source: UNESCO-IHE Institution for Water Education, 2006

In design, some basic data are required at the initial stages of a new constructed wetlands. These data concern, among others:

- Expected influent volumes and concentrations (flow rate, BOD, COD, etc.)
- Required effluent concentrations (as described in national environmental law)
- Climatic conditions (precipitation, temperature)
- Soil characteristics of chosen site

According to Metcalf (1991), the principal design parameters for constructed wetland are focus on hydraulic retention time, basin depth, basin geometry, BOD_5 loading rate and hydraulic loading rate.

2.8 Grey water treatment mechanisms

Wetland systems can significantly reduce biochemical oxygen demand (BOD_5), suspended solids (SS), and nitrogen, as well as metals, trace organics, and pathogens. The basic treatment mechanisms include sedimentation, chemical precipitation, adsorption, and microbial interactions with BOD_5, SS and Nitrogen, as well as some uptake by the vegetation (U.S EPA, 1988).

2.8.1 BOD Removal

The removal of settleable organics is very rapid in all wetland systems and is due to deposition and filtration in the SF systems. The major oxygen source for the subsurface components, is the gases transmitted by the vegetation to the root zone. In most cases the system is designed to maintain flow below the surface of the bed, so there can be very little direct atmospheric re-aeration. The selection of plant species can therefore be an important factor.

Table 2.4 below reports the removal efficiencies of BOD_5 and SS from constructed wetlands in Canada, U.S.A and Australia (U.S EPA, 1988).

Table 2.3: BOD & SS removal from constructed wetlands

Project	Flow; m^3/d	Wetland type	BOD5 (mg/l)		SS (mg/l)		% reduction		Hydraulic surface loading rate, ($m^3/ha./d$)
			Inf	Eff	Inf	Eff	BOD	SS	
Listowel, Ontario	17	FWS	56	10	111	08	82	93	-
Santee,CA	-	SF	118	30	57	5.5	75	90	-
Sydney,Australia	240	SF	33	4.6	57	4.5	86	92	-
Arcata,CA	11,350	FWS	36	13	43	31	64	28	907
Emmitsburg,MD	132	SF	62	18	30	8.3	71	73	1,543
Gustine,CA	3,785	FWS	150	24	140	19	84	86	412
FWS : Free Water Surface system SF : Sub surface Flow system									

Source: U.S.EPA, 1988

2.8.2 Suspended solids removal

Suspended solids removal is very effective in both types of constructed wetlands. Most of the removal occurs within the first few meters beyond the inlet, owing to the shallow depth of liquid in the system. Controlled dispersion of the influent flow with proper diffuser pipe design can help to ensure low velocities for solids removal and even loading of the wetland so that anoxic conditions are prevented at the upstream end of the channels.

2.8.3 Nitrogen removal

Nitrogen is mainly removed by nitrification or denitrification. Other removal mechanisms include plant uptake and volatilization as ammonia. In constructed wetlands, nitrogen removal ranges from 25- 85 % (US.EPA, 1988).

2.8.4 Phosphorus removal

Phosphorus removal in wetlands is not very effective because of the limited contact opportunities between the wastewater and the soil. The principal mechanisms for phosphorus removal are plant uptake or retention in the soil (U.S.EPA, 1988).

2.8.5 Pathogen removal

Pathogens of concern in constructed wetlands are parasites, bacteria and viruses. Pathogenic viruses are removed by such mechanisms as predation, sedimentation, absorption, and die-off from unfavorable for cell reproduction (U.S. EPA, 1988).

Table 2.5 reports performance data on pathogen removal for both FWS and SF wetlands in the U.S and Canada.

Table 2.4: Pathogen removal in Constructed wetland systems

Location (vegetation)	Influent	Winter Effluent	% reduction	Influent	Summer Effluent	% reduction
Santee, CA (Bulrush)[b]; Total coli, no./100mL	$5*10^7$	$1*10^5$	99.80	$6.5*10^7$	$3*10^5$	99.54
Iselin, PA (Cattails)[c]; F.C,no./100mL	$1.7*10^6$	6,200	99.64	$1.0*10^6$	723	99.93
Arcata, CA (Bulrush)[d] Faecal coli, no./100mL	4300	900	79.07	1800	80	95.56
Listowel, Ont.(Cattails)[d]; Faecal coli,no./100mL	556,000	1,400	99.75	198,000	400	99.80
b is gravel bed, subsurface flow; c is sand bed, subsurface flow and d is free water surface						

Source: modified from Reed et al, 1988

The efficacy of CW on improvement of microbial quality of water has also demonstrated by different authors. See the table 2.6 below.

Table 2.5: Experiences for Pollutants Removal Using Constructed Wetland

Description	Pollutants removal	Reference
1.Nitrogen removal from a stream in the Herrings Marsh, North Carolina	Nitrate-N level removed from 7 parts per million to < 1 ppm during warmer months and < 5 ppm in cooler months.	Hunt P. G (1998).
2. Efficiency of a Subsurface Constructed Wetland System Using Native Southwestern U.S. Plants.	-The effluent fecal coliform counts were below the (200 cfu/100 mL). -The loss of N suggests that a combined nitrification/denitrification process is active in the wetland	Maschinski, et al (1999).
3. Investigating Dairy Lagoon Effluent Treatability in a Laboratory-Scale CW System	- Results showed consistently high nitrogen-removal efficiencies (65 to 81%) for all treatments.	Benham and Mote, (1999).
4. Wetlands for wastewater treatment: Opportunities and limitations	- In the Netherlands, CW can remove more than 90% of BOD, COD, SS and bacteriological pollution. - Removal of N and P remains, however closer to 50% in most cases.	Verhoeven et al, (1998).
5. CW with effluent from WSPs at the University of Dar es Salaam,Tanzania	- TC removed at 90% -FC removed at 91%; COD:65.7% Removal; SS:79.8% Removal	Mashauri et al, (1999).
6.Bacterial removal by subsurface flow wetlands	1.5-2.1 log reductions for E-Coli	Green et al, (1997).

Source: Keraita, 2005

2.8.6 Organics removal

Adsorption of trace organics by the organic matter and clay particles present in the treatment system is thought to be the primary physicochemical mechanism for removal of refractory compounds in wetlands. Other mechanisms can be biological degradation of easily degraded organic compounds, sedimentation and volatilization (U.S.EPA, 1988).

2.9 Functions and Benefits of Wetlands

According to the UNESCO-IHE (2006) Constructed wetland systems directly support millions of people and provide goods and services to the world. People use constructed wetland soils for agriculture, in fishery, for timber and constructed wetland reeds to make mats and to thatch roofs. Direct use may also take the form of recreation, such as bird watching or scientific study. The water is temporarily stored there during the flooding. It is therefore crucial to quantify the functions of a wetland before valuing it.

2.10 Environmental information

Environmental information helps us to give an overview of the most important features and interrelations (Climate, Hydrology, Geology, Geomorphology, Soils, Ecological, Flora and Fauna). Relationships between vegetation and fauna and between fauna species and groups as far as these relationships should be known in order to manage the area properly.

Information on present land use, landscape or socio-economics have an impact on the wetland management (US EPA, 1993).

3 MATERIALS AND METHODS

3.1 Description of Project Area

3.1.1 Location and climate

Kwame Nkrumah University of Science and Technology “KNUST” is one of the tertiary Education in Kumasi Metropolis in Ashanti Region located in the central part of the Republic of Ghana. KNUST is covered by green vegetation so that its landscape can be referred to as “Garden area”. KNUST is located on the East of the Kumasi-Accra main road. On the North, it is bounded by Bomso and Ayigya, on the south by Ahinsan. The boundary to the west is Ahinsan and Bomso suburbs. On the Eastern boundary is Ayeduase. KNUST covers a total estimated area of 2 km^2. It lies on latitude 6°35´N-6°45´N and longitude 1°30´W-1°45´W. The topography of the KNUST is gentle with two major outfalls (Wiwi stream and other stream is located between Buroburo and Asuogya roads). KNUST is characterized by academic building, staff houses, halls, hostels, guest houses, hospital, churches, sport facilities, ect. which are placed in good urbanism (see figure 3.1).

The KNUST climate is wet sub-equatorial type with two rainfall seasons. The major rainfall season starts from May to June while the minor starts from September to October. The mean monthly rainfall ranges between 15 mm in January, and 214 mm in June. The minimum daily temperature ranges between 20.1 ^oC in January to 34 ^oC

in February. The evapo-transpiration is between 86 mm in October to 157 mm in January while the mean annual evapo-transpiration is 1412 mm. December to February, the whether is also very hot, refer Appendix 1.

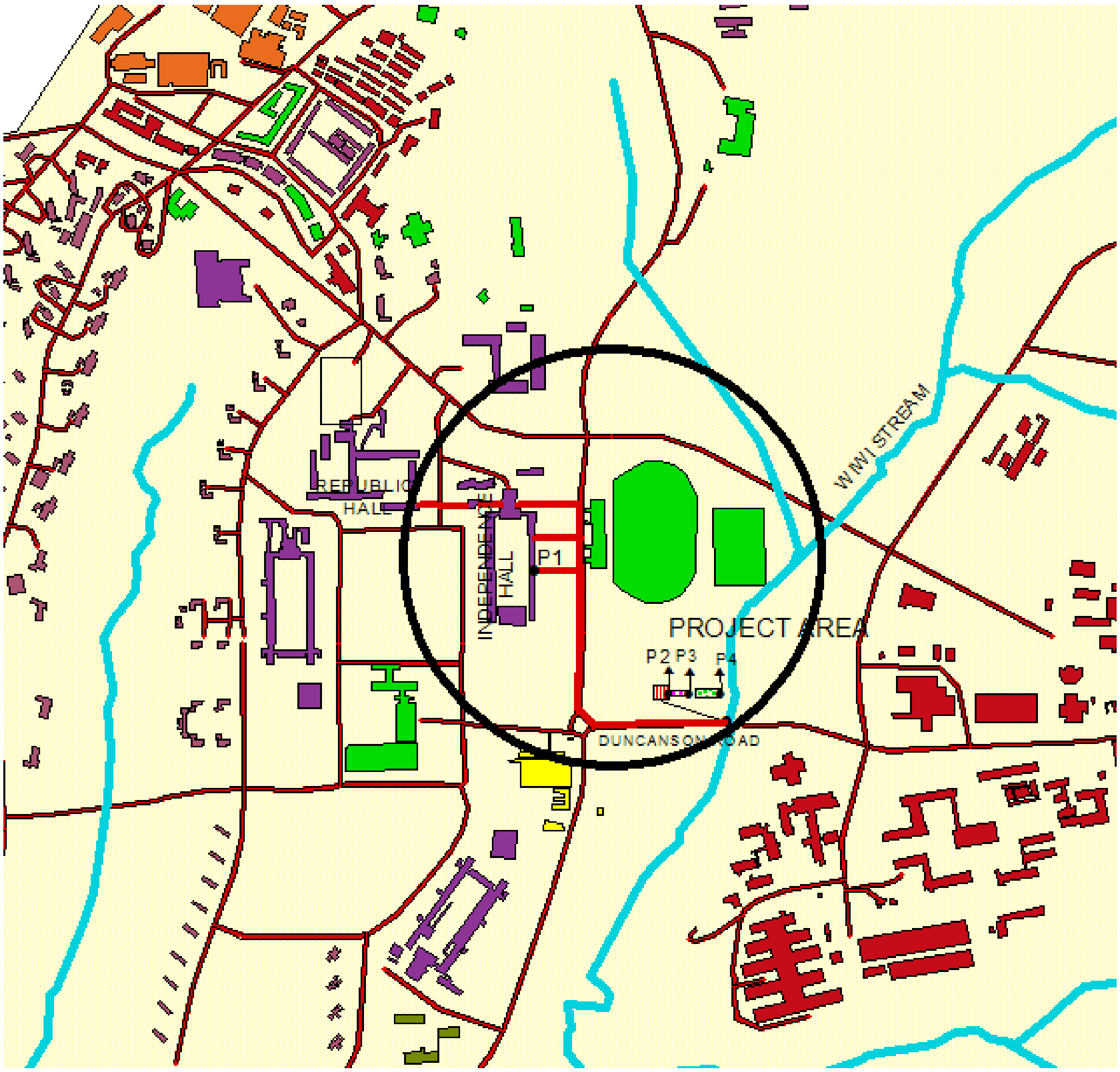


Figure 3.1: Grey water treatment plant location

3.1.2 Infrastructure and Soil characteristic of project area

Housing development at KNUST has in some cases led to the devegetation of small hills due to increasing infrastructure. In addition to this, the existing drains and streams channels have been become incapable of coping with the high amount of runoff, especially in rain season due to the silts or rubbish dump occurring into the drains or stream.

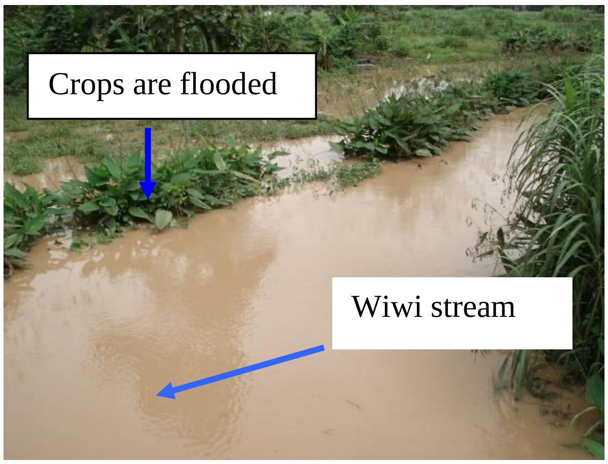


Plate 3.1: Crops in wetland flooded by Wiwi Stream

3.1.3 Biological Quality of the Wiwi Stream

The level of quality of water can be pre-diagnosed or indicated by presence of different communities of aquatic organisms established in the water. The biological diversity of some macroinvertebrates, algae and microorganisms are usually considered to respond to organic pollution compared to others. The Wiwi stream is still used due to the fishing activities in the stream (plates 3.2, 3.3 and 3.4)

Background parameters of Wiwi stream, the stream has BOD range of 46.7-63.4 mg/L and COD range of 80 – 110 mg/L (Environmental Quality Engineering Laboratory; unpublished data, 2005).

Plate 3.2: Fish being caught from Wiwi stream

Plate 3.3: A farmer washing his face at the stream's bank

From plate 3.4 below it could be seen that the grey water colour from Independence hall which enters the Wiwi stream is entirely different from the Wiwi stream. This means that there is some form of stream pollution. Therefore, the ecosystem is also threatened.

Plate 3.4: Grey water discharge into Wiwi stream

3.2 Description of Grey Water Management Situation In KUNST

At KNUST, the wastewater has a combined system of septic tanks in some staff's houses and a centralized sewerage system collecting majority of sewage from the halls, faculty area, and some staff households to be treated using trickling filter treatment plant before being discharged into wiwi stream. However, the grey water of

KNUST is channeled directly into the drains to be discharged into the wetland or streams. Wiwi stream receives the grey water from Unity hall, Independence hall, a half of the Republic hall, University hall, Steven Paris hostel, and Guss hostel ,etc. while the wetland occurring between Buroburo road and Asuogya road collects the grey water from Africa hall, another half of Republic hall, Queen's hall etc. (see the figure 3.1).

3.3 Description and Design of the Treatment Plant

3.3.1 Description of the treatment plant

The Constructed Wetland system receives grey water from the Independence Hall's drains. The C.W system to treat grey water and the storm water from the slopes of the hills of the Independence hall consists of a collector water pond, a sedimentation tank for settling of the heavy particles and floating materials. Then the effluent from sedimentation tank flows into Constructed wetland where it is treated before being discharged into the Wiwi stream. However, there are two chambers for taking samples, one at outlet of sedimentation tank and the second at outlet of constructed wetland. The wetland is designed such that the plant species, cattails (*typha latifolia spp*) grows in the filter medium to assist in the removal of pollutants and oxidation of the filter medium.

The plant is located in the flood plains of the Wiwi stream bridge on left of Duncanson road from Administration roundabout (refer to figure 3.1). The Schematic flow diagram shows the continuous flow from the source of the raw grey water to the discharge.

A means the Raw grey water source from Independence Hall

B means the Storage Tank

C means the Sedimentation Tank

D means the Constructed Wetland

E means the Effluent collector

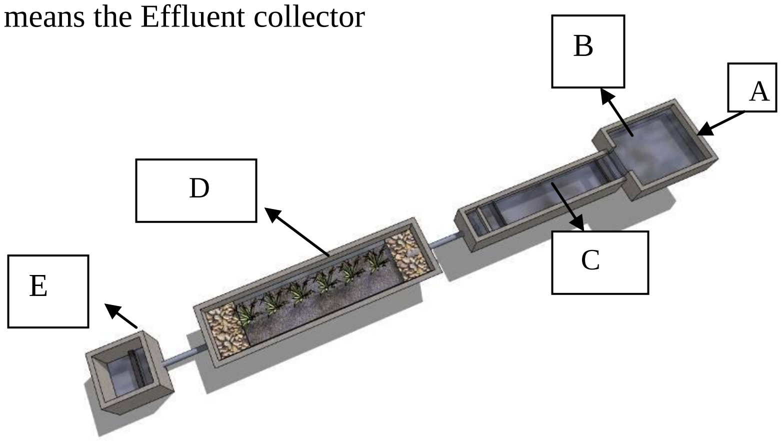


Figure 3.2: Schematic flow diagram for Treatment plant

The raw grey water was channeled from Independence Hall and only 0.48 m^3/d was collected and stored into Storage tank to be pretreated. The pre-settled grey water flowed through the Constructed wetland for treatment. Finally, the effluent is discharged into environment.

3.3.2 Design of the pilot plant

Certain principal information is necessary at the beginning stage of a new constructed wetland design. These data were collected by field survey and were analysed in order to know the decision to be taken without threat the ecosystem or to avoid any occurrence of problem later. Among them are following:

- Site characteristic:

***** Site levels: 268 m – 282m

* Wetland levels: 268m – 272m

* Surface area: 1.8 ha

* Ground water level: 0.6m

* Nature of soil : Silty Clay

- **Characteristic of receiving water**:

* Function of receiving water: (aquaculture, ground water recharge and irrigation of vegetable crop)

- **Preliminary Laboratory of Tests**

Sieve analysis and Hydraulic conductivity of different aggregates of sands and gravels were done in order to determine the appropriate filter medium to be used in constructed wetland. The analysis showed a high flow when gravels and crushed stones were used while there was no flow for raw river sand. Except the sand sieved between 0.6-2 mm gave a good flow and a reasonable hydraulic conductivity, See the details of other filter media checked at appendix 4.

The identification of plants species in the wetland were done by Technicians from the Department Theoretical and Applied biology where they confirmed that cattails (*Typha latifolia spp*), common reeds (*Phragmites*), rush (*Juncus spp*), bulrushes (*Scirpus spp*) and sedges (*Carex spp*) were available and can withstand the high conditions in grey water. They have capacity to grow quickly and carry enough oxygen through their roots. Cattails were selected among others because of their economic use in construction for roofing, in basket wears, in landscape garden and they require small amounts of water. In addition to these, the grey water pH is easily tolerated by cattails. Therefore, the Constructed wetland Treatment Plant was

designed for influent flow rate of 0.48 m^3/day. The designed influent BOD loading was 280 mg/L, COD of 339 mg/L and SS of 81 mg/L. It is required that the effluent BOD and SS should be respectively 35mg/L and 15 mg/L. These values were taken based on the required effluent by Ghana EPA guidelines where final effluent BOD must be less than 50 mg/L and SS, less than 35 mg/L.

The wetland of Sub-Surface Horizontal Flow "SSHF" was selected and designed due to its high efficiency in pollutant removal compared with the surface flow or sub-surface Vertical flow constructed wetland. Measurement of wetland unit was done by using relationship for plug flow reactor and first – order model;

$\frac{dC}{dt} = -k_v C$ ……… (3.1) ; Where C is organics concentration,

k_v is a reaction constant. Equation (3.1) can be rearranged and integrated as follows:

$$\frac{dC}{C} = -k_v dt \rightarrow \int_{in}^{out} \frac{dC}{C} = -k_v \int_{in}^{out} dt \, ;$$

$$\rightarrow \left[\frac{C_{out} - C^*}{C_{in} - C^*} \right] = e^{(-k_v t)} \xrightarrow{2,3,4} \left[\frac{C_{out} - C^*}{C_{in} - C^*} \right] = e^{(-k_A / HLR)}$$

C_{in} = C(t=0) while as C_{out} = C(t=τ). The following formulas were used to transform the above equation: kA = kV ε d............................(3.2)

HLR = Q / A ....(3.3); HLR is the hydraulic loading rate.

V = Q τ = A d ε.……….…….(3.4)

explanation of symbols:

kv = first-order volumetric removal rate (1/day)

kA = first-order areal removal rate (m/day)

C* = background concentration (mg/L)

τ = hydraulic residence time (days); A = surface area (m2)

d = water depth (m) and ε = porosity (dimensionless)

The final equation is given by Cout = Cin * $e^{(-kBOD/HLR)}$ …………..(3.5)

for the BOD_5 (Rousseau,2005); Ah is the plan area of the wetland unit (m^2); kBOD is the specific removal rate constant at 20 ^oC,

The sand media selected among different gravel and crushed stones is coarse sand (0.6 – 2 mm diameter with hydraulic conductivity and porosity were 368.78 and 40%) respectively, while the adopted effective depth was 0.6m. Hydraulic conductivity (K_h) and Porosity (n) of the sand media were measured in Soil laboratory. From equation (3.1), the hydraulic retention time (HRT) is calculated as follows: $\ln\frac{Cout}{Cin} = -k.HRT \rightarrow HRT = \frac{-\ln(Cout/Cin)}{k}$ …………..(3.6); where as $k_t = k_{20}o^{(T-20)}$ ..….(3.7) and the detail of the design is given in Appendix 5.

3.4.2 Experimental set up

The plant was built based on the results obtained in treatment plant design. Plates 3.5, 3.6, 3.7 and 3.8 show the details.

The experimental set up used in this study is shown in different plates.

Plate 3.5: CW Under construction

Plate 3.6: Lining in the CW

Plate 3.5 shows the CW under construction, the plate 3.6 indicates the lining to avoid the infiltration or seepage. Then the plate 3.7 shows the Completed C.W while the plate 3.8 indicates how the plants are ready for harvest.

The sandy unit was planted with the available locally species plants, namely Cattails (*Typha latifolia spp*); see plate 3.7:

Plate 3.7: Completed CW **Plate 3.8: HSSF CW in Operation.**

The efficiency and effectiveness of the constructed wetland was determined by measuring the flow rate at he inlet and outlet. The work was completed in the early month of February 2007(plate 3.7). According to Georgia Environment Protection Development "GEPD" (2002); wetlands need at least four to six weeks for vegetation and biofilm establishment (plate 3.8, the plants were at 6 weeks). In our research, the cattails used were transplanted from a natural wetland and after two weeks were in good condition. Due to the available time limit, the initial sampling started after three weeks and half (Towards beginning of March 2007). Table 3.1 below shows a summary of the design parameters and Appendix 5 also shows details of design of treatment plant.

