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GREYWATER TREATMENT USING NATURAL WETLAND SYSTEM

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GREYWATER TREATMENT USING NATURAL WETLAND SYSTEM

by

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In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In

WATER SUPPLY AND ENVIRONMENTAL SANITATION

Faculty of Civil and Geomatic Engineering,

College of Engineering

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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

Greywater in Ghana does not receive any adequate treatment before it is discharged into drains, streams and wetlands. As a result the receiving streams and rivers have become polluted (Awuah et al, 2002). An alternative approach in addressing this situation is the adoption of natural wetland treatment system, which offers low construction and maintenance costs. The natural wetlands systems at Kwame Nkrumah University of science and technology of Kumasi/Ghana were used in this case study. The objective of this study was to determine the potential of natural wetlands in treating Greywater from some halls of residence at Kwame Nkrumah University of Science and Technology Campus. Characterization of the Grey and the contaminant removal efficiency were done through analysis of influent/ effluent quality and material balance. The study was conducted over eight weeks duration. Best performance was obtained at suspended solid removal efficiency of 98.8%.

Results of the Greywater characteristics analysis show that the removal efficiencies of the Turbidity, Suspended Solids, COD, BOD, Total Coliform were ranged between 85-99%; Phosphates and Nitrite-N ranged between 70-85% ;Conductivity and Nitrate –N were less than 50% ; heavy metals(Mn and Pb)were less than 50%,Cu and Fe ranged between 50-70% , Zn was 78.8%, and Cd increased by 51% meaning there was probably some leachates from the wetland soil or accumulation of Cd in the soil. These ranges after treatment gave good results compared to Environmental Protection Agency of Ghana effluent discharge guidelines for wastewater being discharged into waterbodies. These results show that the greywater has less pollution potentials after treatment in the natural wetland. The inflow greywater ratio of COD to BOD was 1.7:1. The heavy metals concentrations in the

soil were as high as 1890.69mg/kg for the Fe. The soil were sandy loam with the clay portion less than ideal distribution for wetland soil of 15**%.** The in flow rate was 7.16 l/s and outlet flow rate was 45% of inlet flow rate. The Hydraulic loading rate was 1.4cm/d.The wetland species present in the natural wetland were predominantly *Colocasia esculenta, Xanthosoma sp, Thala sp. and Coix lacryma (job's tears),*contributing to the efficient removal of the pollutants. The natural wetland has the potential for treating the Greywater .

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Acronyms and Abbreviations

AAS: Atomic Absorption Spectrophotometer
AK: Available Potassium
Al: Aluminum
AP: Available Phosphorus
Av.: Average
BOD: Biochemical Oxygen Demand
BOD_5 : Biochemical Oxygen Demand at Fifth Day
C: Carbon
CBOD: Carbonaceous Biochemical Oxygen Demand
Cd: Cadmium
CH_4: Methane Gas
CO_2: Carbon Dioxide
Cu: Copper
EFF: Exit point of the wetland.
EPA: Environmental Protection Agency
Fe: Iron
GA1: Entry point for influents from the Africa residential student hall.
GA2 : Entry point for influents from the Africa hall mainly kitchen.
GDS: Greywater Diversion Devices
GQ1 : This area of discharge point for influents from the Queen's annex and part of the republic Hall main.
GQ2: The exit point of influent greywater from Queen's hall main.
GTS: Greywater Treatment System
HLR: Hydraulic Loading Rate
Inf: Influent
JUNC: Meeting point of greywater from four gutters above mentioned.
KNUST: Kwame Nkrumah University of Science and Technology
LS: Lower Slope
Max: Maximum
Mg: Manganese
MID: Middle course of greywater under treatment
Min: Minimum
Mn: Magnesium
MS: Middle Slope
Pb: Lead
PC: Prior Converted
pH: Hydrogen Ion
S: Sulfur
SD: Standard Deviation
SE: Standard Error
SF: Surface Flow
SNTC: South National technical Center
SSF: Subsurface Flow
STR: Stream receiving effluent after wetland treatment.
TDS: Total Dissolved Solid
US: United States
US_p: Upper Slope
WL: Wetland
Zn: Zinc

1 CHAPTER I: INTRODUCTION

1.1 Background of the study

Natural wastewater treatment systems are simple, low cost methods that utilize the physical, chemical and biological processes that occur in the natural environment between water, soil, plants, microorganisms and the atmosphere (Kadlec and Knight, 1996). Characteristic of greywater is that it often contains high concentrations of easily degradable organic material, i.e. fat, oil and other organic substances from cooking, residues from soap and detergents. The continuous decline in sanitation coverage could be attributed to the booming population growth, rapid urbanization and lack of investment in the sector.