Table 3.1: Summary of the design parameters for C.W

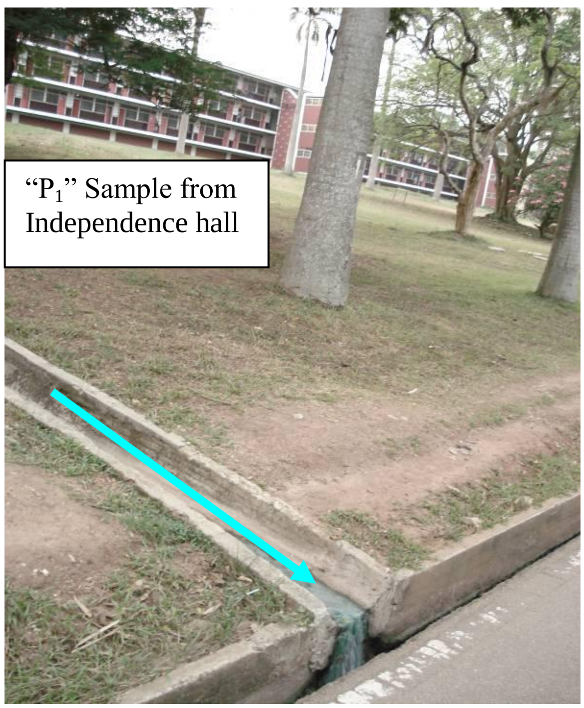
Parameters / Description	Flow rate (m^3/d)	BOD (mg/L)	SS (mg/L)	Reduction %	Hydraulic conditions and media filter	Retention time (hrs)	Dimension (m)
Storage tank	-	-	-	-	-	-	L=1.8, W=1.5, D=0.4
Sedimentation tank	0.480	280	81	SS=60 BOD=25	S = 1%	24	L=3.65,W=0.65,D=0.40
Constructed wetland	0.480	210	32.4	SS=53.7 BOD=83	K_h=368.87; n=40%; S=3.5‰; HLR=17cm/d (8 -30cm/d) D=0.6m;D_w=80%D;Cattails, Coarse sand(0.6-2mm)	36	L=3.5,W=0.80,D=0.80 (Rectangular shape) or L=3.5,W_1=0.6,W_2=1.0 D=0.8(Trapezoidal)
Outlet	-	35	15		-	-	L=0.40,W=0.40,D=0.30

The pilot plant received and treated 0.48m^3/day, a part of the grey water generated by Independence's hall at KNUST. To provide a uniform flow of grey water, gravel (crushed stones) of 10-25mm diameter were used at inlet and outlet of the C.W.

3.4.3 Monitoring and analysis methods

- **Monitoring**

The grey water sampling for analysis was taken from the Independence Hall to the outlet of C.W(P1-P4), but the analysis was focused on sampling taken at the inlet and outlet of C.W(P3-P4), (see plates 3.9 and 3.10).



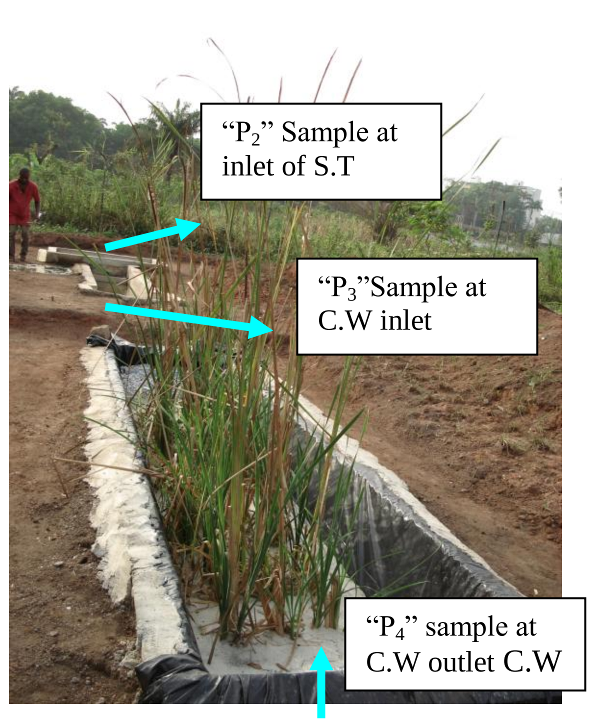


Plate 3.9: Grey water from Independence hall **Plate 3.10: Sampling points**

Grey water influent and effluent from the pilot plant unit were characterized and recorded. The sampling was done once after five days at the morning at 6 a.m (T1) and at the evening at 5 p.m (T2). The sampling work started from the beginning

of March 2007 and was ended in the middle of April 2007. Samples were taken through the manholes using 0.5 liter plastic bottles in every five days at 6h:00 am and at 5h:00 pm. The night sampling was not taken because of the difficulty in getting to the site and the grey water flow is almost negligible.

Then the samples collected labeled immediately based on the steps of treatment, (See plate 3.11). As a precaution, samples were taken a little below the water surface to prevent the sampling of floating substances.

Plate 3.11 Test analysis in situ

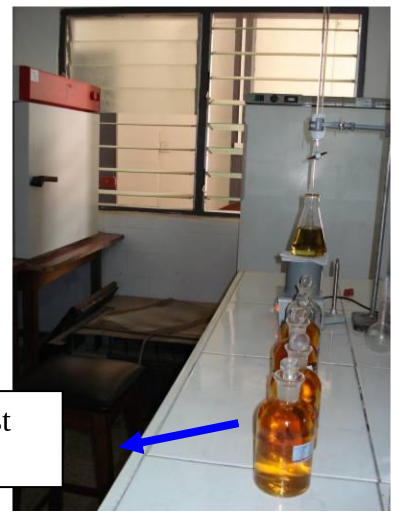


Plate 3.12 Test analysis in Lab.

The following physical parameters were determined:

1. Temperature and pH, a digital double junction pH Scan 3+ measuring kit with probe was used to measure them. These parameters were taken in situ to avoid changing of values due to environmental condition.
2. Suspended solids were determined using the gravimetric method.

Other parameters Conductivity, Grease, nutrients were determined in the laboratory on the same day and the analysis for COD was done using the open reflux titrimetric method with potassium dichromate in sulphuric acid as oxidation reagent; while as

BOD, 5 days in incubation at 20^oC with Winkler Modification method for oxygen determination was used (See plate 3.12).

a. NO_3^- - N, the Cadmium Reduction Method with Nitra Ver 5 powder pillows as reagent was applied after filtration and dilution of the samples and NO_2 – N, the Diazotization method using powder pillows while as PO_4– P was used with Phos Ver 3 phosphate powder pillows.
b. FC, TC was calculated using the spread plate method with chromocult as media.

- The analyses which could not be performed on the same day, the water samples were stored at ± 4 ^oC without adding chemicals for 1 day. Then, the average values of the different parameters were obtained. The meteorological daily average data (air temperature, precipitation, sunshine and evaporation) were provided from the nearest meteorological station of the Kumasi metrological services stationed around the Kumasi- Airport. The water quality parameters were measured using the standard Methods for the Examination of Water and Waste Water (APHA, 1992 and Hach Company, 1996).

- **Statistical analysis**

To determine whether the treatment performances of the treatment plant at inlet and outlet or between morning and at evening were statistically different, one-way ANOVA at a significance level of 0.05 was applied for each of the water quality parameters. Beside these, the effluent water quality for the treatment plant were compared with water quality parameters for Ghana EPA. These analyses were

conducted by using a sub-program of Microsoft Office Software EXCEL XP and SPSS program.

4 RESULTS AND DISCUSSION

4.1 Design and construction of C.W at KNUST

4.1.1 Soil used in Constructed Wetland

Based on the results obtained in the table 4.1, the washed and sieved sand from Afisiyaso in Kumasi was selected and used in constructed wetland due to its good hydraulic conductivity of 368.87 cm^3/ d which gives the hydraulic loading rate of 0.17m/d, (details were given in appendix 5). Referring to the design criteria as summarized in table 2.2, the hydraulic loading rate was in range recommended, (0.08 < HLR > 0.30 m/d).

Table 4.1: Characteristics of the different filter media

Description	Size Particle (mm)	Porosity (%)	Hydraulic conductivity "Kh" (cm^3/d)	Uniformity Coefficient	Percentage Passing under 0.6mm (%)
Barekese sand	0.075 - 9.5	31	5,394.35	38.89	19.48
River material	0.60 - 6.70	35	1,258.50	1.64	0.04
Afisiyaso raw sand	0.075 – 13.20	34	0.0016	5.45	34.79
Washed and sieved Afisiyaso sand	0.60 – 2.00	40	368.87	2.57	0.02
Afisiyaso sieved sand	2 – 9.5	33	939.94	5.45	0.02

It was observed that the higher the difference between particle size aggregates, the higher hydraulic conductivities, but the lower the porosity (See the table 4.1). This may be caused by the small percentage of fine particle in the sample.

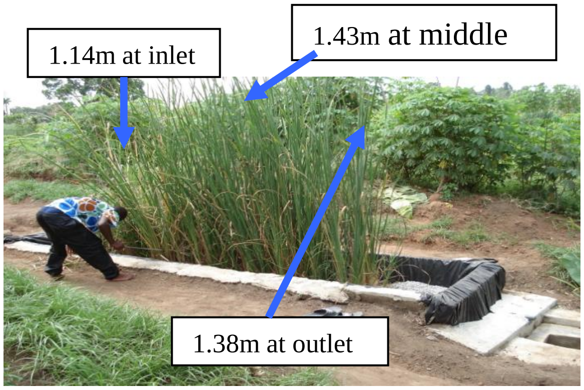
The presence of high fine particles in sample caused the clogging during in our experience in laboratory and the hydraulic conductivity was very small (the 34.7% of passing in 0.6mm sieve in Afisiyaso raw sand caused the small hydraulic conductivity of 0.0016 cm^3/d). According to Metcalf (1991), the characteristics of the filter media used in subsurface flow system were medium sand, coarse sand or gravelly sand. In our study, the partical size distribution curve of the filter media was checked during design where the hydraulic loading rate of 17 cm/d was in range between 8 – 30 cm/d (see the table 2.2 or the details in appendix 5).

About the uniformity coefficient, the US EPA recommends the maximum of 4 (US EPA, 1993). For this project, the soil selected had a Uniformity coefficient of 2.57 and there good for dewatering as recommended (see the grading chart of sieve analysis in appendix 4).

4.1.2 Species plants used in Sub-surface flow Constructed Wetland

Cattails, Common reeds, rushs, bulrushs and sedge were available in some wetlands of Kumasi Metropolitan Assembly (in Atonso, Ahensan) and in huge quantities are located in Bosomtwi lake wetland in Atwima Kwanwoma District. These plants are the major species recommended by US EPA (1988), Metcalf (1991). Planted cattails in constructed wetland as same as samples of rush and bulrush were grown well (see the plate 3.10 and 4.1). It was observed that the plants grew more in the middle of the C.W than in the extremities where the average length measurements

from inlet to outlet were 1.14m, 1.43m and 1.38m respectively. This could be due to availability and quantity plant needs. It means that, at the inlet, the nutrients may be high so as become dangerous to the plants while as at outlet they may be low.



The design and construction of constructed wetland was done and it operated efficiently. At this stage the plants were ready for harvest.

Plate 4.1: Harvest can be used for the purpose

The plants species should be grown well without any problem because the Independence Hall grey water characteristics were in range of water quality for irrigation, (table 4.2). Beside this, based on the table 2.1 the parameters like temperature of 10-30 ^{o}C, pH of 4-10 for the cattails were most matched with the grey water characteristics. The problem was feacal coliforms which were very high in grey water likely to contaminate the crops.

Table 4.2: Application of grey water in irrigation

References	pH	Salinity mg/L	NO_3^- -N mg/L	Conductivity µs/m	T(^oC)	F.C No/100mL
KNUT Grey water characteristic *	7.74 ± 0.43	0.36 ± 0.19	15.25 ± 3.31	0.987± 0.26	29.55 ± 0.85	8.48E+04
Water quality for irrigation **	6 - 8	0 - 3	5 -30	0.7 – 0.2	-	1.0E+04

Source:* Results done during the research
Source: ** Published by Carr, et al., (2004).

4.2 Performance of the pilot plant

4.2.1 Flow rate in Horizontal Sub-surface Flow Constructed Wetland

The figure 4.1below shows the trend of the flow rate variations for constructed wetland in which has almost the same inlet values, while outlet values varied. The effluent flow rate of the plant is 0.327 m^3/ day instead of 0.48 m^3/ day.

Factors contributing to the difference may be due to the evapotranspiration (Rousseau, 2005). The water loss from 0.48 m^3/ day to 0.327 m^3/ day is high and is true. With Water balance calculation, the daily average outflow discharge (Qo) was 0.483 m^3/ day which is the same with the design flow rate. Thus, daily average outflow discharges (Qo) were calculated by adding the difference of the evapotranspiration (ETP) and rain values (P) multiplied by area (A) 2.8 m^2 to the daily measured inflow values (Qi). As follows: Qo = Qi +(P–ETP)x A, (Korkusuz et al, 2004).

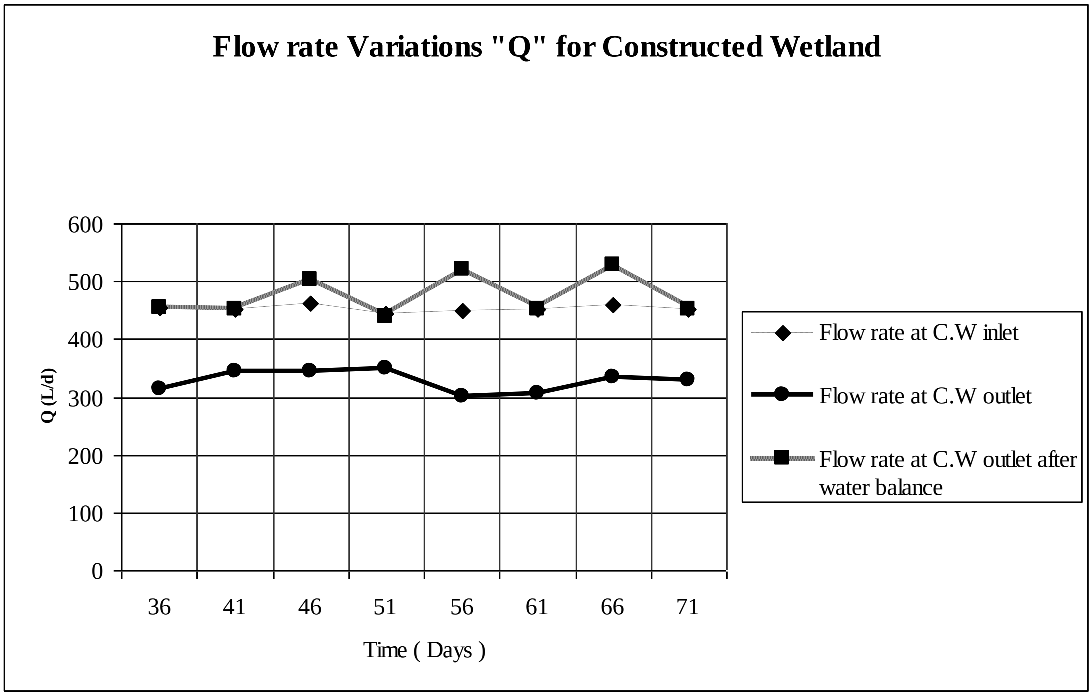


Figure 4. 1: Flow rate Variations in C.W

The figure 4.2 shows how the evapotranspiration affects flow rate observed in figure 4.1.

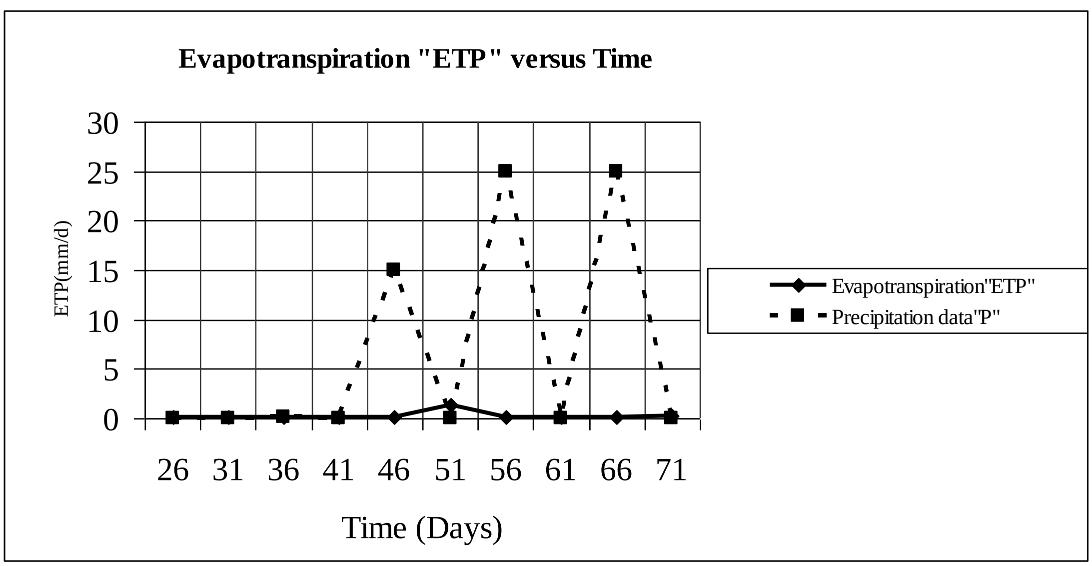


Figure 4.2: Evapotranspiration versus Time

- **The consequence of the water balance on the pollutant concentrations of the constructed wetland.**

The addition or loss of water (precipitation, evapotranspiration) in construction wetland have impact on the inflow and outflow concentrations of the pollutants, they causing water quality parameter fluctuations (figures 4.5 - 4.11). This was also quoted by IWA (2000) where the pollutant concentrations were affected by the additional water.

Figures 4.9 and 4.10 show how the parameters were affected by precipitation in those days. The COD concentrations decreased from 176 mg/L to 96 mg/L and from 40 mg/L to 16 mg/L for 51^{st} to 56^{th} and 61^{st} to 66^{th} days respectively. These reduced pollutant concentrations resulted from dilution by precipitation within the wetland, resulting in lower effluent values. In contrast, evaporation and evapotranspiration concentrate the pollutant concentrations in the wetland due to the decrease in the water levels so that the measured effluent values were higher than the rain period. For COD concentration, from 46^{th} to 56^{th} days the values were increased and decreased on 51^{st} day because of respective adverse evapotranspiration changes, (figure 4.2).

4.2.2 Retention Time in Horizontal Sub-surface Flow Constructed Wetland

Considering the figure 4.3, the retention time was increased with the time. This may be due to accumulation of organic matter in the filter media and formation of film by microorganism. Again the value of retention time increased with the high removal of BOD (See the trend of BOD in figure 4.9)

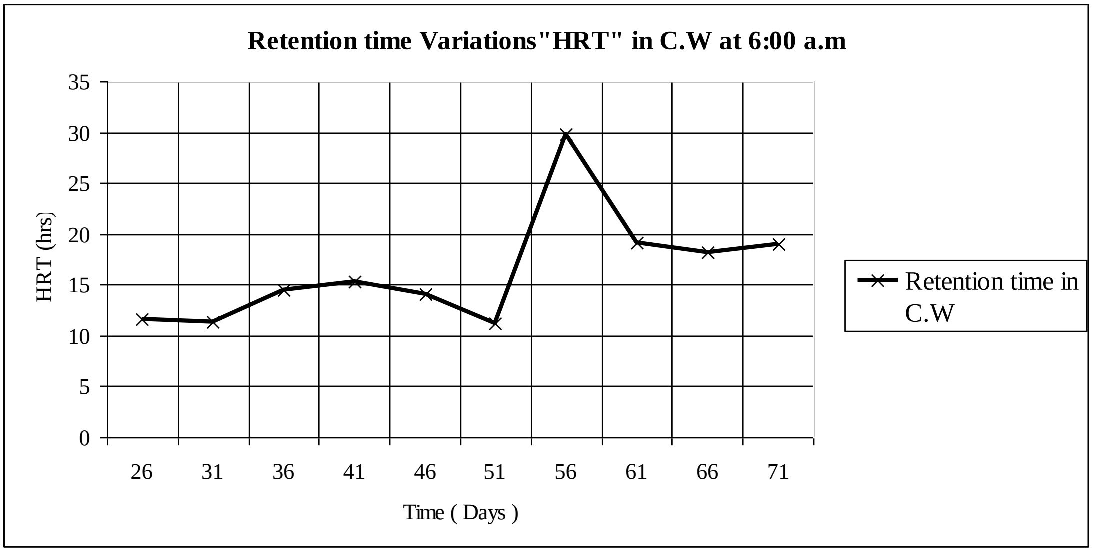


Figure 4.3: Retention time Variations at 6:00 a.m

The average Retention Time or Hydraulic Retention Time (HRT) was 16 days. Rapid increase in HRT on the 51st day may be due to higher contaminant load in the influent. Higher precipitation can reduce the HRT as seen from 56th day to 61st day.

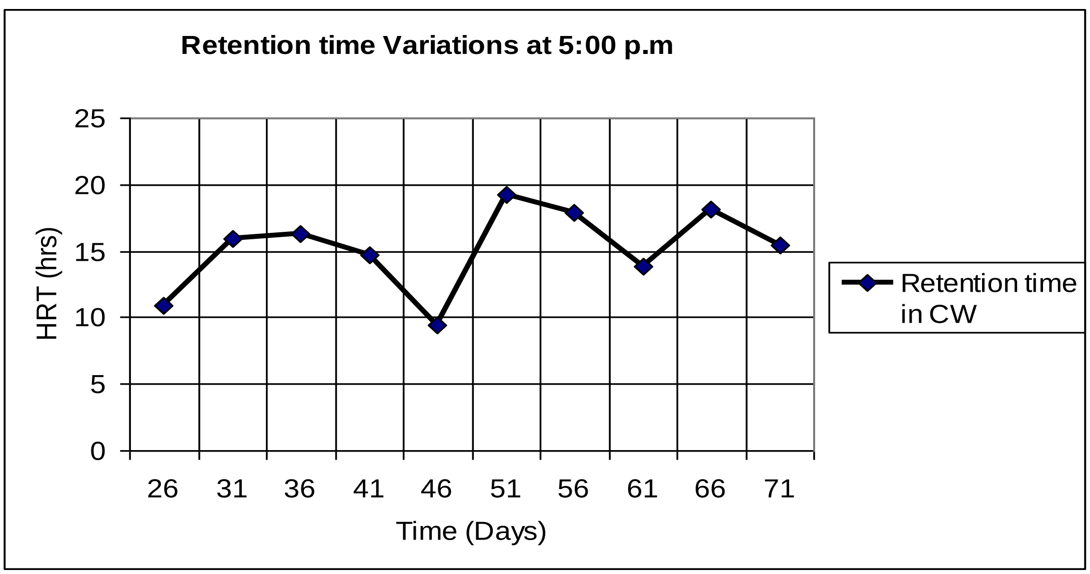


Figure 4.4: Retention time Variations at 5:00 p.m

The average Hydraulic Retention Time was 15 days. There is no difference between retention time at 6:00 a.m and at 5:00 p.m, therefore the retention time for the treatment could be 15 hours.

The retention period measured in C.W was less than the design retention period (15hrs versus 36hrs expected). This difference might have resulted from the test errors, power cuts during BOD incubation or the environment condition fluctuation during the day of sampling.

4.2.3 Efficiencies of pilot plant.

The results obtained for major parameters analysed are shown below in table 4.3 while other parameters could be found in appendix 7.

Table 4.3 below gives the summary of the average parameters for physical, chemical and bacteriological qualities where the treatment effectiveness was evaluated and indicated mean removal efficiencies.

- As shown in table 4.3, the constructed wetland showed satisfactory removal with respect to SS, BOD, COD, Grease, F.C between 72 to 79% while Nitrate – Nitrogen, Nitrite- Nitrogen, Phosphate- Phosphorus showed removal efficiencies between 34 – 52%.

Table 4.3: Average Percentage Removal efficiencies of the C.W at KNUST

(Grey water from Independence Hall).

Parameters	Efficiency at 6:00 a.m (%)	Efficiency at 5:00 p.m (%)	Efficiency of the plant (%)	P-Values for significance
S.S(mg/l)	77 ± 15	81 ± 9	79 ± 12	0.53
Grease(mg/l)	77 ± 7	74 ± 4	75 ± 6	0.34
NO_3^- -N(mg/l)	55 ± 28	51 ± 27	53 ± 27	0.79
NO_2^- -N(mg/l)	61 ± 25	45 ± 25	52 ± 25	0.18
PO_4^{3-} -P(mg/l)	29 ± 15	39 ± 26	34 ± 21	0.29
BOD(mg/l)	73 ± 10	71 ± 6	72 ± 8	0.65
COD(mg/l)	74 ± 15	79 ± 9	77 ± 12	0.36
F.C(No/100ml)	80 ± 10	71 ± 28	75 ± 22	0.40
P > 0.05 non significant				

- According to Hammer, 1988, the constructed wetland has capacity to remove BOD, COD, SS and Bacteriological at 90% while N and P are removed at 50%. Therefore, the obtained results are less than the values of literature. The results of the pilot plant are closer to the literature values (the study made at University of Dare-salaam, see table 2.6), in which, FC removed was 91%. COD and SS showed 65.7% and 79.8% Removal.

- The P-Values of all parameters are more than 0.05 ($P > 0.05$), it means that the performance of the treatment at morning and at evening were not statistically different.

- The high removal in constructed wetland observed, justify the

performance of the filter media, plants species used within the pilot plant, and the microorganisms responsible for breaking down the contaminant load. These are supported by IWA (2000) where in the wetland systems, COD was removed by aerobically and anaerobically heterotrophic microorganisms.

- The Ultra Violet "UV" light has impact on coliforms removal thus some

coliforms were killed. The role of algae and bigger microorganisms might contributed to the reduction in coliforms. Moreover factors like straining and adsorption during filtration contribute to the coliform reduction. Grey water coming out of a sedimentation tank contains little or no oxygen, which possibly affected aerobic bacteria

4.2.4 Effluent water quality of C.W

The effluent water qualities (at morning 6:00 a.m and at 5:00 p.m) of the pilot plant obtained during the study are summarized in table 4.4 below and compared with Ghana EPA Guidelines and design parameters in table 4.5.

The removal efficiency of the pollutants by the constructed wetland in the morning and evening showed no significant statistically difference. Since P Values were greater than 0.05 ($P > 0.05$) for all parameters.

Table 4.4: Average Influent and Effluent Concentrations of the C.W

Parameters	Influent		Effluent		P-Values for efficiency	
	morning	evening	morning	evening	morning	evening
SS	165.50 ± 86.0	157.00 ± 60.24	33.30 ± 21.63	34.00 ± 21.45	0.00	0.00
Grease	153.80 ± 30.53	139.20 ± 6.86	36.90 ± 14.81	36.00 ± 7.06	0.00	0.00
NO_3^- - N	11.36 ± 3.72	8.25 ± 1.71	4.98 ± 2.88	4.20 ± 2.71	0.00	0.00
NO_2^- - N	5.21 ± 5.46	4.14 ± 4.23	2.88 ± 3.05	2.47 ± 2.68	0.25	0.32
PO_4^{3-} - P	12.10 ± 3.68	10.07 ± 3.81	8.55 ± 3.05	5.63 ± 2.29	0.03	0.01
BOD	357.50 ± 141.19	250.00 ± 48.59	96.00 ± 49.71	71.00 ± 17.92	0.00	0.00
COD	428.00 ± 106.15	370.40 ± 101.83	113.60 ± 71.44	84.00 ± 48.63	0.00	0.00
FC	6.9E+04 ± 3.9E+04	6.55E+04 ± 7.31E+04	1.35E+04 ± 7.97E+03	1.46E+04 ± 1.63E+04	0.00	0.04
N.B: All parameters are given in mg/L except FC which is given in No/100mL ; P > 0.05 Non significant						

Based on the obtained results (table 4.5 below), only the major water quality parameters were used to make discussion, observation, conclusion and recommendations.

- SS effluent values of the treatment plant (33.65 ± 20.97) were less than Ghana EPA guideline (< 50 mg/L).
- COD effluent values of the treatment plant were less than Ghana EPA
- Grease, NO_3^- -N, NO_2^- -N, PO_4^{3-} -P, BOD and F.C effluent values were higher than Ghana EPA guideline.
- The values of other parameters done are given in appendix 7.

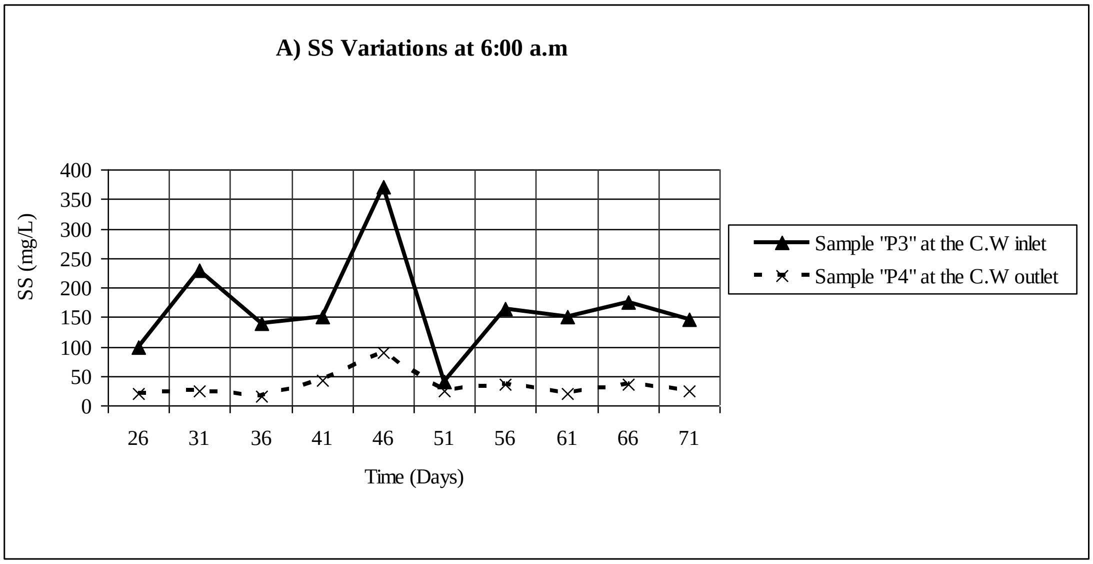
Table 4.5: Average Final Effluent Parameters Compared with EPA Guidelines and design parameters.

Parameters	Average Effluent Values	Design Parameter	EPA Guideline*
S.S(mg/L)	33.65 ± 20.97	15	< 50
Grease(mg/L)	36.45 ± 11.30	-	10
NO_3^--N(mg/L)	4.59 ± 2.75		0.1
NO_2^--N(mg/L)	2.67 ± 2.80	-	0.1
PO_4^{3-}-P(mg/L)	7.09 ± 3.02	-	2
BOD(mg/L)	83.50 ± 38.56	35	< 50
COD(mg/L)	98.80 ± 61.38		<2 50
F.C(No/100mL)	1.4E+04 ± 1.2E+04	-	500
Source: * Ghana Environmental Protection Agency, 1997			

The reasons why these effluent water qualities did not meet Ghana EPA guideline may be attributed to the following:

- Raw grey water fluctuations were observed (see the figures 4.5 to 4.11) and they are higher than the background grey water or grey water characteristics during the constructed wetland design (see table 2.1 and 3.1).

The trend given by the inlet and effluent water quality parameters show that there were fluctuation in raw grey water. As a result, there were also variations in removal of the pollutants (figure 4.5 below). For physical parameters, i.e SS; the high removal efficiency shown in figure 4.5, might be caused by filtration and sedimentation mechanisms as quoted by Vymazal, (2000).



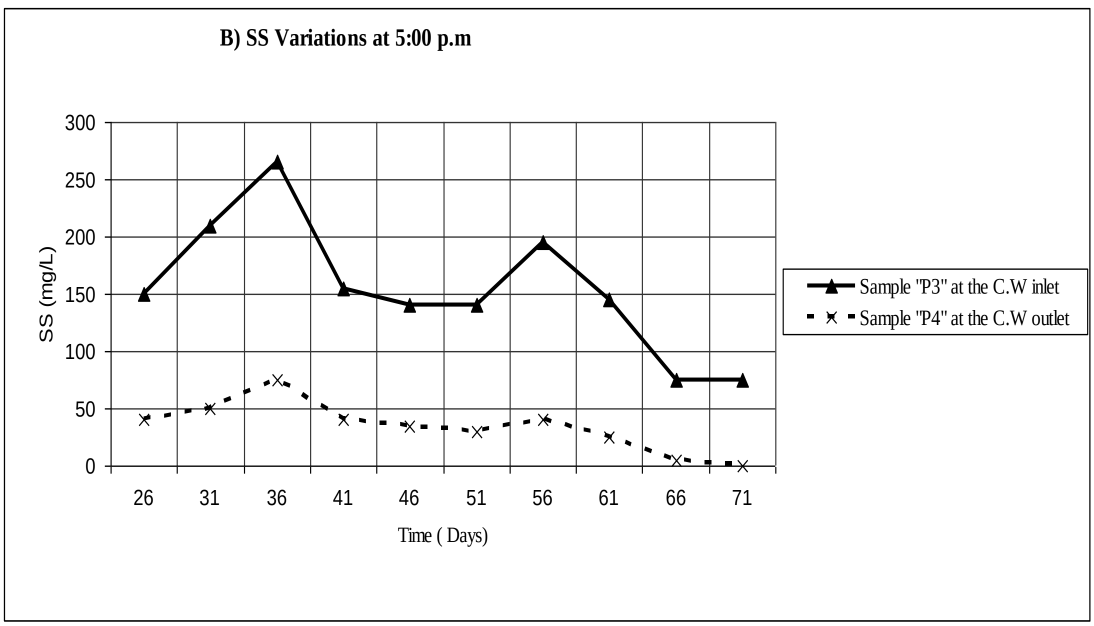


Figure 4.5: SS Variations at 6:00 a.m and at 5:00 p.m

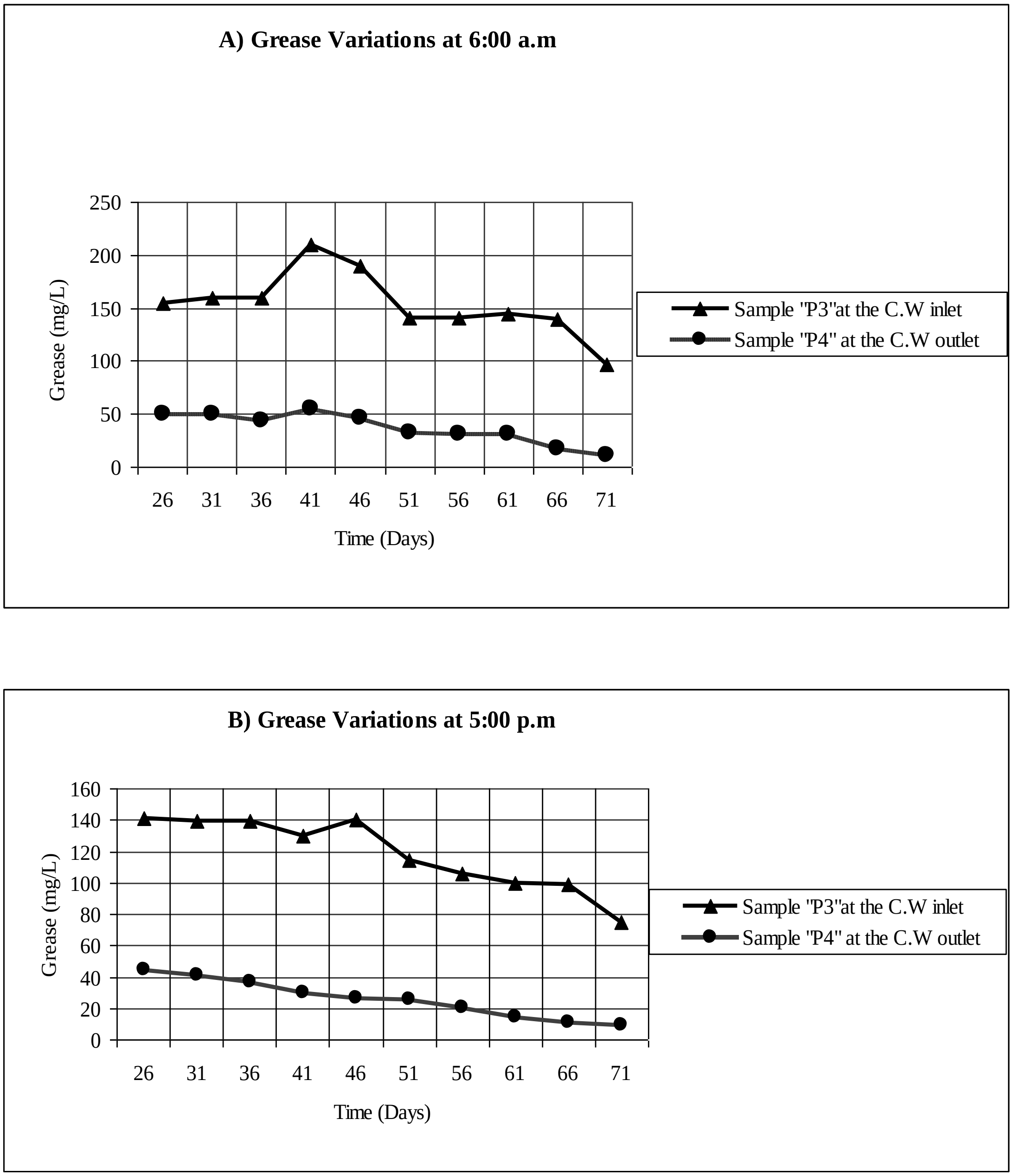
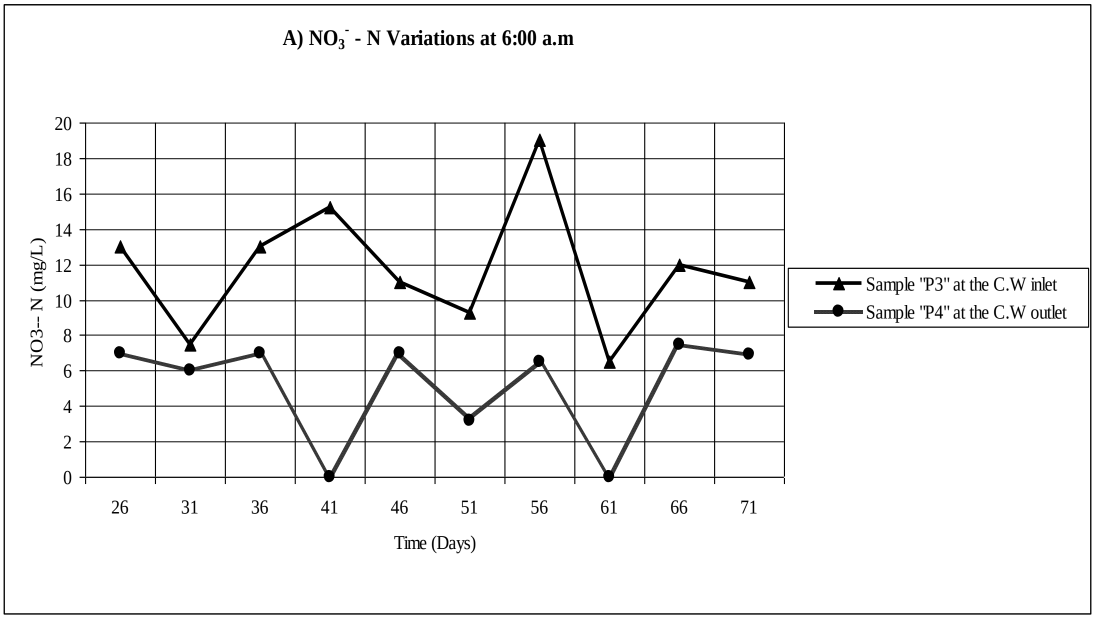


Figure 4.6: Grease Variations at 6:00 a.m and at 5:00 p.m

The high removal efficiency shown in figure 4.6, might be caused by flotation and filtration as quoted by Metcalf, et al., (1991).



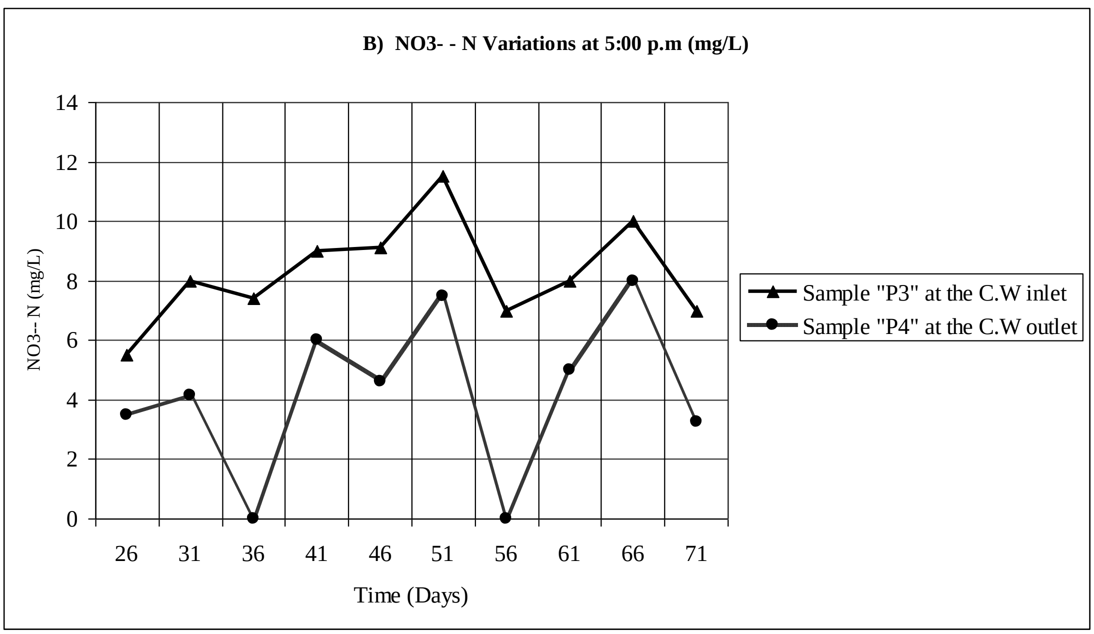


Figure 4.7: Nitrate Nitrogen Variations at 6:00 a.m and at 5:00 p.m

The removal efficiency shown in figure 4.7 might be caused by Volatilization by leaves or settling by filter media as quoted by Hammer, (1988).

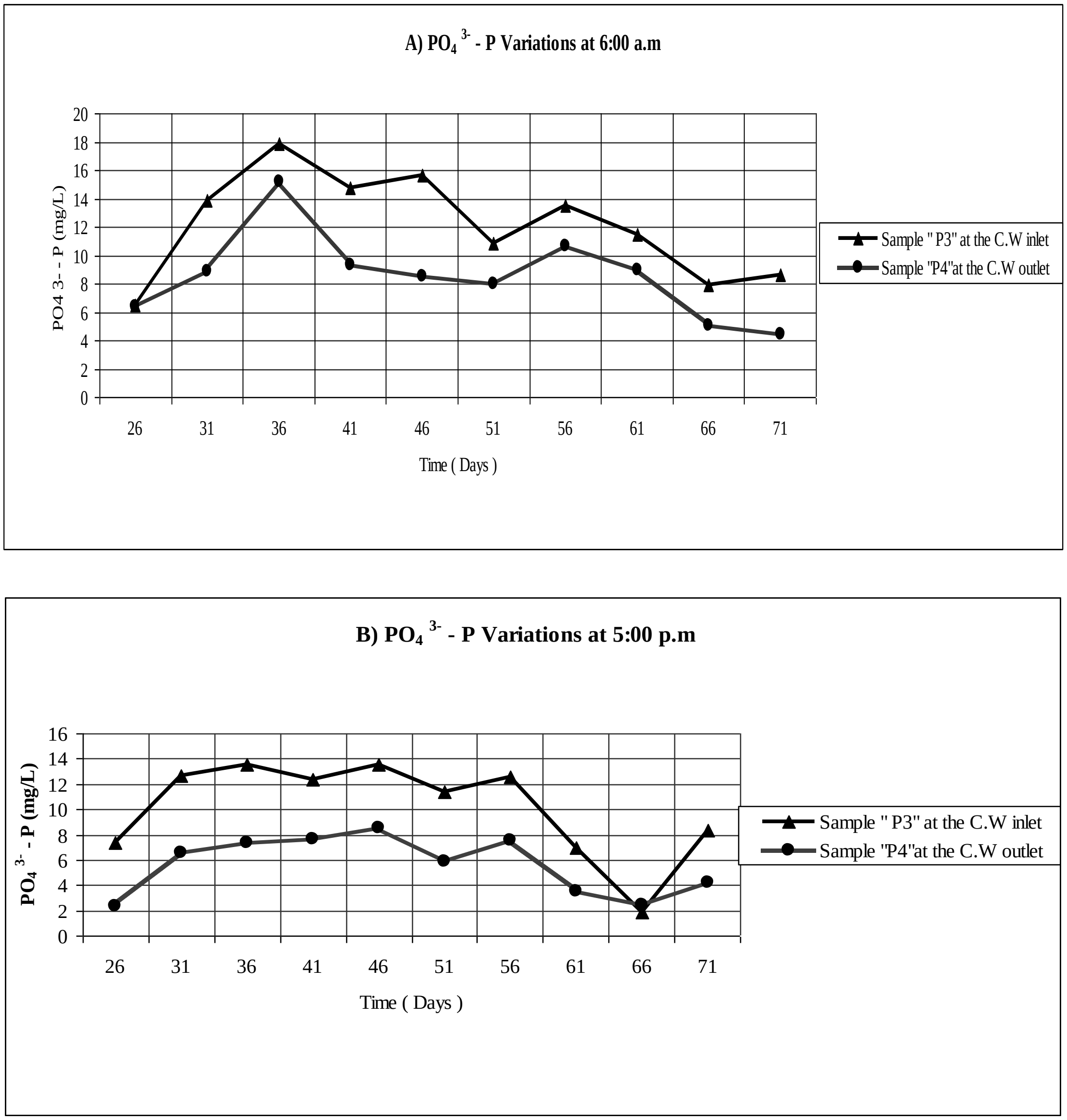
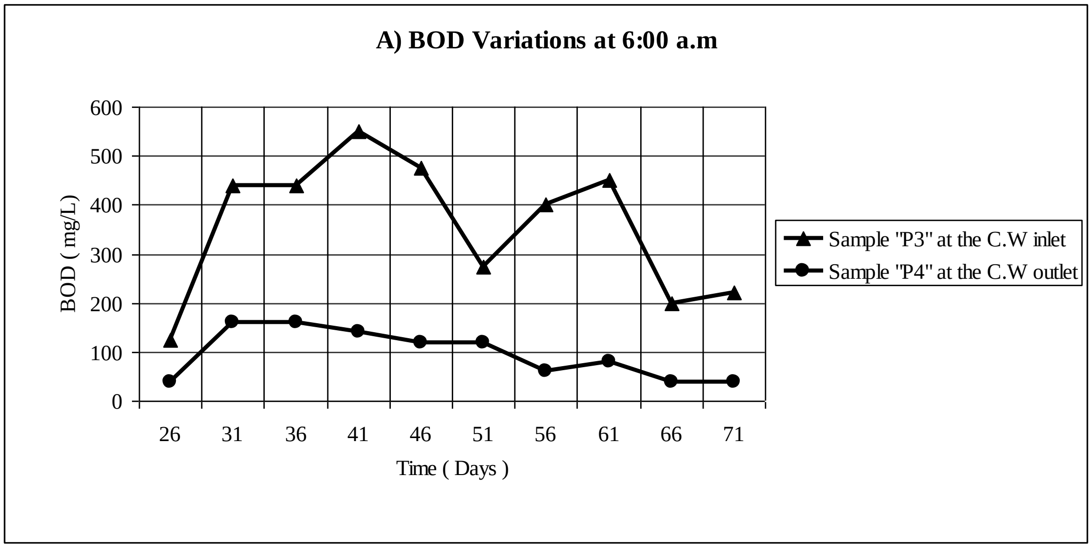


Figure 4.8 : Phosphate - Phosphorus Variations at 6:00 a.m and at 5:00 p.m

The phosphate removal shown in figure 4.8 might be caused by uptake by roots, adsorption by filter media and sedimentation mechanisms as quoted by EPA (1993).