Present day, wastewater treatment technologies have grown increasingly complex with the requirement of relatively sophisticated and expensive plants. In addition to capital cost, considerable outlay is required for operation and maintenance expenses. Natural treatment systems are a viable alternative that can produce effluents of high quality at a fraction of the cost and without requiring skilled operation. Their main limitation for application in industry is the fact that they take up lots of space. However, they can also serve to enhance the environment and make the facilities suitable for recreation.

The processes involved in natural systems include many of those used in mechanical or in-plant treatment systems (sedimentation, filtration, gas transfer, adsorption, ion exchange, chemical precipitation, chemical oxidation and reduction, and biological conversion and degradation plus others unique to natural systems such as

photosynthesis, plant uptake etc). In natural systems, the processes occur at "natural" rates and tend to occur simultaneously in a single "ecosystem reactor", as opposed to mechanical systems in which processes occur sequentially in separate reactors or tanks at accelerated rates as a result of energy input.

1.2 *Problem statement and justification*

Greywater in Ghana does not receive any adequate treatment before it is discharged into drains, streams, wetlands. As a result, the receiving streams and rivers have become polluted (Awuah et al, 2002). Improving greywater quality using natural systems is one approach, which can be adopted, but the extent of treatment is not known as well as that of receiving waterbodies. Fortunately, the natural wetlands around some of the receiving stream and rivers are still intact, and the treatment potential of these natural systems in the removal of pollutants from grey water can be harnessed.Disease problems associated with wastewater, including pathogenic bacteria and viruses, occurred primarily through direct contact with human waste in cities. Environmental pollution problems also occurred as excessive amounts of wastewater from growing populations overloaded nearby water bodies. Despite this misuse, human culture, plants and soil microbes have had a long-standing mutual and symbiotic relationship. The project seeks to assess the extent of pollution of the water body and the Greywater treatment in the existing natural wetland.

1.3 Objectives

The primary objective of a treatment wetland is to improve the quality of the greywater flowing through it with minimal cost, energy and maintenance input. The Objective of this study is to determine the potential of a natural wetlands in treating greywater on Kwame Nkrumah University of Science and Technology Campus.

1.4 Specific objectives

- To characterize greywater and the soil receiving greywater at study site
- To determine effluent quality after treatment in natural wetland
- To measure heavy metals affect in receiving water bodies and nearby soil.
- To measure flow rates of influent and effluent.
- To identify the dominant species in the natural wetland under study.
- Make recommendation for use of natural wetlands in greywater treatment

1.5 Expected results

1. The quality of greywater of the study site established
2. Efficiency of treatment using a natural wetland
3. A list of species that can be used in natural treatment systems
4. Heavy metal accumulation in the soil of natural wetland under study
5. Recommendations for natural wetlands in greywater treatment

2 CHAPTER II: LITERATURE REVIEW

2.1 Grey water

2.1.1 Definition

Greywater or graywater and also known as sullage, is wastewater generated from processes such as washing dishes, laundry and bathing. Sometimes, the term excludes kitchen wastewater containing significant food residues. It is quite distinct from blackwater in the amount and composition of its chemical and biological contaminants. Greywater gets its name from its appearance and possibly also from its status as being neither fresh (white water from groundwater or potable water), nor heavily polluted (blackwater from faeces or other toxic chemicals). From the point of view of treatment and pollution prevention, greywater decomposes much more quickly and is easier to treat and eliminate than blackwater, but it is still considered to be a health and pollution hazard if released into the natural environment untreated.

2.1.2 Sources of Greywater .

Greywater is generated by every residential household that is occupied, and can be reused to provide a reliable source of water for those final uses that do not require drinking water (including irrigation, toilet flushing and washing machine use).

The characteristics of greywater produced by a household will vary according to the number, age, lifestyle, health status and water usage patterns of the occupants (www.greywater.com) There are essentially two different greywater streams:

1. Bathroom greywater (bath, basin, and shower) – contributes about 59 per cent of the total usable greywater volume in a typical household (Loh & Coghlan, 2003). Bathroom greywater can be contaminated with hair, soaps, shampoos,

hair dyes, toothpaste, lint, nutrients, body fats, oils and cleaning products. It may also contain some faecal contamination (and the associated pathogens) through body washing.