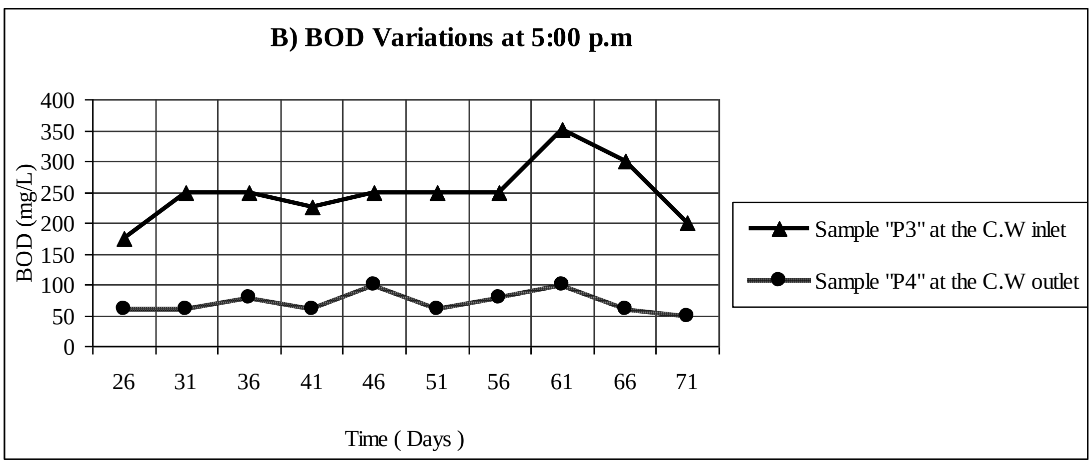
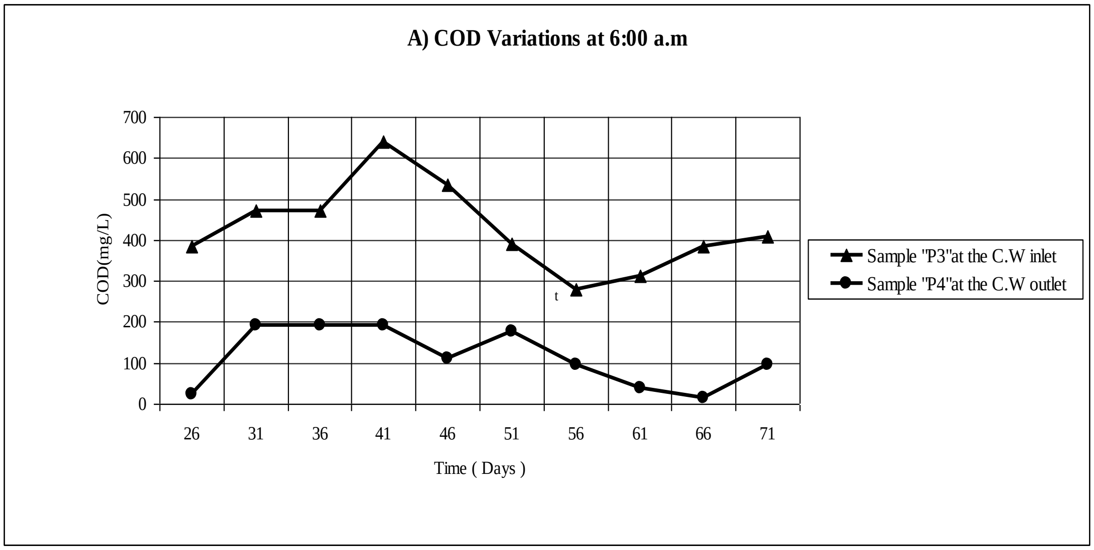


Figure 4.9 : BOD Variations at 6:00 a.m and at 5:00 p.m

The high BOD removal efficiency shown in figure 4.9 might be caused by microbial respiration by stems and leaves and sedimentation mechanisms as quoted by Vymazal, (2000).



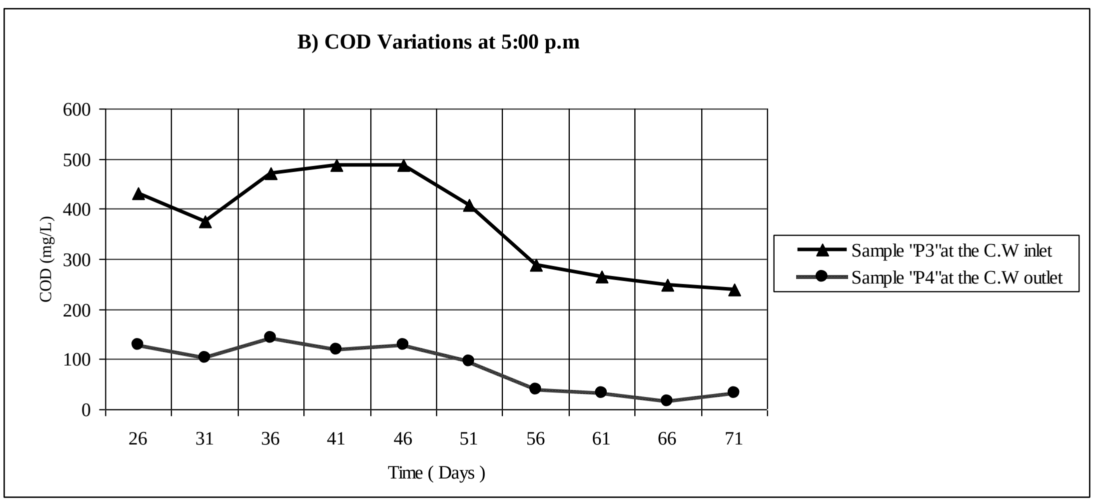
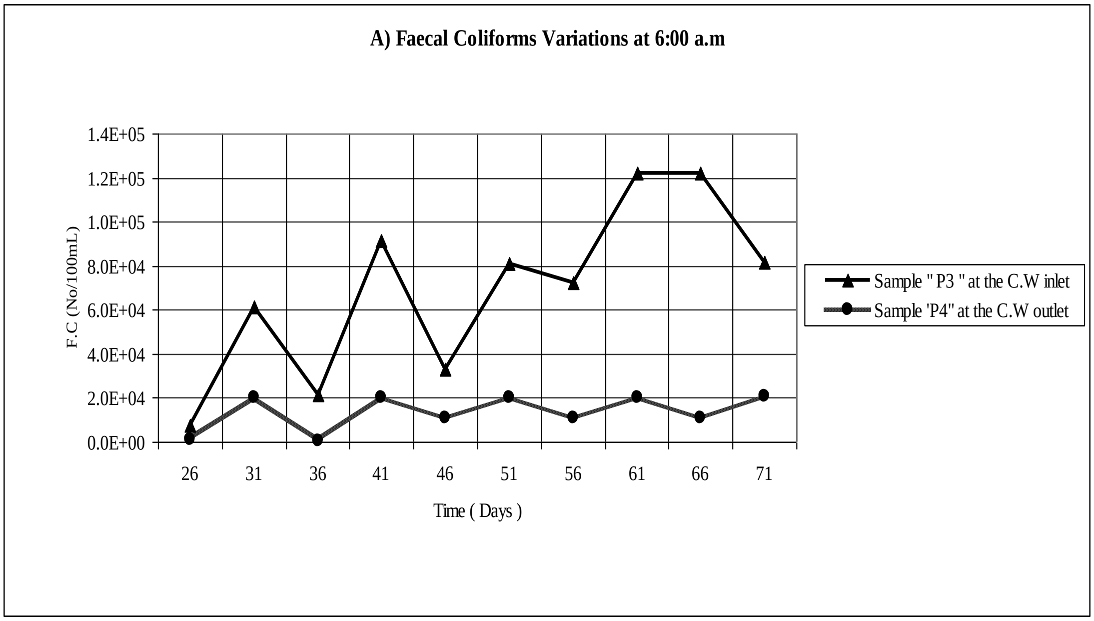


Figure 4.10: COD Variations at 6:00 a.m and at 5:00 p.m

The high COD removal efficiency in constructed wetland shown in figure 4.10 might be caused by retention time and sedimentation mechanisms, (http:/www.ingentaconnect.com/wef/wer/2001/00000073/00000005/art00010).



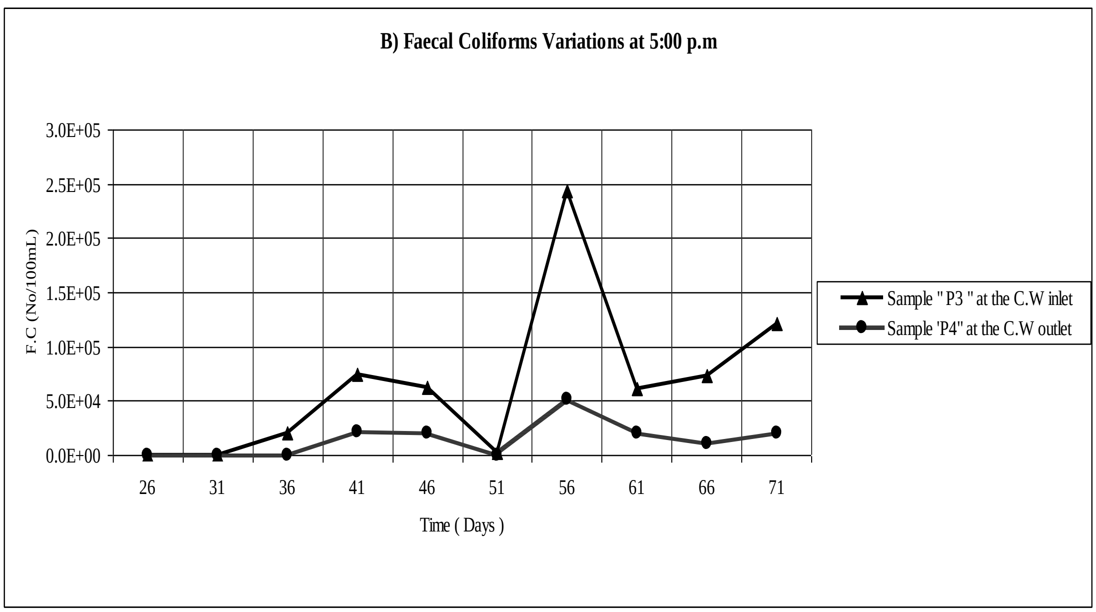


Figure 4.11: FC Variations at 6:00 a.m and at 5:00 p.m

4.3 Characteristics of grey water generated from KNUST

Table 4.6: Characteristics of Grey water Generated at KNUST
(Independence Hall)

References	Parameters								
	pH	SS	Grease	$NO_3^- - N$	$NO_2^- - N$	$PO_4^{3-} - P$	COD	BOD	FC
Raw grey water (KNUST)	7.74 ± 0.43	347.03 ± 90.18	287.30 ± 55.62	15.25 ± 3.31	57.50 ± 20.09	26.18 ± 13.98	874.00 ± 233.74	538.50 ± 159.44	8.49E+4 ± 9.9E+04
Final effluent treated	7.08 ± 0.26	33.65 ± 20.97	36.45 ± 11.30	4.59 ± 2.75	2.67 ± 2.80	7.09 ± 3.02	98.80 ± 61.38	83.50 ± 38.56	1.4E+04 ± 1.2E+04
Typical domestic waste water values *	7.95± 2.95	166.55 ± 163.4	-	0.0	-	37.00 ±36.99	691.9 ±688.9	746.5± 713.5	-

Source: * Khan S.J et al., (2005).

These characteristics were very high compared with literature results (table 4.6). This may be caused by mixing the grey water from the kitchen with the grey water from laundry and bathroom. Beside this, the users are not aware of the danger of grey water so that they can not avoid the solid particles in waste water.

Observation:

Temperature (see appendix 7 and 8)

For the constructed wetland (at morning 6 a.m), the grey water temperature seemed to be more or less constant (no significant variation) for their inlet and outlet (see table 7.1 and figure 8.1 in appendix 7 and 8 respectively). Again the average temperatures at morning were higher at the outlet and variations ranged from 29.14 to 29.89 ^{o}C. These happened because of the sub-surface flow, the accumulated heat

from the sun influenced the inlet temperature, giving rise to higher of influent grey water temperature.

At evening, the average temperatures at inlet and outlet of the constructed wetland were closer (average temperature varied from 29.57 to 30.01 ^{o}C). It means that the filter media continue to keep the heat.

Conductivity (see appendix 7 and 8)

The conductivity from the inlet to outlet (i.e evening) ranged between 617.98 micro s/cm and 566.91 micros/m. This is characterised by movement of inorganic ions in solution which are not easily removed by factors affecting filtration thus the low removal rate (Sawyer and McCarty, 1978)

pH value (see appendix 7 and 8)

During the sunlight hours of the day, the algae remove CO_2 from the water for use in photosynthesis and release O_2, this increases the pH.

This process is reversed during the dark hours of the day, resulting in diurnal pH and dissolved oxygen variations (Sawyer and McCarty, 1978). So, the observed lowering of pH (from inlet to outlet) was probably attributed to the dilution from rain-fall or from activities of algae occurred in CW during the dark hours and pH was increased during the day due to the sunlight and presence of algae.

F.C removal

Due to high microbiological activity in C.W, probably a high reduction in coliform group was achieved, but the value of Ghana EPA was not achieved. Other attributes for the coliform removal were filtration, natural die-off, ultraviolet radiation and excretion of antibiotics from roots of *Typha latifolia*.

- The high pathogen removal obtained in CW could be also due to the Sunlight penetration causing the damage to the cytoplasmic content (Ewuah et al.,2002; Darvis-Colley et al.,1997).

- As quoted by (Curtis, 1990) high D.O levels could be the cause of high removal of some bacterial in the presence of some algae, light during afternoon period and as well as the long retention period (Oragui et al, 1987).

- Fluctuation in pH (Parhad and Rao, 1974) and presence of predators (Ellis, 1983) could also be one of the reason of die-off of pathogens.

- Aeration enhances F.C die-off rates (Klock, 1971). This could be confirmed by the F.C variations from P_1 to P_2, in which the grey water was in open channel.

The fluctuations in the influent concentrations reflected the hourly, daily, and weather variations of the raw grey water received from the gutters.

Since the gutters also received the surface runoff, the concentrations of some of the grey water parameters changed when it rains.

Especially during the heavy rainy days at 46th days and 66th days, the influent concentrations of SS (Figure 4.5), PO_3^{4-}-P (Figure 8.8 in appendix 8) showed increases due to the additional inorganic materials carried by the surface runoff, whereas the nitrogen concentrations (Figure 8.6 in appendix 8) of grey water decreased because of dilution by the rain water.

Constructed wetland treatments require relatively simple O&M procedures which local people can be easily trained to do. During the monitoring, only one person was used to check the clogging and fetching grey water.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In order to assess the potential of constructed wetland in the treatment of grey water at Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, the conclusions drawn from the study with respect to the objectives are the following:

- A Horizontal Sub-surface Flow "HSF" constructed wetland with dimension of 3.5m x 0.8m x 0.8m was designed and implemented in February 2007 on the campus of KNUST to treat primarily treated grey water from sedimentation tank.
- In the wetland bed, the filter media selected among the different filter media was coarse sand with size particle of 0.6-2mm and the hydraulic conductivity of 368.78 cm^3/ d, with uniformity coefficient of 2.57. Cattail (*Typha latifolia spp*) selected as the plants species for the vegetative growth.
- The effluent flow rate of the plant is 0.327 m^3/ day instead of 0.48 m^3/ day and the retention period measured in Constructed Wetland was 15hrs compared to 36hrs expected.
- The Sandy vegetated constructed wetland performed efficiently in sense of the pollutants removal. The removal efficiencies of effluent water quality were as follows:

- BOD, COD, SS, Grease, F.C showed between 72% to 78% removal for the period of seven weeks of monitoring.

- The average nutrients (Nitrogen and Phosphate) removal efficiency ranged between 33% to 52%.
- Statistically, there were no significant differences between the morning results and the evening results ($P > 0.05$) except nitrite.
- The effluent water quality doesn't meet Ghana Environmental

Protection Agency standards for discharge into the environment. Only, six parameters out of thirteen were below of the Ghana standards.

- From bacteriological and chemical results, the constructed wetland could not

completely remove the coliforms or other pollutants from the influent; but the constructed wetland can be used to upgrade the quality of effluent grey water to an acceptable level.

- The time frame allowed for this research was too short, since monitoring

started after only three and half weeks. This probably reduced the efficient expected, because the microorganisms didn't get enough time to establish in the filter media. Again the percentage performance of the CW in removal of BOD, COD, was less than the performance published by Harmer (1988) where the BOD,COD were removed at 90%. However, in all the parameters the removal efficiencies were increasing with time, hoping that the performance could increase to standard level if allowed to operate for a longer period.

- Since this was a first study in Ghana, the results and the pilot plant can be

used in different design of constructed wetland or an illustration for Civil engineering students and others.

- Except the potential of constructed wetlands in pollutant removal,

the constructed wetland doesn't need any complex operation and maintenance procedures. This can be the most option for waste water treatment especially in any developing country like Ghana with little technological advancement.

- The plant species can also be harvested to be used as compost, raw material for basket wearing and roofing materials. Wetlands are also potential for groundwater recharge, therefore, the return of cleaned water to the eco-system close to where it is used, increases aquifer recharge and river flow.

- The discharge of the treated grey water can resolve the problem of flooding pollution occurred in wetland or in crops around Wiwi stream.

5.2 Recommendations

- The pre-treatment using sedimentation tank must be reviewed or replaced by vertical flow biofilter due to the presence of flies at the surface of sedimentation tank.
- Due to the high loading rate of grey water, the kitchen waste should be separated from the bathrooms or laundries.
- Operation and maintenance of the plant should be respected in order to avoid the scum layer entering into the constructed wetland
- The high percentage of the removal by the pilot C.W could be used in design and construction of the bigger treatment plant for grey water from the Halls of residence.
- Further monitoring of the plant should be carried out over a longer period to determine its peak performance.

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APPENDICES

APPENDIX 1: Meteorological Data of Kumasi (1961-1990)

Month	Average Rainfall (mm)	Average Temperature (^{o}C)	Max. Daily Temperature (^{o}C)	Min. Daily Temperature (^{o}C)	Mean Evaporation (mm)
January	15	26.2	31.9	20.4	157
February	66	27.8	33.5	22.0	127
March	137	27.5	32.4	22.3	135
April	129	27.3	32.3	22.4	130
May	174	28.5	31.3	22.2	135
June	214	25.6	29.5	21.6	99
July	157	24.6	28.0	21.2	109
August	90	24.3	27.7	21.0	94
September	165	24.4	28.7	21.1	99
October	153	25.8	30.1	21.5	86
November	74	26.4	31.2	21.7	122
December	26	25.8	30.7	20.8	119

Source: Ghana Meteorological Agency, Kumasi

CLIMATOLOGICAL DATA

STATION : KUMASI MONTH : FEBRUARY TO APRIL YEAR : 2007

Date	Rain fall	Tempe	rature	Evapo.	Sunshine	Rain fall	Temp	rature	Evapo.	Sunshine	Rain fall	Temp	rature	Evaporation	Sunshine
		Max	Min				Max	Min				Max	Min		
	mm	^{o}C	^{o}C	mm	hr	mm	^{o}C	^{o}C	mm	hr	mm	^{o}C	^{o}C	mm	hr
1	0	35.1	23.5	5.5	5.3	0	35.3	23.1	6.8	5.8	46	34.8	22.5	6.1	7.9
2	0	35.7	23.3	7.2	6.5	0	35.8	22.9	7.1	6.8	0	29.5	20	3.3	0.1
3	0.1	35.7	23.9	6.4	4.1	0	35.9	23.1	7.6	7.2	0	34.7	22	6.8	9
4	0	34.3	22.5	7.1	5.3	0	35.9	23.5	7.6	2.8	20	33.5	23.2	6.2	5.8
5	1	34.5	23.3	6.4	5.7	0	36.2	23.4	8.7	5.2	25	30	19.5	2	0.5
6	0	34.7	21.5	5.6	6.5	0	36.6	24	9.4	6	0	32.8	18.9	6	8.7
7	0	35.3	22.3	5.6	6	0	35.9	24	9.5	3.8	26	33.5	22.6	3.4	6.3
8	9.6	34	24	3.6	3.3	0	36.6	23	11	7.4	0	30.2	19.9	3.1	4.2
9	5.8	34	20.5	3.7	7.4	0	36.5	24.1	9.2	6.8	0	33.8	21.9	5.5	9.7
10	0	32.9	20.6	4.9	5.6	0	35	22.6	6.9	4.8	0	33	23.2	5.2	5.5
11	0	33.8	22.5	4.7	6.6	0	35.7	23.1	7.6	7	0	33.1	23	6.4	7.8
12	0	33.3	22	5.1	6.4	0	37	22.9	10.7	6.4	0.1	33.6	23	6.4	7.5
13	0	34.7	22.5	7.6	8.3	0	36.8	24.4	10.9	6.2	0	22.4	22.9	4.6	2.8
14	0	35.3	21.9	10.9	8.9	0	36.8	24.2	9.9	5.9	0	34.4	23.3	6.1	5.1
15	0	34.7	21.8	7.5	9	8.2	36.5	24	8.3	5.5	25	32.7	23	4.3	3.5
16	0	34	22.8	6.8	7.2	0.2	30.5	20.5	3.9	1.3	0	32.4	19.9	5.1	4.8
17	0	34.3	22.6	7.1	6.9	6.4	34.7	20.1	5.7	7.1	12	32.9	22	5.7	9.3
18	0	34.5	23	7.2	6.5	0	34	22	5.9	4.7	0	30.9	21.6	2.8	3.1
19	0	35	23.4	8.3	7	0	33.8	21.5	8.7	7.2	0	22.7	23	4.7	9.1
20	0	32.7	22.4	6.1	2.1	0	35	22	9	9	0	33.6	23.1	6.2	8.5