2. Laundry greywater – contributes about 41 per cent of total usable greywater volume in a typical household (Loh & Coghlan, 2003). Wastewater from the laundry varies in quality from wash water to rinse water to second rinse water. Laundry greywater can be contaminated with lint, oils, greases, laundry detergents, chemicals, soaps, nutrients and other compounds. It may also contain some faecal contamination (and the associated pathogens) through washing contaminated clothes. Greywater generated from the laundry is often the easier source of greywater to access, although it is usually more contaminated than bathroom greywater (Jeppesen and Solley,1994; Christova-Boal et al., 1996).

Kitchen wastewater is sometimes considered as a greywater stream; however, for the reuse of greywater by greywater diversion devices (GDDs) it is not appropriate to include kitchen wastewater due to the amount of contaminants (food particles, oil and grease).

2.1.3 Grey Water Discharges

Grey water discharges originate from onboard sinks, showers and washing machines. These discharges may bring with them potential pollutants in the forms of soaps and detergents, food wastes and dyes. Of these pollutants, detergents are the most significant. Detergents often contain phosphates, which can contribute to nutrient enrichment as described above. Additionally they may contain chlorine which can be toxic to flora and fauna.

2.1.4 Greywater use and the environment

Compared to blackwater, greywater usually contains less nitrogen, fewer pathogens, and breaks down in the environment much faster (Awuah et al., 2002). Because of these factors, greywater systems are not as likely to cause severe water pollution.

In Ghana and in other developing countries ,where available water supplies are limited and especially in view of a rapidly growing population, a strong imperative exists for adoption of alternative water reuse technologies.

2.1.4.1 Ecologically Sustainable Development

Because greywater use, especially domestically, reduces demand on conventional water supplies and pressure on sewage treatment systems, its use is very beneficial. In times of drought, especially in urban areas, greywater use on gardens or in toilet systems helps to achieve ecologically Sustainable Development by helping to meet its principles.

2.1.4.2 Dangers associated with Greywater use

When treated properly, greywater is of sufficient quality to use on landscapes but it contains impurities and microorganisms that are capable of causing disease and illness.

A recent study carried out by the Queensland Department of Natural Resources, Mines and Energy covering the quality of domestic greywater found that greywater has organic strength and harmful organisms equal to and in some instances greater than effluent from the toilet (www.greywater.com)

Many substances used for cleaning and washing are designed to be treated in a sewage treatment plant. The term "Biodegradable" means the product is designed to degrade in a wastewater treatment plant where the established specialised bacteria

are colonised in controlled conditions for that purpose - not the natural environment. Laundry wastewater can contain harmful microorganisms such as *Escherichia coli* and diseases such as Hepatitis, which can remain in the correct ground conditions for extended periods of time.

2.1.4.3 Reuse of greywater

Greywater comprises 50-80% of residential "waste" water. It may be reused for other purposes, especially landscape irrigation (www.greywater.com).

Greywater typically breaks down faster than blackwater and has much less nitrogen and phosphorus (Knight,1986). However, all greywater must be assumed to have some blackwater-type components, including pathogens of various sorts.

Given that greywater may contain nutrients (e.g. from dead skin cells and the kitchen sink), pathogens (from our skins) and be discharged warm, it is very important not to store it before using it for irrigation purposes unless you treat it first.

Recycled greywater from showers and bathtubs can be used for flushing toilets, which saves great amounts of water. Many attempts at this have been made in Germany. (Gosselink and Mitsch, 2000). However, untreated greywater cannot be used as flush-water as it will start to smell and discolor the flush toilet fixture if left for a day or more. Although the level of treatment required in this case requires the water to have low or nil BOD, it is not necessary for it to be treated to the same standards as potable water. The reuse of greywater for toilet flushing had been generally considered to not be economical or environmentally favorable at a residential scale.