21	0	34.6	22.5	6.9	4.8	0	34.8	23.1	7	4.9	26	33.5	23.1	4.7	9.2
22	0	33.8	23.4	6.1	5	3.8	34.7	23	7.4	6.4	4.1	32.5	18.8	4.3	8.2
23	0	33.4	23	9	0	2.6	35.5	22	5.5	5.4	0	32.3	20.3	3.8	6.6
24	0.1	36.1	20.9	12.3	7.3	0	32.8	20.4	6.1	4.2	0	33.1	22.4	4.8	7.8
25	0	35.4	21.6	9	6.8	0	33.7	20.5	8	6.6	20	33.6	22.5	5.7	9.4
26	0	35	22.2	9.3	5.4	15	31.6	24	3.9	1.9	73	31.4	20.1	3.8	5.9
27	0	34.3	22.6	7.2	3.8	0	32.6	18.7	5.7	7	20	31.1	20	2.2	2.8
28	0	35.5	23.4	7	6.6	0	35.2	21	9	9.5	0	33.1	21.2	4	7.5
29						0	34	23.5	7.7	7.2	0	32.5	21.8	3.7	8.3
30						20	36.2	23.4	5.7	7.6	14	33.1	22.9	3	6.8
31						0	33.6	21.1	6.2	7.2					
	16.4	34.5	22.5		5.9	56	35	22.5	7.6	6	311	32.7	21.7		6.4

APPENDIX 2: General Effluent Quality Guidelines for Discharges into Natural Water Bodies

Parameter	**Maximum Permissible Level**
Temperature (°C)	< 3 °C above ambient
Turbidity (FTU)	75
Conductivity (µs/cm)	750
Suspended Solids (mg/l)	50
TDS (mg/l)	50
pH value	6 - 9
Biochemical Oxygen Demand (mg/l)	50
Chemical Oxygen Demand (mg/l)	250
Nitrate – Nitrogen (mg/l)	0.1
Nitrate (mg/l)	75
Phosphate – Phosphorus (mg/l)	2.0
Grease (mg/l)	10
Faecal Coliforms (No./100ml)	500
E-Coli (No./100ml)	10

Source: Ghana Environmental Protection Agency, 1997

APPENDIX 3: Guidelines for interpretation of water quality for irrigation

Potential irrigation problem		**Units**	**Degree of restriction on use**		
			None	**Slight to moderate**	**Severe**
Salinity					
Ec_w[1]		dS/m	< 0.7	0.7 - 3.0	> 3.0
or					
TDS		mg/l	< 450	450 - 2000	> 2000
Infiltration					
SAR[2] = 0 - 3 and EC_w			> 0.7	0.7 - 0.2	< 0.2
	3 -6		> 1.2	1.2 - 0.3	< 0.3
	6-12		> 1.9	1.9 - 0.5	< 0.5
	12-20		> 2.9	2.9 - 1.3	< 1.3
	20-40		> 5.0	5.0 - 2.9	< 2.9
Specific ion toxicity					
Sodium (Na)					
	Surface irrigation	SAR	< 3	3 - 9	> 9
	Sprinkler irrigation	me/I	< 3	> 3	
Chloride (Cl)					
	Surface irrigation	me/I	< 4	4 - 10	> 10
	Sprinkler irrigation	m^3/l	< 3	> 3	
Boron (B)		mg/l	< 0.7	0.7 - 3.0	> 3.0
Trace Elements					
Miscellaneous effects					
Nitrogen (NO_3-N)[3]		mg/l	< 5	5 - 30	> 30
Bicarbonate (HCO_3)		me/I	< 1.5	1.5 - 8.5	> 8.5
pH		Normal range 6.5-8			

[1] EC_w means electrical conductivity in deci Siemens per metre at 25°C
[2] SAR means sodium adsorption ratio
[3] NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen

Source: FAO(1985)

APPENDIX 4 : GRADING TEST

PROJECT: DATE:

SITE :- BARIKESI SITE (CONSAR)

DESCRIPTION: BULK SAMPLE

GRADING TEST Total Dry Weight (g) 738.0

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing (%)
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1½ in	37.10			
1 in	26.50			
¾ in	19.00			
½ in ⅜ in	13.20			100.00
	9.50	11.83	1.60	98.40
1/4	6.70	305.14	41.35	57.05
3/16	4.75	46.13	6.25	50.80
1/8	3.18	49.51	6.71	44.09
No. 7	2.36	42.10	5.70	38.39
No. 14	1.18	77.39	10.49	27.90
No. 25	0.600	62.14	8.42	19.48
No. 36	0.425	24.54	3.33	16.16
No. 52	0.300	21.01	2.85	13.31
NO. 72	0.212	17.60	2.38	10.92
No. 100	0.150	15.60	2.11	8.81
No. 200	0.075	25.64	3.47	5.34

PROJECT: DATE:

SITE :- SAND FROM AFISIYASO

DESCRIPTION: BULK SAMPLE

GRADING TEST Total Dry Weight (g) 287.4

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing (%)
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1 ½ in	37.10			
1 in	26.50			
¾ in	19.00			100.00
½ in	13.20	9.94	3.46	96.54
⅜ in	9.50	11.09	3.86	92.68
¼	6.70	7.14	2.48	90.20
3/16	4.75	5.12	1.78	88.42
1/8	3.18	8.21	2.86	85.56
No. 7	2.36	12.89	4.49	81.08
No. 14	1.18	62.20	21.64	59.43
No. 25	0.600	70.83	24.65	34.79
No. 36	0.425	30.11	10.48	24.31
No. 52	0.300	24.42	8.50	15.81
NO. 72	0.212	17.96	6.25	9.57
No. 100	0.150	11.50	4.00	5.56
No. 200	0.075	9.71	3.38	2.19

PROJECT: DATE:

SITE :- RIVER MATERIAL)

DESCRIPTION: BULK SAMPLE

GRADING TEST Total Dry Weight (g) 342.4

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing (%)
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1½ in	37.10			
1 in	26.50			
¾ in	19.00			
½ in	13.20			
⅜ in	9.50		0.00	100.00
¼	6.70	17.45	5.10	94.90
3/16	4.75	104.93	30.65	64.26
1/8	3.18	144.77	42.28	21.98
No. 7	2.36	59.31	17.32	4.66
No. 14	1.18	15.65	4.57	0.08
No. 25	0.600	0.17	0.05	0.04
No. 36	0.425			
No. 52	0.300			
NO. 72	0.212			
No. 100	0.150			
No. 200	0.075			
PROJECT:			DATE:	

SITE :-0.6-2mm SAND FROM AFISIYASO

DESCRIPTION: BULK SAMPLE

GRADING TEST Total Dry Weight (g) 194.3

Sieve size		Weight retained (g)	Percentage retained (%)	Percentage passing (%)
BS designation	Metric (mm)			
3 in	75.00			
2 ½ in	63.00			
2 in	53.00			
1½ in	37.10			
1 in	26.50			
¾ in	19.00			100.00
½ in	13.20	9.94	5.12	94.88
⅜ in	9.50	11.09	5.71	89.17
¼	6.70	7.14	3.68	85.50
3/16	4.75	5.12	2.64	82.86
1/8	3.18	8.21	4.23	78.64
No. 7	2.36	12.89	6.64	72.00
No. 14	1.18	62.20	32.02	39.98
No. 25	0.600	70.83	36.46	3.52
No. 36	0.425			
No. 52	0.300			
NO. 72	0.212			
No. 100	0.150			
No. 200	0.075			

GRADING CURVES FOR SOIL ANALYSIS

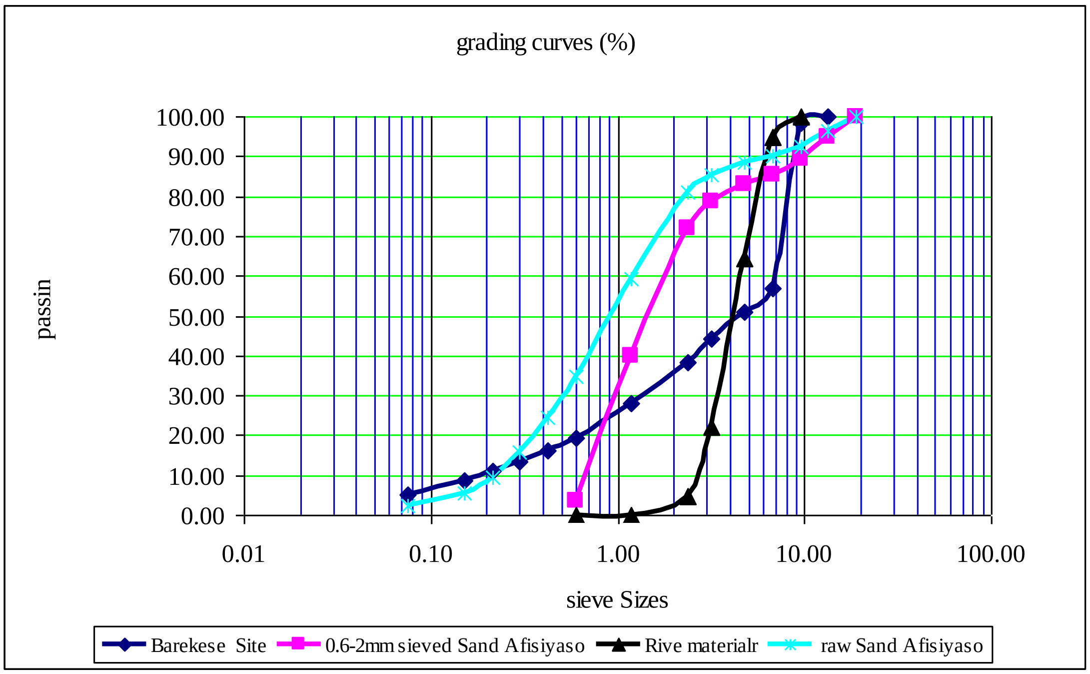
Sand Afisiyaso: D_{10} = 0.22; D_{60}=1.2 →C_u=D_{60}/ D_{10} = 5.45

0.6-2mm Sand Afisiyaso: D_{10} = 0.7; D_{60}=1.8 →C_u=D_{60}/ D_{10} = 2.57

Barekasi: D_{10} = 0.18; D_{60}=7.0 →C_u=D_{60}/ D_{10} = 38.89

River material:D_{10} = 2.8; D_{60}=4.6 →C_u=D_{60}/ D_{10}

=1.64



APPENDIX 5: Grey water treatment plant design

Design of Treatment Plant

Data:

- Population = 1764 students
- Demand = $0.09 m^3/c/d$
- Climatic conditions (precipitation, temperature,…)

  Temperature between 20.4 and 34 ºC (Kumasi meteorological service; Appendix 3)

  Average annually temperature = 26.1 ^oC

  Annual Evapo-transpiration = 1,357 mm

  Annual Rainfall = 1,412 mm
- Soil characteristics of chosen site: Silt clay
- Influent volumes and concentrations :

  BOD of grey water =280mg/l (source: EQE Labo, January 2007)

  COD of grey water =339mg/l (source: EQE Labo, January 2007)

  Suspended Solids (SS) = 81mg/l (source: EQE Labo, January 2007)

  Effluent flow rate =influent waste water + precipitation – infiltration – evapotranspiration. Infiltration becomes nil (using plastic material)

  Taken a grey water flow rate of 0.48 m3/d for our project.
- Plant species = Cattails, bulrushes, reeds, sedges
- Locally available materials = crushed stones, river gravel, coarse sand
- Required effluent concentrations as described in national environmental law

  Final effluent BOD= 35mg/l or 87.5% (< 50mg/l as in EPA guidelines)

  SS= 15mg/l or 81.5% removal(<35mg/l as in EPA guidelines)
- Assume a steady flow of 0.02 m3/hr or hydraulic loading rate of 0.04m/hr

Design of Sedimentation Tank

- **Proposed Options**
  - Flat bottom circular or rectangular tank
  - Horizontal or vertical flow settling tanks
  - Hopper bottom imhoff or Dortmund tanks
- **Selected Option**

Rectangular tank is chosen for the following reasons:

- Low area requirement;
- high stability of the flow pattern and
- Economies of scale when several units can be constructed with common walls the rectangular sedimentation tank is chosen.

- **Calculation**

Typically the L:B ratios are 4 to 6:1 and L:D ratio are 12 to 25:1

Taking L:B = 6:1 $\Rightarrow$ L = 6B

Also, L:D = 17:1 $\Rightarrow$ L =17D and Bottom slope = 1/10

where: L = Length, B = Breath or Width and D= Depth

But Volume V = L× B × D

$$= L \times \frac{L}{6} \times \frac{L}{17} = \frac{L^3}{102}$$

$\Rightarrow$ L^3 = 102V

$\Rightarrow$ L = $\sqrt[3]{102V}$

Hydraulic Retention time, τ is given by: $\tau = \frac{V}{Q}$

Where: V = volume (m^3)

Q = discharge or peak flow rate (m^3/hr)

Grey water treated via a sedimentation tank must be designed to provide at least 24h .

Greywater systems that treat all greywater from kitchen, bathroom and laundry must have a sedimentation tank that has a minimum volume of 1820L(Australia Department of environment,2005) .

$24 = \frac{V}{Q}$ $\Rightarrow$ V = 24Q

$= 24 \times 60^2 (0.0000556) =$ **0.475 m³**

Substituting the value of V = $0.475 m^3$

L = $\sqrt[3]{102 x 0.475}$ = **3.64m**

Hence B= $\frac{L}{6} = \frac{3.64}{6}$ = **0.606 m** and D = $\frac{L}{17} = \frac{3.64}{17}$ = **0.21 m (≈0.25m)**

Adding free board of 0.2m to the depth; $\Rightarrow$ d = 0.45m

Therefore, dimension of the rectangular sedimentation tank is 3.65m×0.65m×0.45 m

About 25-40% (Metcalf & Eddy, 2003) of the BOD is treated by settling tank.

Consider the minimum value 25% treatment before using wetland. It means that 70 mg/l are removed and effluent BOD is **210 mg/l.**

The primary settling tank would remove 60% of the SS i.e. 48.6 mg/l is removed and the remain SS is 32.4 mg/l. At this stage the SS is less than 35 mg/l which recommended by EPA standard (35mg/l). These removals can be achieved due to the stable hydraulic flow pattern in the settling tank and by installation of orifice at inlet or outlet the tank.

Details of measurement flow.

Uniform distribution of the inflow is required in order to get the performance of sedimentation tank. Beside this a baffle is provided to avoid a high turbulence in settling tank and orifice is used to prevent no-uniform effluent discharge.

For an orifice, Q = A. V; V= $(1/2)m^{2/3} i^{1/2}$; $\rightarrow V = \frac{1x0.025^{2/3} x0.0035^{1/2}}{0.0015x10^{-3}} = 3372 m/s$;

with Q = 0.48 m^3/d or Q = 0.0000055 m^3/s ; V= 3372m/s

A = 0.48/33721= 0.00014 m^2 ; d=0.013 m ; d= 13mm

Therefore, dimension of the orifice is 13.0mm and chosen 3 orifices with d= 4.3mm at pipe.

HORIZONTAL SUB-SURFACE FLOW CONSTRUCTED WETLAND

HSSF CW – FULL DESIGN : BOD-UK METHOD (Rousseau.D, 2005)

* $C_{out} = C_{in}$ x $e^{(-kBOD/HLR)}$; or kBOD=k_v x n x Dw; where n is porosity, Dw =water depth

- Minimum water temperature =20.4 ^oC , n = 0.40; k_h = 368.87.; K_{20} = 1.6
- Minimum water temperature theory =18.6 ^oC (20.4 - <10% of 20.4)
- kBOD=1.6x0.40x0.48; where k_v = 1.60 for coarse sand, n = 0.40 and Dw= 0.48m
- kBOD=0.307; → 35 = 210 x $e^{(-0.307/HLR)}$; $\rightarrow \ln\left(\frac{35}{210}\right) = \frac{-0.307}{HLR}$;

  $\rightarrow HLR = \frac{-0.307}{-1.7918}; \rightarrow HLR = 0.171 m/day$
- HLR= $\frac{Q}{A_h}; A_h = \frac{Q}{HLR} = \frac{0.48}{0.1713} = 2.80\,\text{m}^2$,
- Take gravel bed depth 0.6 m and Assume the slop of 3.5‰
- Q = Kh * B * Dw * (dh/L) → B = $\frac{Q}{\left(K_h * Dw * \left(\frac{dh}{L}\right)\right)}$
- Known that $\rightarrow B = \frac{(Q)}{(K_h * Dw * S)}$
- B = $\frac{(0.48)}{(368.87 * 0.48 * 0.0035)}$ =0.77 m ; **B=0.80m and L=3.50m**
- Value of K_T at 20 ^oC ; $K_T = 1.6(1.1)^{(18.6-20)} = 1.40\ d^{-1}$
- $t = \frac{-\ln C_e / C_o}{K_T} = \frac{-\ln 35/210}{1.40} = 1.5d$

For rectangular wetland, dimensions become B=0.80m; L=3.50m; D=0.60m

For trapezoidal wetland, dimensions become B=1.0m; b=0.6m; L=3.5m; D=0.60m

Checking HLR= 0.17m/d is within recommended range (0.08 < HLR <0.20 m/d)

APPENDIX 6: Washing, Drying and Sieving of Sand

Plate 6.1: Washing & drying of sand

Plate 6.2: Sieving of sand

Plate 6.3: Cattails in C.W

APPENDIX 7 : Summary Of Parameters Measured

TABLE 7.1 Temperature (^oC)

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days										Maximum	Minimum	Average
	26	31	36	41	46	51	56	61	66	71			
	T(^{o}C)												
P1	29.4	29.3	29.5	29.3	28.8	29	30.5	28	29.2	28.4	30.5	28	29.14
P2	29.6	29.7	29.8	29.6	29	29	31	28	30.6	28.6	31	28	29.49
P3	29.7	29.9	29.9	30.2	29	28.7	31.5	28.2	30.4	29	31.5	28.2	29.65
P4	30	29.9	30.4	31.4	29.1	30	30.1	28.8	30	29.2	31.4	28.8	29.89

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days										Maximum	Minimum	Average
	26	31	36	41	46	51	56	61	66	71			
	T (oC)												
P1	31.1	30.8	29.8	30.7	29.4	30.3	28.5	28.9	30.3	29.8	31.1	28.5	29.96
P2	29.8	30.1	30.1	30.3	29.2	30.1	28.2	29.1	29.8	29	30.3	28.2	29.57
P3	30.7	30.3	30.1	30.4	29.6	30.2	28.2	29	29.9	30.3	30.7	28.2	29.87
P4	30.9	30.4	30.4	31.2	29.7	30.6	28	29.5	30.1	29.3	31.2	28	30.01

TABLE 7.2: pH

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days										Maximum	Minimum	Average
	26	31	36	41	46	51	56	61	66	71			
	pH												
P1	6.7	7.65	7.86	7.8	7.25	7.67	7.85	8.66	8.13	8.07	8.66	6.7	7.76
P2	6.9	7.36	7.65	6.78	7.12	7.52	7.57	8.02	7.36	7.98	8.02	6.78	7.43
P3	7.1	7.06	7.32	7.1	7.4	7.4	7.65	8.2	8.26	7.95	8.26	7.06	7.54
P4	6.86	6.94	6.98	6.95	6.62	6.93	6.98	7.25	7.3	7.2	7.3	6.62	7.00

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days										Maximum	Minimum	Average
	26	31	36	41	46	51	56	61	66	71			
	pH												
P1	7.3	7.82	7.8	7.7	7.52	7.5	7.65	8.58	7.72	7.64	8.58	7.3	7.72
P2	6.8	8.09	8.1	8	7.81	7.35	7.36	8.41	8.06	7.13	8.41	6.8	7.71
P3	6.9	8.24	7.9	7.8	7.6	7.45	7.32	8.82	8.28	7.68	8.82	6.9	7.80
P4	6.98	7.18	7.4	7.32	7.45	7.15	6.84	7.15	7.15	6.92	7.45	6.84	7.15

TABLE 7.3: Conductivity

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days 26	31	36	41	46	51	56	61	66	71	Maximum	Minimum	Average
	Conductivity (µs/cm)												
P1	705	608	935	925	642	992	1056	1490	931	1368	1490	608	965.20
P2	683	578.4	798	747	684	653	691	584	711	548	798	548	667.74
P3	623	534.3	729	620	732	756	660	576	657	509	756	509	639.63
P4	377	486.1	584	427	756	709	766	473	654	437	766	377	566.91

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days 26	31	36	41	46	51	56	61	66	71	Maximum	Minimum	Average
	Conductivity (µs/m)												
P1	763	1185	835.5	1029	655	906	895	1375	1210	1236	1375	655	1008.95
P2	702	592	721.4	831	683	711	615	541	586	723	831	541	670.54
P3	641	543	684.8	762	624	657	564	543	531	630	762	531	617.98
P4	393	509	587.6	462	567	586	512	510	557	546	587.6	393	522.96

TABLE 7.4: Suspended Solid "SS"

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days										Maximum	Minimum	Average	% SS removal
	26	31	36	41	46	51	56	61	66	71				
	SS (mg/l													
P1	250	390	400	265	620	350	360	335	350	305	620	250	362.5	
P2	165	365	360	210	545	600	245	210	250	200	600	165	315	13.10
P3	100	230	140	150	370	40	165	150	175	145	370	40	166.5	47.14
P4	20	25	15	43	90	25	35	20	35	25	90	15	33.3	80.00

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days										Maximum	Minimum	Average	%SS removal
	26	31	36	41	46	51	56	61	66	71				
	SS(mg/L)													
P1	400	455	480	390	280.5	350	385	280	220	220	480	220	346.05	
P2	250	305	375	270	200	205	283	200	97	95	375	95	228	34.11
P3	150	210	265	155	140	140	195	145	75	75	265	75	155	32.02
P4	40	50	75	40	35	30	40	25	5	0	75	0	34	78.06

TABLE 7.5: Nitrate to Nitrogen

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days										Maximum	Minimum	Average	% NO_3^- -N removal
	26	31	36	41	46	51	56	61	66	71				
	NO_3^- - N (mg/L)													
P1	12	9	13.5	21.7	21	16.25	13.5	20.5	17	14	21.70	9.00	15.85	
P2	10	8	10	17.9	15.5	14.1	16	16.5	13.5	12	17.90	8.00	13.35	15.75
P3	13	7.5	13	15.2	11	9.25	19	6.5	12	11	19.00	6.50	11.75	12.02
P4	7	6	7	0	7	3.2	6.5	0	7.5	6.95	7.50	0.00	5.12	56.45

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days										Maximum	Minimum	Average	% NO_3^- -N removal
	26	31	36	41	46	51	56	61	66	71				
	NO_3^- - N(mg/L)													
P1	10.5	11	17.3	16.5	14.6	15	17	14.5	14	14	17.30	10.50	14.44	
P2	8.5	9.5	13.5	12	11.9	13	13	11	9	9	13.50	8.50	11.04	23.55
P3	5.5	8	7.4	9	9.1	11.5	7	8	10	7	11.50	5.50	8.25	25.27
P4	3.5	4.15	0	6	4.6	7.5	0	5	8	3.25	8.00	0.00	4.20	49.09

TABLE 7.6: Nitrite to Nitrogen

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days										Maximum	Minimum	Average	% NO_2^- -N removal
	26	31	36	41	46	51	56	61	66	71				
	NO_2^- - N (mg/L)													
P1	0.02	25	21	15.5	17	0.08	22.5	0.125	0.12	0.1	25.00	0.02	10.14	
P2	0.02	17	16.25	13.5	14	0.075	15	0.05	0.055	0.07	17.00	0.02	7.60	25.06
P3	0.13	11	11.5	10	9.3	0.07	10	0.01	0.015	0.045	11.50	0.01	5.21	31.50
P4	0.01	7	5.2	6	5.45	0.01	5	0.13	0	0.025	7.00	0.00	2.88	44.64