2.1.5 Composition of Greywater

2.1.5.1 Microbiological Quality

The thermotolerant coliform group of bacteria are used as an indicator of microbiological quality. Thermotolerant coliforms are also known as faecal coliforms and are a type of micro-organism which typically grow in the intestine of warm-blooded animals (including humans) and are shed in their millions in each gram of faeces. Occurrence of faecal coliform bacteria in water indicates a risk of human illness or infection through contact with the water. In general, the number of faecal coliforms in greywater is low unless greywater is generated from washing nappies or clothes contaminated with faeces or vomit (Jeppesen and Solley, 1994). This suggests that the numbers of harmful pathogens are also low.

2.1.6 Chemical and Physical Quality

There is a high amount of variability in the chemical and physical quality of greywater produced by any household, due to factors such as the source of water, the water use efficiency of appliances and fixtures, individual habits, products used (e.g. detergents, shampoos, soaps etc.) and other site-specific characteristics. The amount of salt (sodium, calcium, magnesium, potassium and other salt compounds), oils, greases, fats, nutrients and chemicals in greywater can largely be managed by the types of products used within a household.

2.1.7 Nutrients

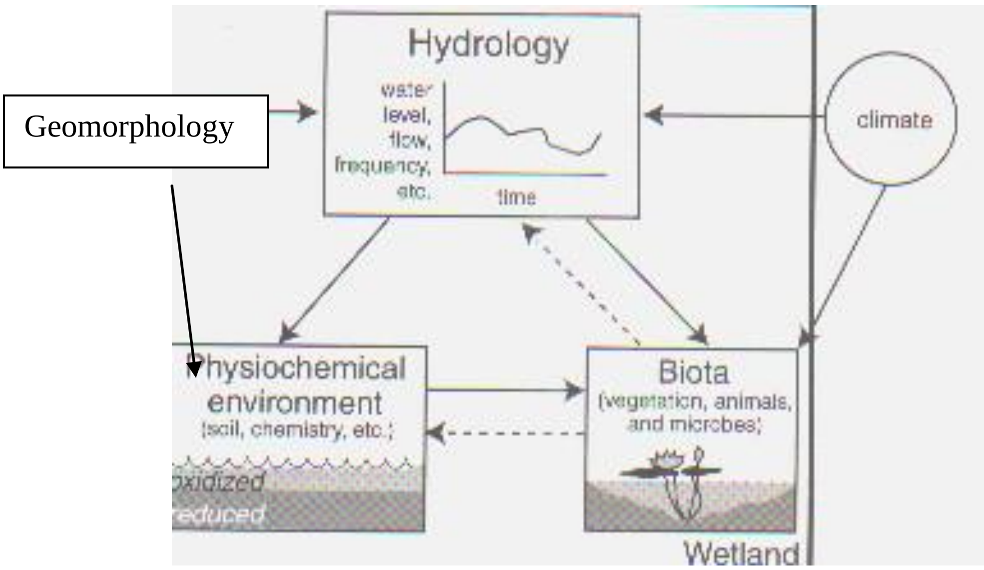
Phosphorus and nitrogen are nutrients necessary for plant growth. Greywater, containing nutrients generated from the bathroom and laundry, may be substituted for fertiliser and can provide phosphorus and nitrogen to the garden and lawn. The

reuse of greywater has the potential to significantly reduce the need for fertiliser application on gardens and lawns. The application of nutrients through the irrigation process is also preferred, as the nutrients will be applied more gradually and will reduce the risk of nutrients being washed away during rain events.

2.2 Wetland

2.2.1 Wetland definition

A wetland is an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate (Gosselink and Mitsch, 2000*)*. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation.



Source: Gosselink and Mitsch, 2000

Figure 1: Three basic components of wetland

Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation (Figure 1).

These features will be present except where specific physicochemical, biotic, or anthropogenic factors have removed them or prevented their development Wetlands

generally include swamps, marshes, bogs, and similar areas.{The United States Army Corps of Engineers (Federal Register 1981) and the EPA (Federal Register 1980)} . Wetlands are presently defined and classified by their hydrologic systems, vegetative communities, and soil conditions .The wetland must have at least two things, among others these are the presence of plants and presence of water.

2.2.2 History

Wetlands have been used for at least 90 years for the disposal of wastewater; most discharges were to natural wetlands (U.S. EPA, 1999). Studies on the use of constructed wetlands for wastewater treatment began in the 1950's at the Max Planck Institute in Germany (Seidel, 1976). Research efforts in the U.S. were developing in the 1970's and 1980's. Some systems were installed in the 1970's with an increasing number in the 1980's. The 1990's saw a major increase in the number of these systems as the application expanded for use not only to treat municipal wastewater, but also stormwater, industrial and mining wastes, and to agricultural wastes.