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days										Maximum	Minimum	Average	% NO_2^-N removal
	26	31	36	41	46	51	56	61	66	71				
	NO_2^- - N (mg/L)													
P1	0.14	15.25	16.5	16.75	15.5	0.12	20.5	0.15	0.055	0.08	20.50	0.06	8.50	
P2	0.09	11.8	12.5	11.6		12 0.1	14.5	0.1	0	0.06	14.50	0.00	6.28	26.22
P3	0.053	7.9	8.2	6.5	8.1	0.075	10.5	0.025	0.015	0.03	10.50	0.02	4.14	34.03
P4	0.03	4.35	4.5	3.75	5.45	0.045	6.5	0.01	0.015	0	6.50	0.00	2.47	40.46

TABLE 7.7: Phosphate to Phosphorous

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days										Maximum	Minimum	Average	% PO_4^{3-}- Removal
	26	31	36	41	46	51	56	61	66	71				
	PO_4^{3-} - P (mg/L)													
P1	12	25.4	26.5	25.1	23.2	21.2	27.8	42.5	24.5	14.6	42.5	12	24.28	
P2	9	21.7	21.7	20	19.2	14.1	21.7	12.6	12.2	11.75	21.7	9	16.395	32.48
P3	6.5	13.9	17.9	14.8	15.6	10.8	13.5	11.5	7.9	8.6	17.9	6.5	12.1	26.20
P4	6.4	8.9	15.2	9.3	8.5	8	10.7	9	5.1	4.4	15.2	4.4	8.55	29.34

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days										Maximum	Minimum	Average	% PO_4^{3-} -P Removal
	26	31	36	41	46	51	56	61	66	71				
	PO_4^{3-} - P (mg/L)													
P1	14.5	19.4	21.5	25.6	23	22.4	25.6	47.5	5.9	14.65	47.5	5.9	22.005	
P2	10.6	16.5	17.3	20.9	17.4	18.1	20.8	20	2.1	13.1	20.9	2.1	15.68	28.74
P3	7.4	12.7	13.5	12.4	13.5	11.4	12.6	7	1.9	8.3	13.5	1.9	10.07	35.78
P4	2.4	6.6	7.4	7.7	8.5	5.9	7.6	3.5	2.5	4.2	8.5	2.4	5.63	44.09

TABLE 7.8: COD

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days										Maximum	Minimum	Average	% COD removal
	26	31	36	41	46	51	56	61	66	71				
	COD													
P1	736	904	880	1208	904	680	608	1656	608	896	1656.00	608.00	908.00	
P2	616	832	832	928	792	480	448	544	472	616	928.00	448.00	656.00	27.75
P3	384	472	472	640	536	392	280	312	384	408	640.00	280.00	428.00	34.76
P4	24	192	192	192	112	176	96	40	16	96	192.00	16.00	113.60	73.46

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days										Maximum	Minimum	Average	% COD removal
	26	31	36	41	46	51	56	61	66	71				
	COD (mg/L)													
P1	864	872	920	952	984	784	720	856	816	632	984.00	632.00	840.00	
P2	592	608	680	728	704	560	456	504	272	520	728.00	272.00	562.40	33.05
P3	432	376	472	488	488	408	288	264	248	240	488.00	240.00	370.40	34.14
P4	128	104	144	120	128	96	40	32	16	32	144.00	16.00	84.00	77.32

TABLE 7.9: BOD

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days 26	31	36	41	46	51	56	61	66	71	Maximum	Minimum	Average	% BOD. removal
	BOD (mg/L)													
P1	350	460	780	850	750	500	500	900	350	580	900	350	602	
P2	225	400	720	750	700	350	500	500	280	320	750	225	474.5	21.18
P3	125	440	440	550	475	275	400	450	200	220	550	125	357.5	24.66
P4	40	160	160	140	120	120	60	80	40	40	160	40	96	73.15

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days 26	31	36	41	46	51	56	61	66	71	Maximum	Minimum	Average	% BOD removal
	BOD (mg/L)													
P1	425	400	500	525	550	450	450	500	550	400	550	400	475	
P2	250	350	350	340	400	350	350	350	400	280	400	250	342	28.00
P3	175	250	250	225	250	250	250	350	300	200	350	175	250	26.90
P4	60	60	80	60	100	60	80	100	60	50	100	50	71	71.60

TABLE 7.10: DO

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days							Maximum	Minimum	Average
	41	46	51	56	61	66	71			
	DO (mg/l)									
P1	0	0.8	0.70	0.80	0.60	0.80	0.6		0.80 0.00	0.61
P2	0	0	0.00	0.00	0.20	0.00	0	0.20	0.00	0.03
P3	0	0	0.00	0.00	0.20	0.00	0	0.20	0.00	0.03
P4	0	0	0.00	0.40	0.30	1.20	2.2	2.20	0.00	0.59

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days							Maximum	Minimum	Average
	41	46	51	56	61	66	71			
	DO (mg/L)									
P1	0	0.8	0.80	1.20	0.80	1.00	1.2	1.20	0.80	0.97
P2	0	0	0.00	0.00	0.20	0.00	0	0.20	0.00	0.03
P3	0	0	0.00	0.00	0.20	0.00	0	0.20	0.00	0.03
P4	0	0	0.40	0.60	0.80	3.20	4.2	4.20	0.00	1.53

TABLE 7.11: Bacteriological Parameters

Time 1 : Sampling in morning at 6:00 a.m

Sample Source	Days 26	31	36	41	46	51	56	61	66	71	Maximum	Minimum	Average	% COD Remov.
	E-Coli (No/100ml)													
P1	2.9E+03	1.0E+05	2.9E+03	1.6E+05	5.1E+04	1.0E+00	1.1E+04	1.6E+05	6.1E+04	1.8E+05	1.8E+05	1.0E+00	7.4E+04	
P2	1.2E+04	7.2E+04	3.2E+04	1.2E+05	4.4E+04	6.1E+04	6.2E+04	1.2E+05	1.2E+05	1.1E+05	1.2E+05	1.2E+04	7.6E+04	-2.96
P3	7.6E+03	6.1E+04	2.2E+04	8.1E+04	3.3E+04	4.1E+04	3.2E+04	8.2E+04	9.2E+04	7.1E+04	9.2E+04	7.6E+03	5.2E+04	31.55
P4	9.0E+02	2.0E+04	5.0E+02	2.0E+04	1.1E+04	1.0E+04	7.0E+02	2.0E+04	1.1E+04	2.1E+04	2.1E+04	5.0E+02	1.2E+04	77.86
	Salmonella (No/100ml)													
P1	0.0E+00	0.0E+00	0.0E+00	4.0E+02	0.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	4.0E+02	0.0E+00	4.1E+01	
P2	0.0E+00	0.0E+00	0.0E+00	6.0E+04	0.0E+00	6.1E+04	6.1E+04	6.1E+04	5.1E+04	3.1E+04	6.1E+04	0.0E+00	3.3E+04	Increased
P3	0.0E+00	0.0E+00	0.0E+00	1.0E+04	0.0E+00	4.1E+04	4.1E+04	4.1E+04	3.1E+04	1.1E+04	4.1E+04	0.0E+00	1.7E+04	46.65
P4	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E+04	1.0E+04	1.0E+00	2.0E+02	3.0E+02	1.0E+04	0.0E+00	2.1E+03	87.95
	F.C (No/100ml)													
P1	2.9E+03	1.0E+05	2.9E+03	1.6E+05	5.1E+04	2.0E+00	1.1E+04	1.6E+05	6.1E+04	1.8E+05	1.8E+05	2.0E+00	7.4E+04	
P2	1.2E+04	7.2E+04	3.2E+04	1.8E+05	4.4E+04	1.2E+05	1.2E+05	1.8E+05	1.7E+05	1.4E+05	1.8E+05	1.2E+04	1.1E+05	-46.87
P3	7.6E+03	6.1E+04	2.2E+04	9.1E+04	3.3E+04	8.1E+04	7.2E+04	1.2E+05	1.2E+05	8.2E+04	1.2E+05	7.6E+03	6.9E+04	36.07
P4	9.0E+02	2.0E+04	5.0E+02	2.0E+04	1.1E+04	2.0E+04	1.1E+04	2.0E+04	1.1E+04	2.1E+04	2.1E+04	5.0E+02	1.4E+04	80.38

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	Days 26	31	36	41	46	51	56	61	66	71	Maximum	Minimum	Average	% Removal
	E-Coli (No/100ml)													
P1	1.7E+03	3.0E+02	0.0E+00	2.1E+04	1.1E+05	1.0E+00	3.6E+05	1.3E+05	5.1E+04	2.4E+05	3.6E+05	0.0E+00	9.3E+04	
P2	9.0E+02	2.0E+02	3.1E+04	3.7E+04	8.4E+04	2.2E+04	2.8E+05	1.1E+05	7.3E+04	1.5E+05	2.8E+05	2.0E+02	7.9E+04	14.32
P3	5.0E+02	1.0E+02	2.1E+04	2.4E+04	6.3E+04	2.0E+03	2.0E+05	6.1E+04	4.2E+04	8.1E+04	2.0E+05	1.0E+02	5.0E+04	37.39
P4	2.0E+02	1.0E+02	5.0E+02	1.2E+04	2.1E+04	1.0E+00	4.1E+04	2.0E+04	1.0E+04	1.0E+04	4.1E+04	1.0E+00	1.2E+04	76.76
	Salmonella (No/100ml)													
P1	0.0E+00	0.0E+00	0.0E+00	3.1E+04	0.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	3.1E+04	0.0E+00	3.1E+03	
P2	0.0E+00	0.0E+00	0.0E+00	6.0E+04	0.0E+00	6.0E+04	7.1E+04	1.0E+00	6.1E+04	5.5E+04	7.1E+04	0.0E+00	3.1E+04	-884.14
P3	0.0E+00	0.0E+00	0.0E+00	5.0E+04	0.0E+00	1.0E+00	4.1E+04	1.0E+00	3.1E+04	4.0E+04	5.0E+04	0.0E+00	1.6E+04	47.31
P4	0.0E+00	0.0E+00	0.0E+00	1.0E+04	0.0E+00	1.0E+00	1.0E+04	1.0E+00	1.0E+02	1.0E+04	1.0E+04	0.0E+00	3.0E+03	81.21
	F.C (No/100ml)													
P1	1.7E+03	3.0E+02	0.0E+00	5.2E+04	1.1E+05	2.0E+00	3.6E+05	1.3E+05	5.1E+04	2.4E+05	3.6E+05	0.0E+00	9.6E+04	
P2	9.0E+02	2.0E+02	3.1E+04	9.7E+04	8.4E+04	8.2E+04	3.5E+05	1.1E+05	1.3E+05	2.1E+05	3.5E+05	2.0E+02	1.1E+05	-14.95
P3	5.0E+02	1.0E+02	2.1E+04	7.4E+04	6.3E+04	2.0E+03	2.4E+05	6.1E+04	7.3E+04	1.2E+05	2.4E+05	1.0E+02	6.6E+04	40.16
P4	2.0E+02	1.0E+02	5.0E+02	2.2E+04	2.1E+04	2.0E+00	5.2E+04	2.0E+04	1.1E+04	2.0E+04	5.2E+04	2.0E+00	1.5E+04	77.85

TABLE 7.12: Retention time

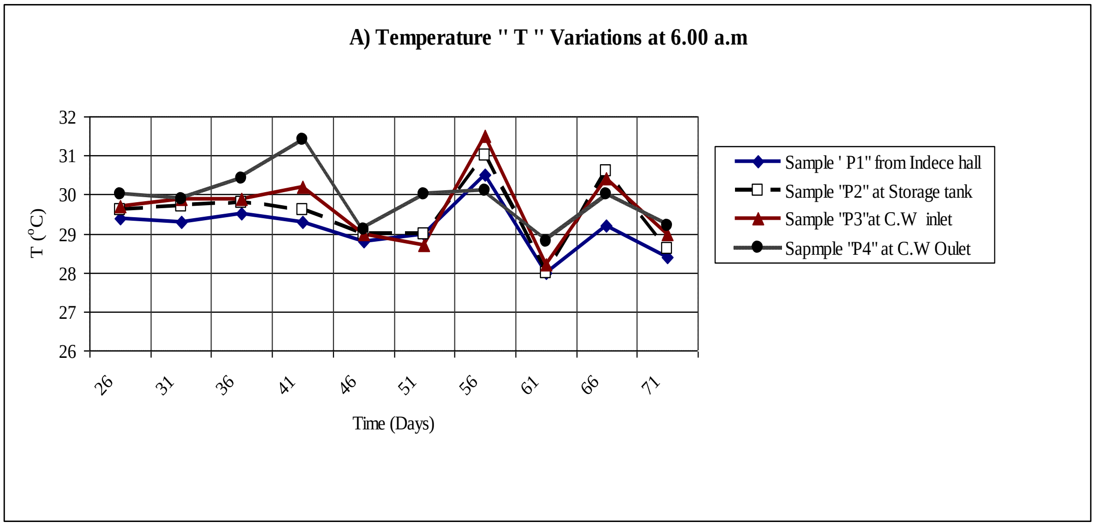
Time 1 : Sampling in morning at 6:00 a.m

Sample Source	**Days**										**Maximum**	**Minimum**	**Average**	**Retention Time(Hrs)**
	26	**31**	**36**	**41**	**46**	**51**	**56**	**61**	**66**	**71**				
	BOD (mg/l)													
P3	125	440	440	550	475	275	400	450	200	220	550	125	357.5	
P4	40	160	160	140	120	120	60	80	40	40	160	40	96	
Dairy temp.	24	23.1	20.5	23.1	24	21.1	19.5	23.2	23	23.1	24	19.5	22.46	
lnx=-ln(Ce/Co)	1.14	1.01	1.01	1.37	1.38	0.83	1.90	1.73	1.61	1.70	1.90	0.83	1.37	
Ka	2.34	2.15	1.68	2.15	2.34	1.78	1.53	2.17	2.13	2.15	2.34	1.53	2.04	
T=lnx/ka"BOD"	0.49	0.47	0.60	0.64	0.59	0.47	1.24	0.80	0.76	0.79	1.24	0.47	0.68	
T in hours	**12**	**11**	**14**	**15**	**14**	**11**	**30**	**19**	**18**	**19**	**30**	**11**	**16**	**16**

Time 2 : Sampling in evening at 5:00 p.m

Sample Source	**Days**										**Maximum**	**Minimum**	**Average**	**Retention Time(Hrs)**
	26	**31**	**36**	**41**	**46**	**51**	**56**	**61**	**66**	**71**				
	BOD (mg/l)													
P3	175	250	250	225	250	250	250	350	300	200	350	175	250	
P4	60	60	80	60	100	60	80	100	60	50	100	50	71	
Dairy temperat	24	23.1	20.5	23.1	24	21.1	19.5	23.2	23	23.1	24	19.5	22.46	
=-ln(Ce/Co)	1.07	1.43	1.14	1.32	0.92	1.43	1.14	1.25	1.61	1.39	1.61	0.92	1.27	
Ka	2.34	2.15	1.68	2.15	2.34	1.78	1.53	2.17	2.13	2.15	2.34	1.53	2.04	
T=lnx/ka"BOD"	0.46	0.66	0.68	0.61	0.39	0.80	0.75	0.58	0.76	0.64	0.80	0.39	0.63	
T in hours	**11**	**16**	**16**	**15**	**9**	**19**	**18**	**14**	**18**	**15**	**19**	**9**	**15**	**15**

APPENDIX 8: Parameters Variations in Treatment Plant



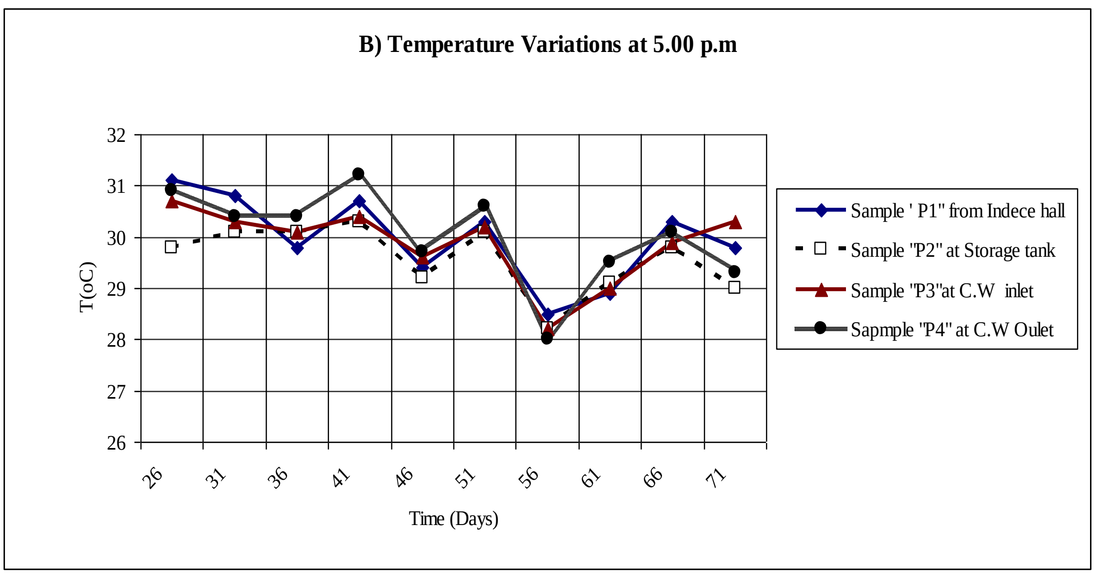


Figure 8.1: Temperature Variations at 6:00 a.m and 5:00 p.m

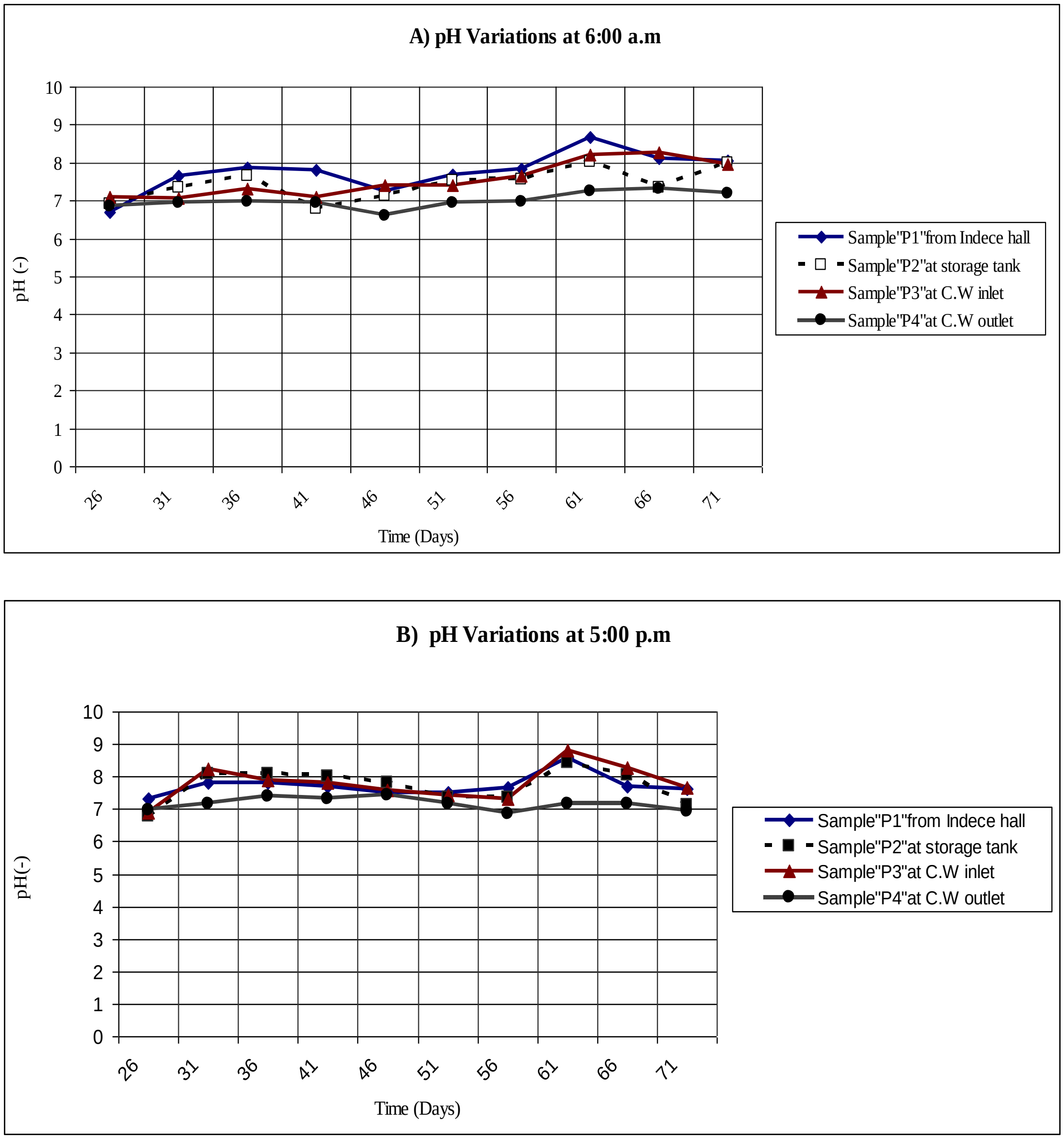
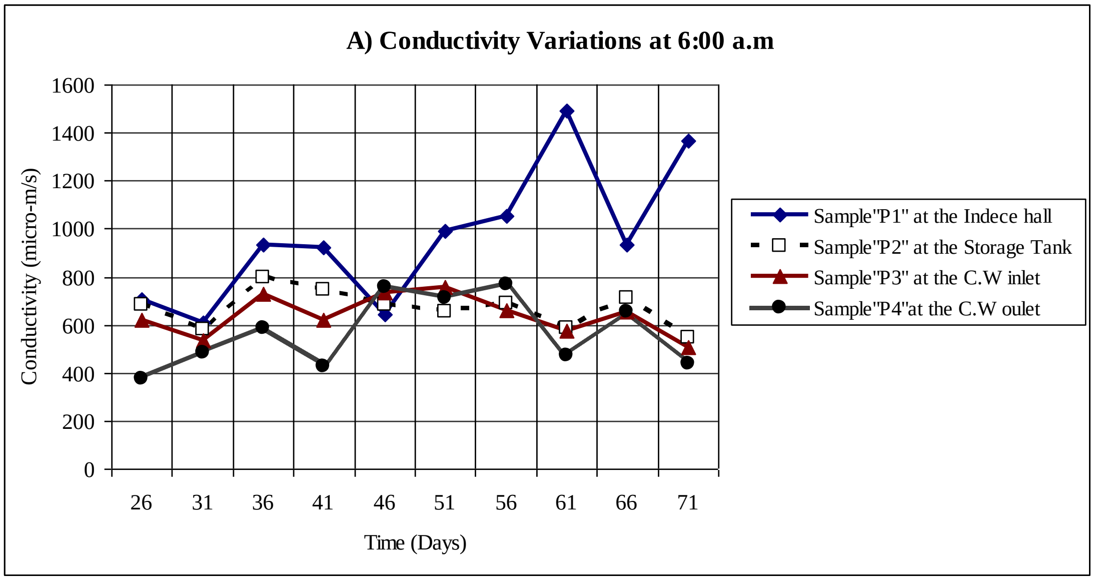


Figure 8.2: pH Variations 6:00 a.m and 5:00 p.m



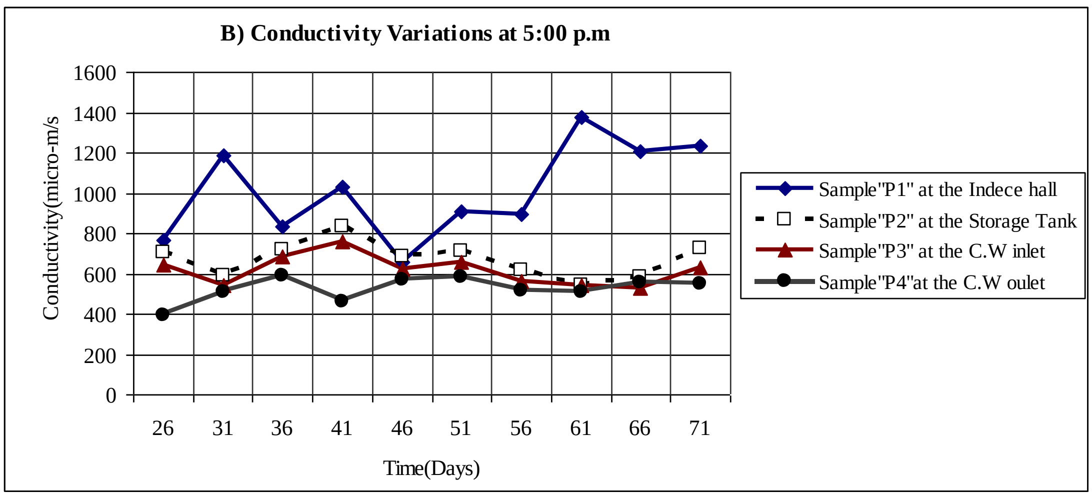


Figure 8.3: Conductivity Variations 6:00 a.m and 5:00 p.m

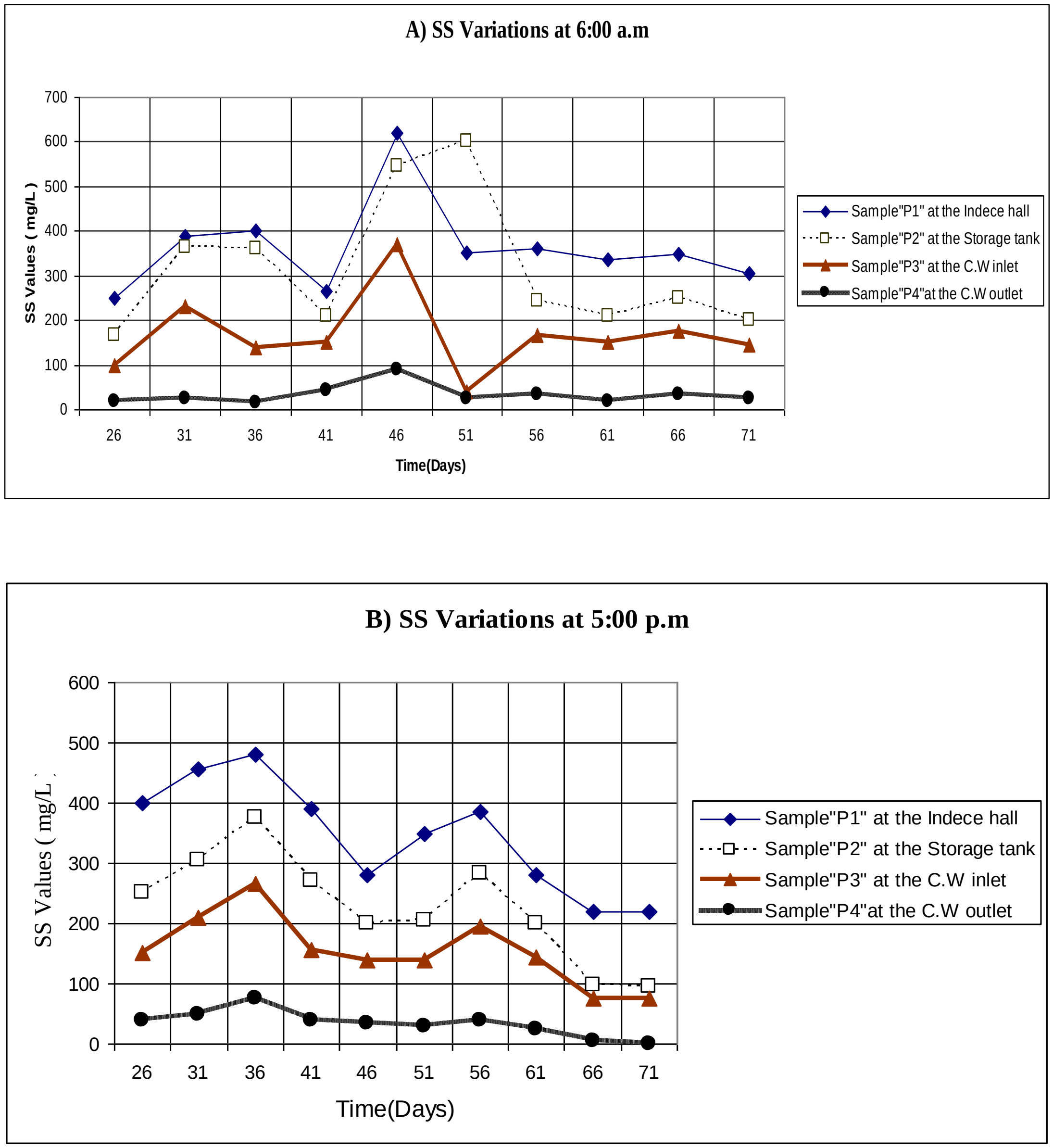


Figure 8.4: SS Variations 6:00 a.m and 5:00 p.m

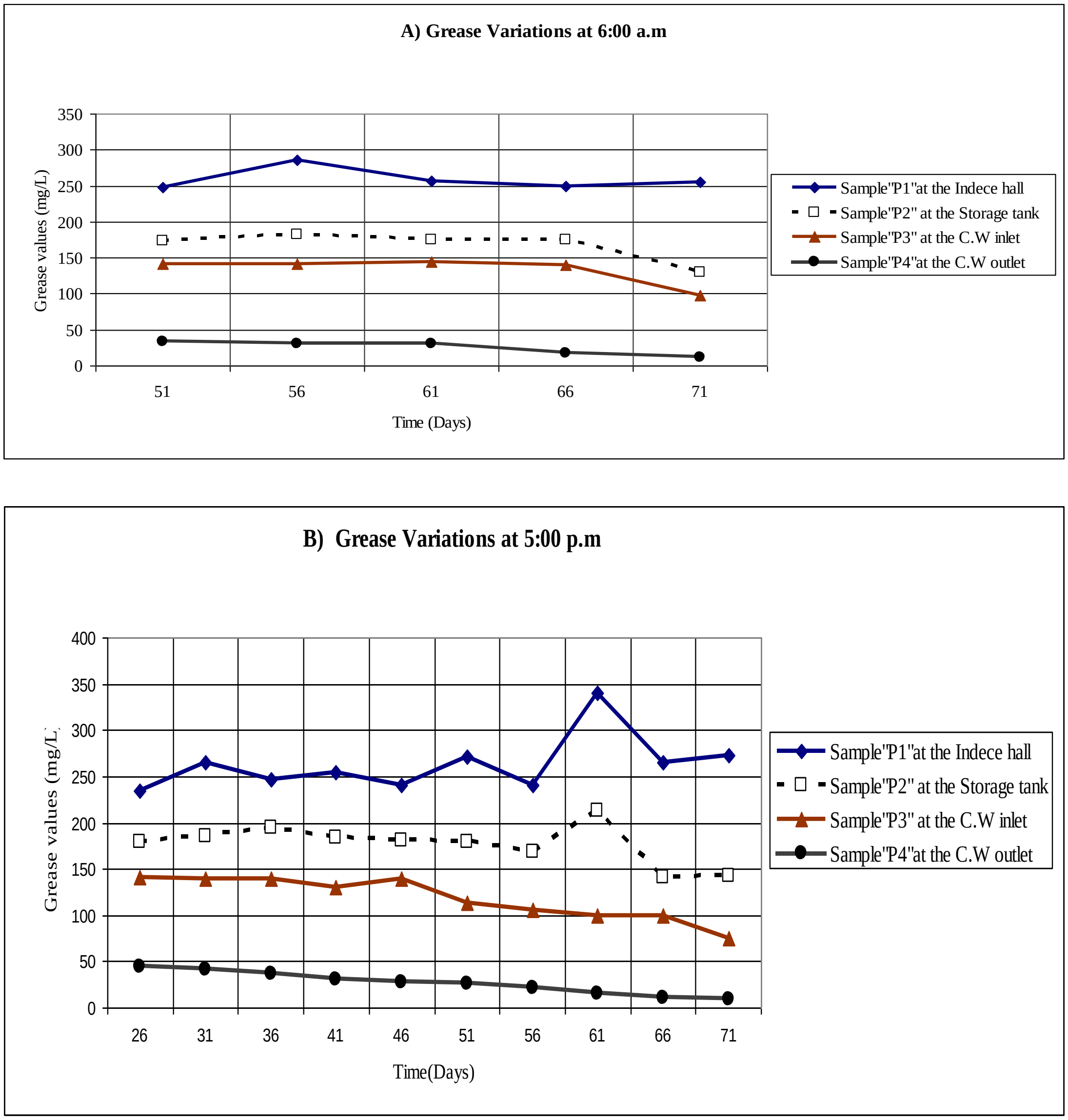
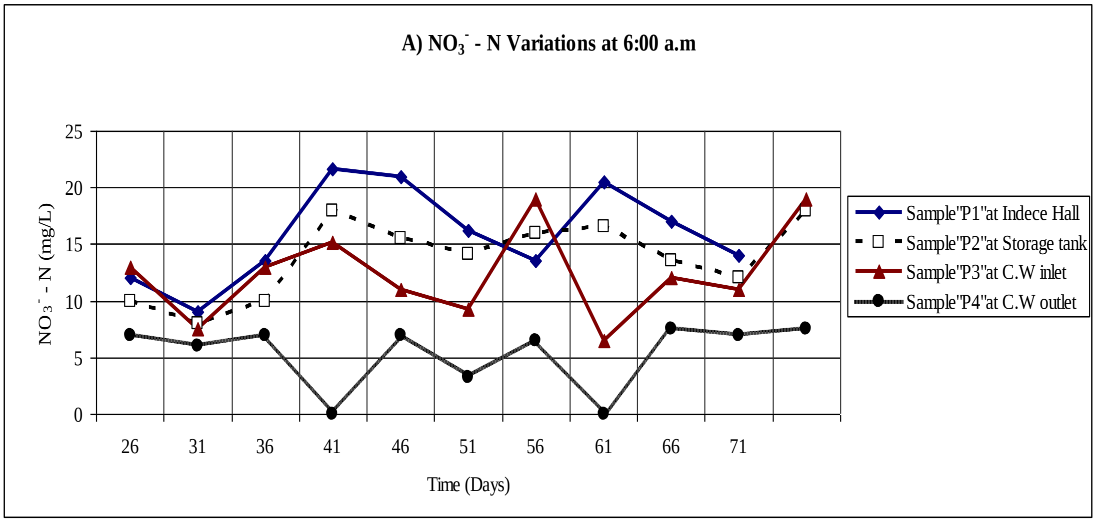


Figure 8.5: Grease Variations 6:00 a.m and 5:00 p.m



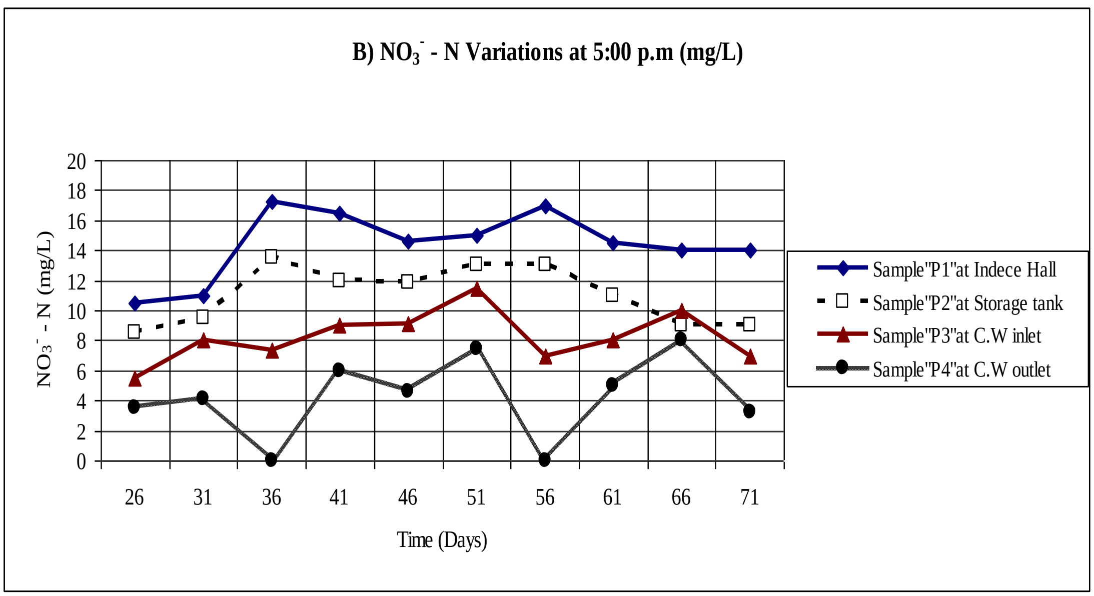
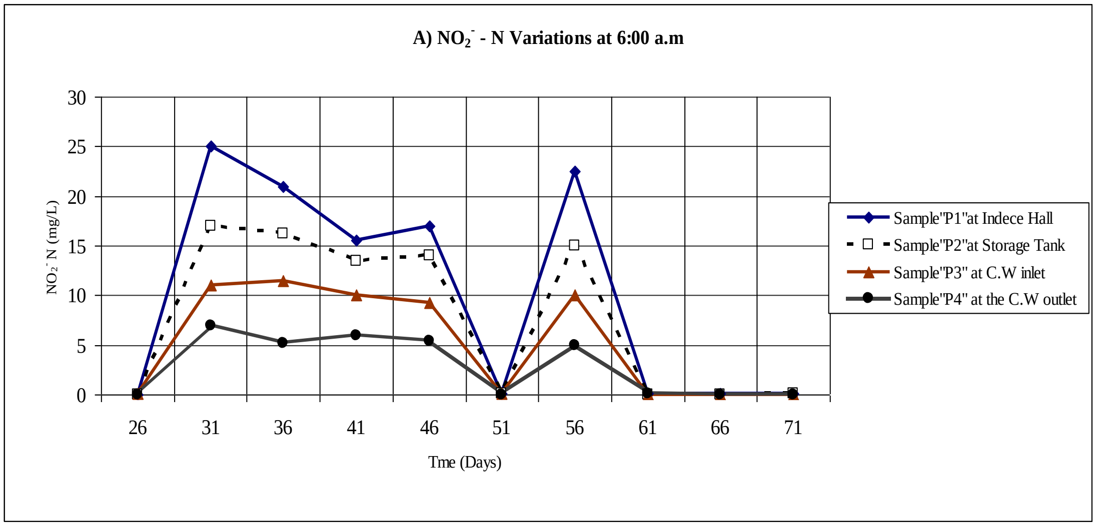


Figure 8.6: Nitrate to Nitrogen 6:00 a.m and 5:00 p.m



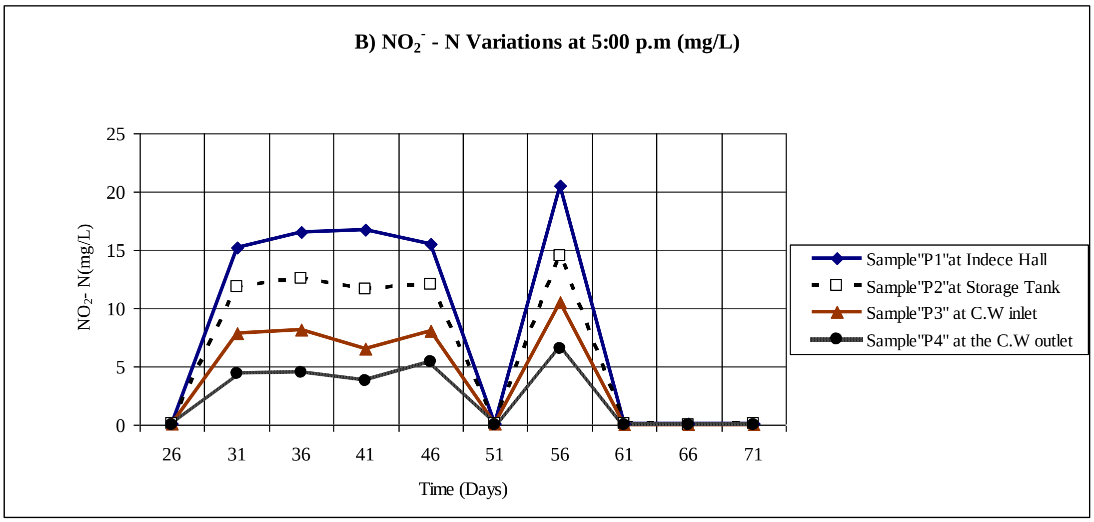
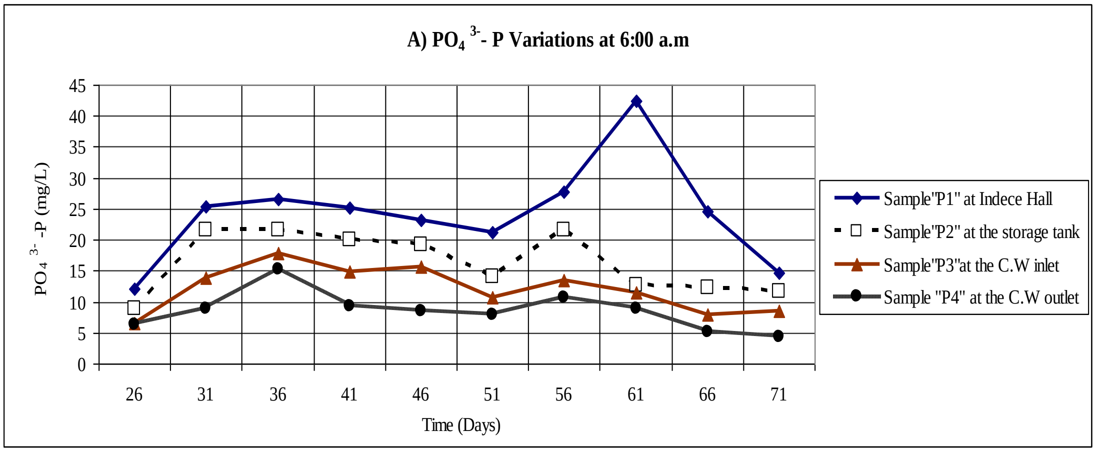


Figure 8.7: Nitrite to Nitrogen 6:00 a.m and 5:00 p.m



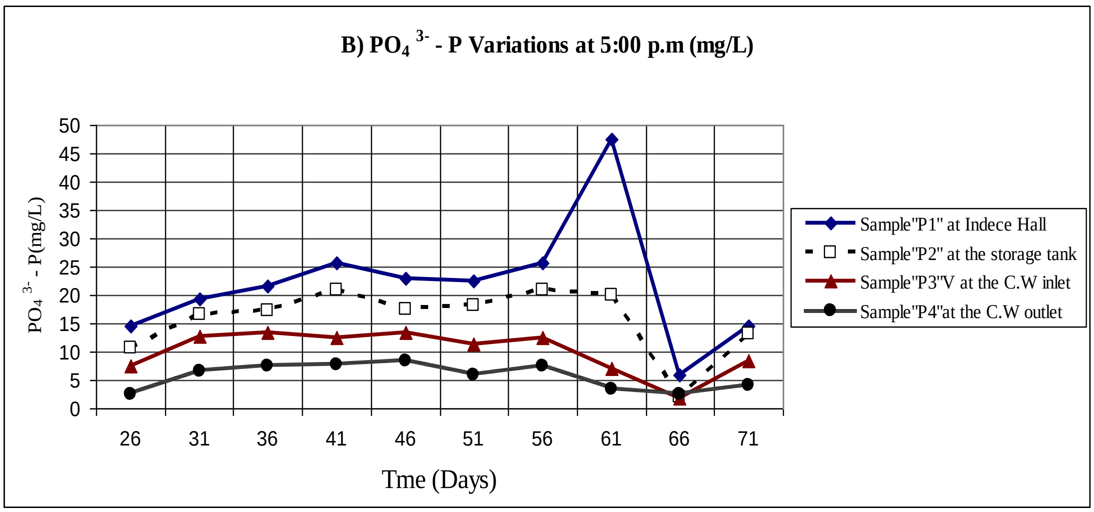
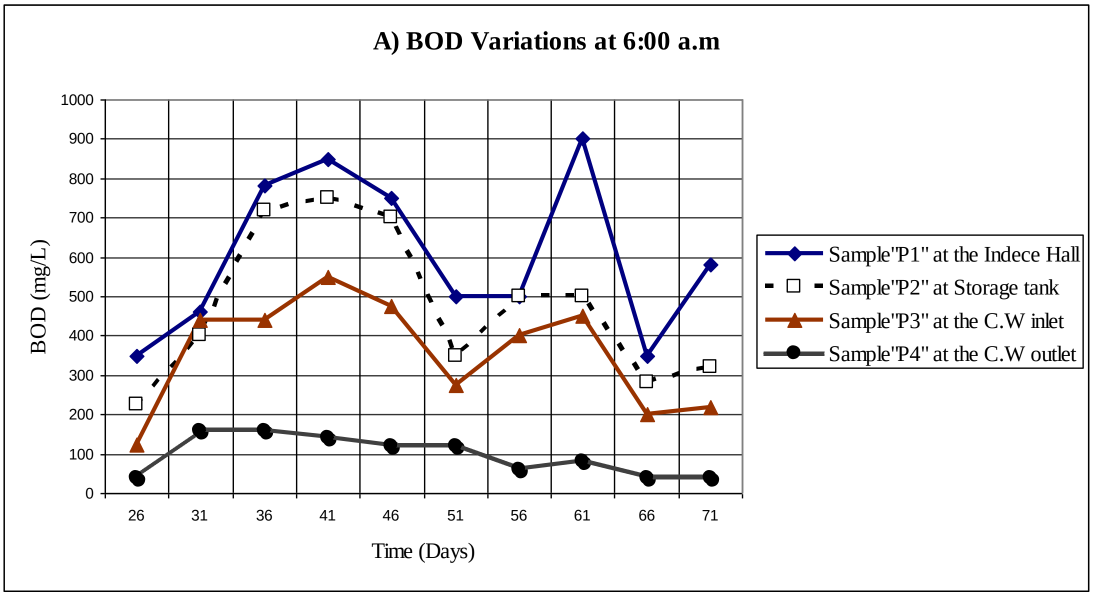


Figure 8.8: Phosphate to Phosphorous Variations 6:00 a.m and 5:00 p.m



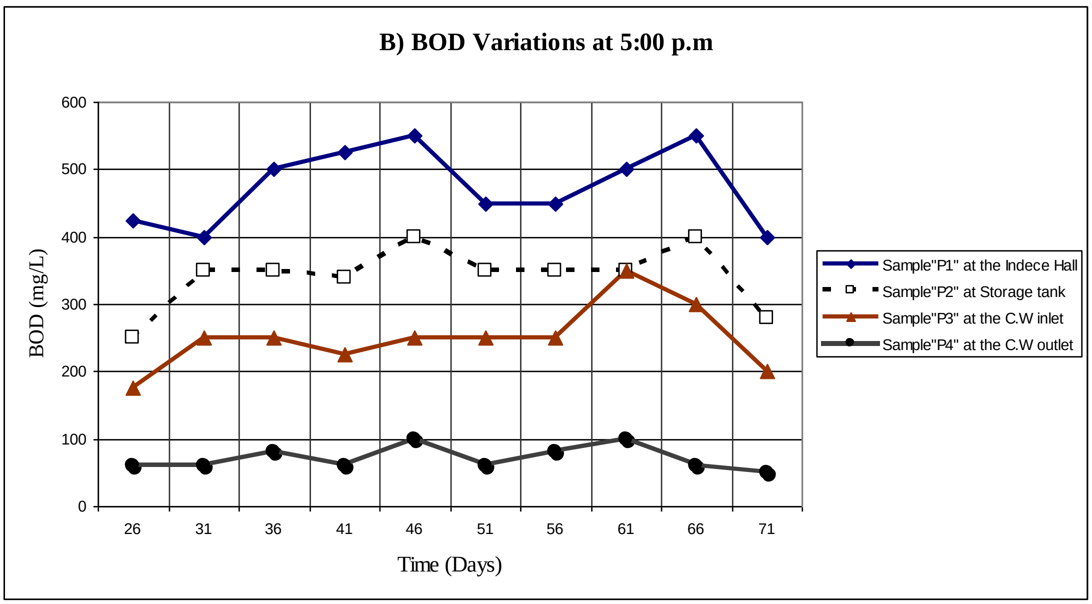


Figure 8.9: BOD Variations at 6:00 a.m and 5:p.m

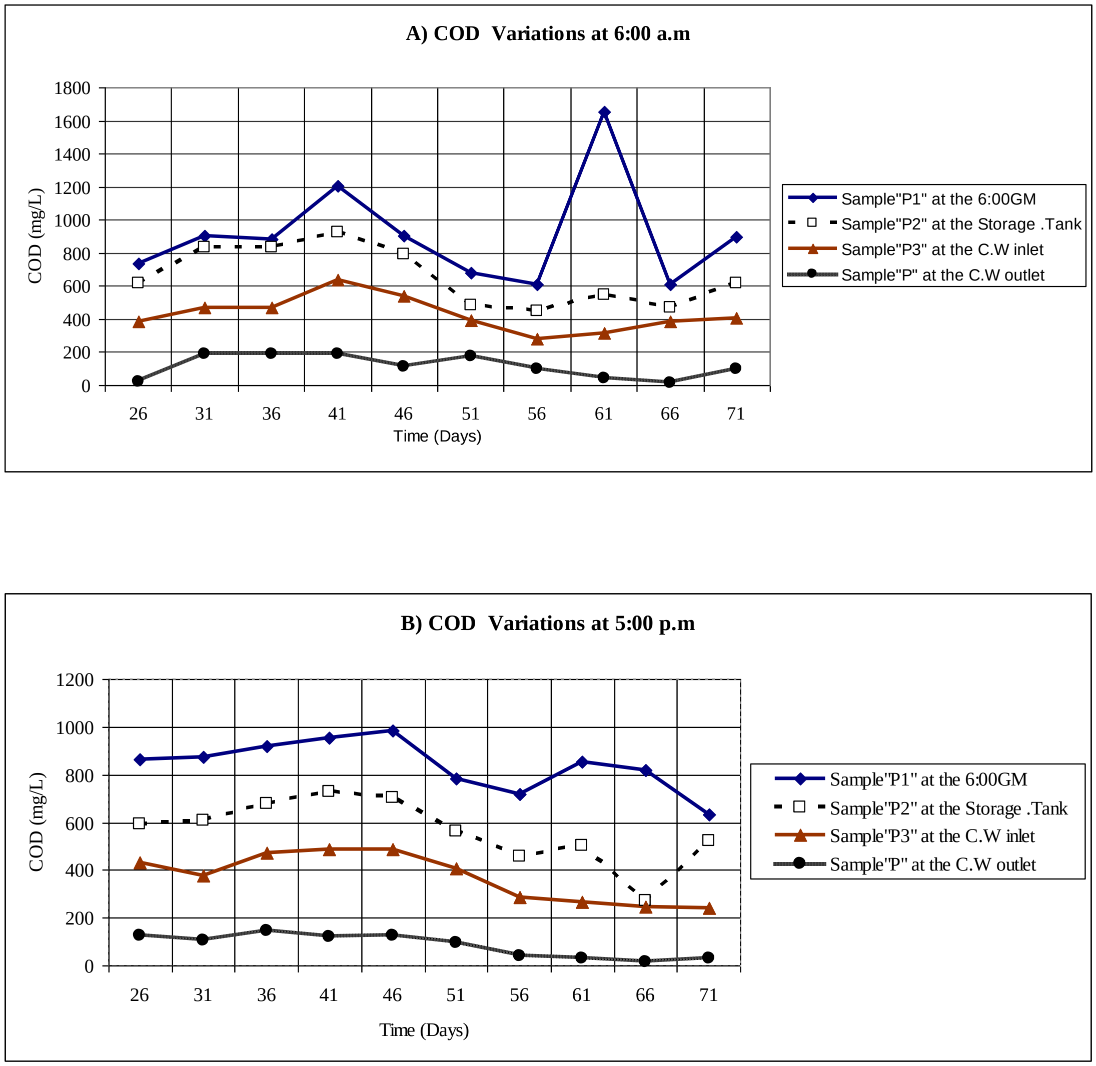
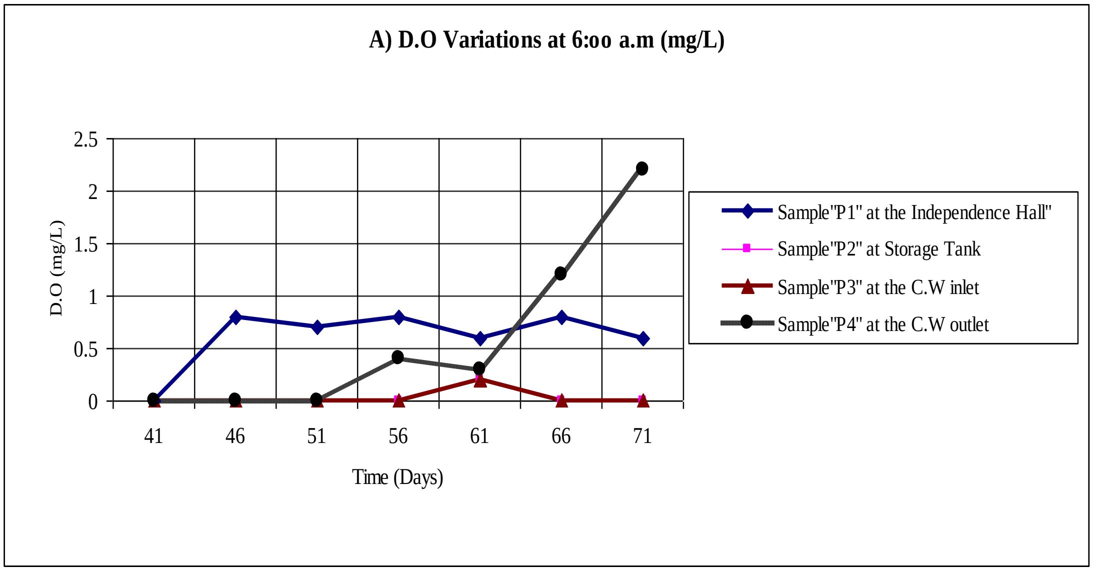


Figure 8.10: COD Variations at 6:00 a.m and 5:p.m



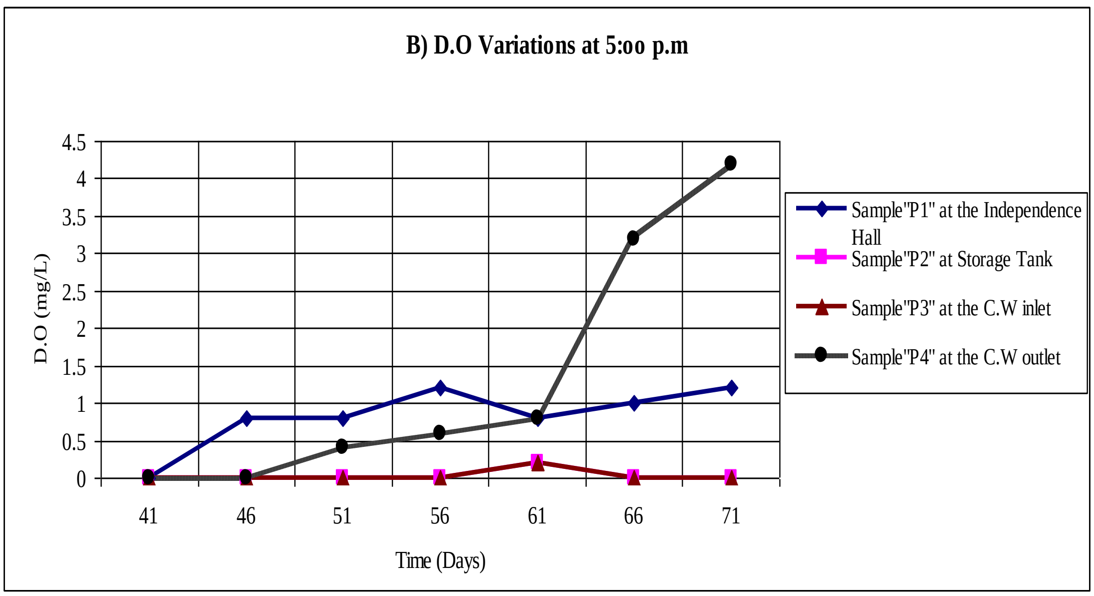
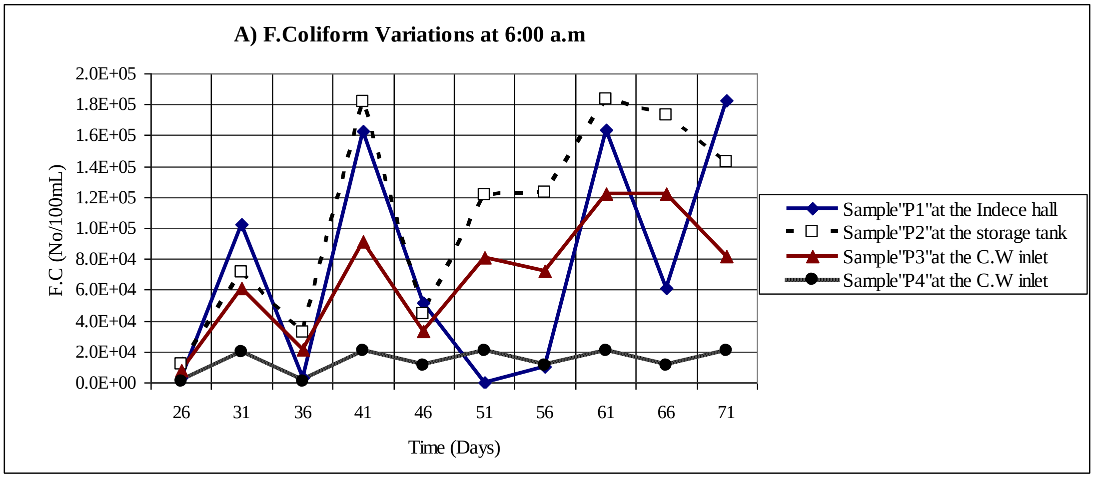


Figure 8.11: DO Variations 6:00 a.m and 5:00 p.m



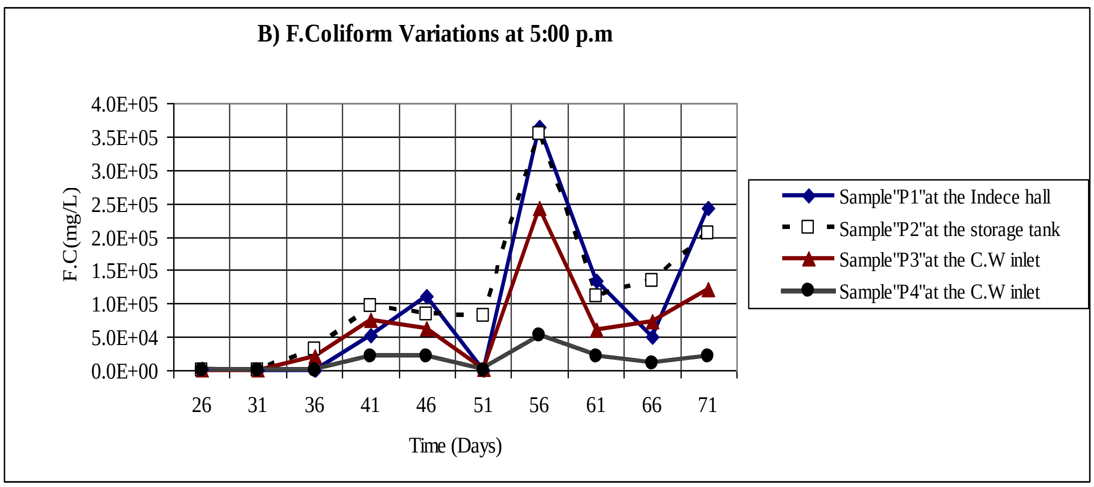


Figure 8.12: Total Coliforms Variations 6:00 a.m and 5:00 p.m

APPENDIX 9: Measured Grey water Flow in Constructed Wetland

Table 9.1: Flow rate from Storage Tank "P2"

Time(hrs)	Days								Max	Min	Average
	36	41	46	51	56	61	66	71			
	Flow rate (L/hrs)										
6H	22	19	22	19	20	20	20	18	22	18	20
7H	21	19	20	18	20	19	20	17	21	17	19
8H	22	18	22	18	20	19	19	18	22	18	19
9H	21	19	21	18	20	19	19	18	21	18	19
10H	19	20	19	18	20	18	20	18	20	18	19
11H	21	20	21	18	19	18	20	18	21	18	19
12H	20	19	20	18	19	17	18	17	20	17	19
13H	20	19	20	18	19	17	18	16	20	16	19
14H	20	18	20	18	19	17	18	16	20	16	18
15H	21	18	21	17	19	17	18	17	21	17	18
16H	20	18	20	18	19	17	18	17	20	17	18
17H	23	20	23	19	19	17	18	17	23	17	19
18H	22	19	22	18	19	17	19	17	22	17	19
19-6H	239	245	245	238	244	247	243	247	247	238	243
L/day	511	492	516	473	494	479	487	470	516	470	490

Table 9.2: Flow rate from Constructed Wetland Inlet "P3"

Time(hrs)	Days								Max	Min	Average
	36	41	46	51	56	61	66	71			
	Flow rate (L/hrs)										
6H	18	18	18	17	17	17	19	18	19	17	18
7H	18	19	18	17	17	17	18	18	19	17	18
8H	18	18	18	17	17	17	17	18	18	17	17
9H	18	16	19	16	17	17	17	16	19	16	17
10H	18	17	18	16	17	17	17	17	18	16	17
11H	18	16	18	16	17	17	17	16	18	16	17
12H	17	17	17	16	16	17	17	17	17	16	17
13H	17	16	17	16	17	17	17	17	17	16	17
14H	16	16	17	16	17	16	17	17	17	16	16
15H	17	16	17	16	17	17	17	17	17	16	17
16H	16	16	17	16	16	17	17	17	17	16	16
17H	16	16	17	16	16	17	17	16	17	16	16
18H	16	16	17	16	17	17	17	16	17	16	16
19-6H	234	234	234	234	235	234	235	233	235	233	234
L/day	454	452	462	444	450	452	459	452	465	441	453

Table 9.3: Flow rate from Constructed Wetland Outlet "P4"

Time(hrs)	Days								Max	Min	Average
	36	41	46	51	56	61	66	71			
	Flow rate (L/hrs)										
6H	15	16	16	15	14	14	14	13	16	13	15
7H	15	15	15	14	13	12	14	13	15	12	14
8H	14	15	15	14	13	12	14	12	15	12	14
9H	14	16	15	15	12	11	14	13	16	11	14
10H	13	20	15	14	11	11	14	13	20	11	14
11H	11	14	15	14	11	11	14	12	15	11	13
12H	11	13	13	14	11	11	14	12	14	11	12
13H	11	14	13	13	11	11	1	12	14	1	11
14H	11	12	13	12	11	11	13	12	13	11	12
15H	11	12	12	12	11	11	13	12	13	11	12
16H	11	11	11	13	11	11	12	12	13	11	12
17H	11	12	11	12	11	11	13	12	13	11	12
18H	12	13	12	13	11	11	13	13	13	11	12
19-6H	152	161	168	176	153	161	171	168	176	152	164
L/day	313	345	344	350	301	307	334	330	365	287	328
Flow rate considering the water balance " Qoutflow = Qinflow +(P-ETP) x A"											
ETP	0.09	0.16	0.10	1.33	0.17	0.17	0.13	0.22	1.33	0.09	0.30
P	0.20	0.00	15.00	0.00	25.00	0.00	25.00	0.00	25.00	0.00	8.15
Qoutflow (L/d)	454	452	504	440	520	451	529	451	528.93	440.08	475.18

ETP: Means Evapotranspiration; P: means Pecipitation

APPENDIX 10: STATISTICAL ANALYSIS USING SPSS

Report of Means for Effiiencies in morning at 6:00 a.m

TRT		GREASE	NO3N	NO2N	PO4P	SS	BOD	COD	FC	TC
1.00	Mean	76.7660	54.6490	-65.5000	28.7950	77.1150	72.9970	74.1780	80.6490	73.2600
	N	10	10	10	10	10	10	10	10	10
	Std. Deviation	7.0234	27.5573	399.3156	14.5320	15.0558	9.6514	14.7009	10.1425	12.4164
Total	Mean	76.7660	54.6490	-65.5000	28.7950	77.1150	72.9970	74.1780	80.6490	73.2600
	N	10	10	10	10	10	10	10	10	10
	Std. Deviation	7.0234	27.5573	399.3156	14.5320	15.0558	9.6514	14.7009	10.1425	12.4164

Report of Means for Efficiencies at evening 5:00 p.m

TRT		GREASE	NO3N	NO2N	PO4P	SS	BOD	COD	FC	TC
1.00	Mean	74.2080	51.3120	44.6050	39.1480	80.6630	71.3470	79.2060	71.1700	68.8550
	N	10	10	10	10	10	10	10	10	10
	Std. Deviation	4.4227	27.3885	24.7402	26.3263	9.1796	5.9479	8.5338	28.4072	11.5696
Total	Mean	74.2080	51.3120	44.6050	39.1480	80.6630	71.3470	79.2060	71.1700	68.8550
	N	10	10	10	10	10	10	10	10	10
	Std. Deviation	4.4227	27.3885	24.7402	26.3263	9.1796	5.9479	8.5338	28.4072	11.5696

Water quality parameter at evening

TRT		GREASE	NO3N	NO2N	PO4P	SS	BOD	COD	FC
1.00	Mean	139.2000	8.2500	4.1398	10.0700	157.0000	250.0000	370.4000	65460.00
	N	10	10	10	10	10	10	10	10
	Std. Deviation	6.8605	1.7142	4.4271	3.8076	60.2403	48.5913	101.8269	73098.22
2.00	Mean	36.0000	4.2000	2.4650	5.6300	34.0000	71.0000	84.0000	14550.20
	N	10	10	10	10	10	10	10	10
	Std. Deviation	7.0553	2.7089	2.6756	2.2940	21.4476	17.9196	48.6256	16280.55
Total	Mean	87.6000	6.2250	3.3024	7.8500	95.5000	160.5000	227.2000	40005.10
	N	20	20	20	20	20	20	20	20
	Std. Deviation	53.3720	3.0306	3.6624	3.8142	76.9296	98.5006	166.1837	57781.21

ANOVA Table for Water quality parameters at 5:00p.m

			Sum of Squares	df	Mean Square	F	Sig.
GREASE * TRT	Between Groups	(Combined)	53251.200	1	53251.200	1099.726	.000
	Within Groups		871.600	18	48.422		
	Total		54122.800	19			
NO3N * TRT	Between Groups	(Combined)	82.012	1	82.012	15.961	.001
	Within Groups		92.490	18	5.138		
	Total		174.503	19			
NO2N * TRT	Between Groups	(Combined)	14.024	1	14.024	1.048	.319
	Within Groups		240.823	18	13.379		
	Total		254.847	19			
PO4P * TRT	Between Groups	(Combined)	98.568	1	98.568	9.976	.005
	Within Groups		177.842	18	9.880		
	Total		276.410	19			
SS * TRT	Between Groups	(Combined)	75645.000	1	75645.000	37.000	.000
	Within Groups		36800.000	18	2044.444		
	Total		112445.0	19			
BOD * TRT	Between Groups	(Combined)	160205.0	1	160205.000	119.457	.000
	Within Groups		24140.000	18	1341.111		
	Total		184345.0	19			
COD * TRT	Between Groups	(Combined)	410124.8	1	410124.800	64.418	.000
	Within Groups		114598.4	18	6366.578		
	Total		524723.2	19			
FC * TRT	Between Groups	(Combined)	1.30E+10	1	1.296E+10	4.621	.045
	Within Groups		5.05E+10	18	2804202822		
	Total		6.34E+10	19			

Means for final effluent parameters

TRT		GREASE	NO3N	NO2N	PO4P	SS	BOD	COD	FC
1.00	Mean	36.9000	4.9750	2.8825	8.5500	33.3000	96.0000	113.6000	13540.00
	N	10	10	10	10	10	10	10	10
	Std. Deviation	14.8133	2.8848	3.0491	3.0511	21.6284	49.7103	71.4348	7970.3896
2.00	Mean	36.0000	4.2000	2.4650	5.6300	34.0000	71.0000	84.0000	14550.20
	N	10	10	10	10	10	10	10	10
	Std. Deviation	7.0553	2.7089	2.6756	2.2940	21.4476	17.9196	48.6256	16280.55
Total	Mean	36.4500	4.5875	2.6738	7.0900	33.6500	83.5000	98.8000	14045.10
	N	20	20	20	20	20	20	20	20
	Std. Deviation	11.3020	2.7525	2.8001	3.0243	20.9668	38.5630	61.3820	12486.53

ANOVA Table for final effluent parameters and signiicance

			Sum of Squares	df	Mean Square	F	Sig.
GREASE * TRT	Between Groups	(Combined)	4.050	1	4.050	.030	.864
	Within Groups		2422.900	18	134.606		
	Total		2426.950	19			
NO3N * TRT	Between Groups	(Combined)	3.003	1	3.003	.384	.543
	Within Groups		140.941	18	7.830		
	Total		143.944	19			
NO2N * TRT	Between Groups	(Combined)	.872	1	.872	.106	.749
	Within Groups		148.101	18	8.228		
	Total		148.972	19			
PO4P * TRT	Between Groups	(Combined)	42.632	1	42.632	5.851	.026
	Within Groups		131.146	18	7.286		
	Total		173.778	19			
SS * TRT	Between Groups	(Combined)	2.450	1	2.450	.005	.943
	Within Groups		8350.100	18	463.894		
	Total		8352.550	19			
BOD * TRT	Between Groups	(Combined)	3125.000	1	3125.000	2.238	.152
	Within Groups		25130.000	18	1396.111		
	Total		28255.000	19			
COD * TRT	Between Groups	(Combined)	4380.800	1	4380.800	1.173	.293
	Within Groups		67206.400	18	3733.689		
	Total		71587.200	19			
FC * TRT	Between Groups	(Combined)	5102520	1	5102520.200	.031	.862
	Within Groups		2.96E+09	18	164291711.3		
	Total		2.96E+09	19			