A wetland is pretty much what is sounds like--"wet land." It's a place where water meets land. Here, in Ghana, some wetlands have open water and cattails, rushes, or several plants one could imagine. Other wetlands look like prairies, until one steps in and water comes out of the ground and gets the feet wet. Some occur along rivers and streams, and others are kilometers from the nearest river, stream or lake.

Wetlands ecosystems are not truly aquatic freshwater systems; rather they are transition zones between terrestrial and truly aquatic systems. Gosselink and Mitsch, (2000); Kadlec and Knight, (1996). Wetland ecosystems both constructed and natural are becoming important mitigating measures in water resource management

around the world, as they have the ability to cycle and retain nutrients such as P (Gale et al., 1993; Mitsch et al., 1995; Reddy et al., 1999).

2.2.3 Description of the technology for natural treatment system

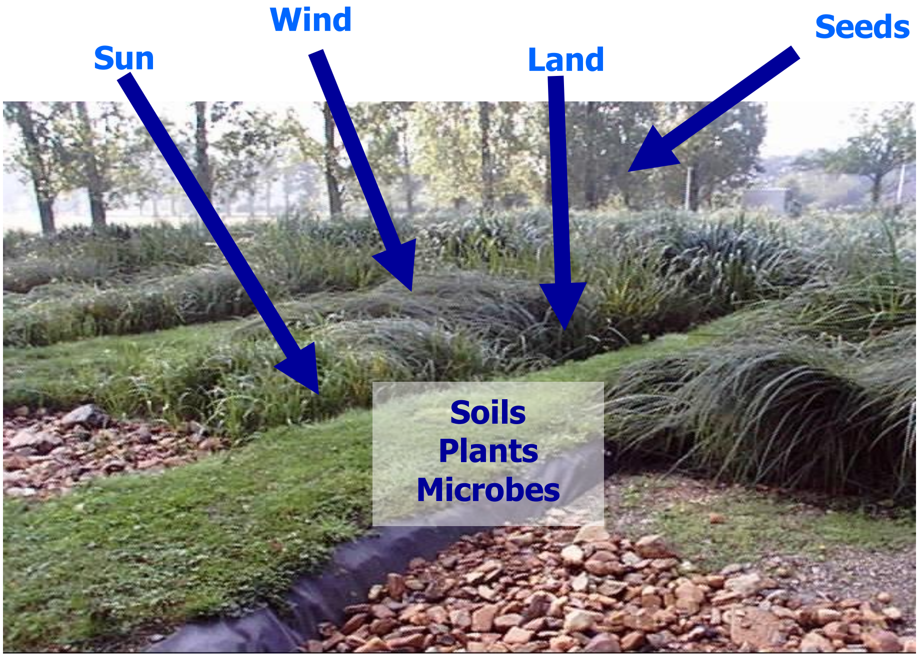


Plate 1:Natural Treatment System

A natural treatment system would refer to any unit process, which would involve water, soil, plants, microorganisms and interaction with the atmosphere (plate 1). If the plants from this equation are removed, then this would refer to any of the conventional biological treatment systems one is familiar with. The addition of plants in this stoichiometry would therefore differentiate it from other systems. In an effort to apply rigidity to the study of this field of Environmental Engineering, different authors have come up with classifications for the different processes under the general label of "natural treatment systems" (Gosselink and Mitsch, 2000). They generally classify them according to the following headings, namely

(a) Aquatic Treatment Units; (b) Wetland Treatment Units; and (c) Terrestrial Treatment

Natural treatment systems provide a good and robust solution for the rising wastewater problem. Compared to common treatment facilities, wetlands are lower in cost investment, lesser to maintain, and are ideal for densely populated rural or suburban areas.

2.2.4 Wetland characteristics

Wetlands come in a variety of shapes, sizes, and functions, but they all have three common characteristics:

- Water (at or near the surface)
- Wetland soil (soils that formed with water)
- Wetland plants (plants that can live in water)

2.2.4.1 Water

Water is the first ingredient of a wetland, but water doesn't have to be present year round. Some wetlands are wet continuously through out year because of the source of water and others wet in the spring and fall and dry during the hot summer months. The latter are known as *seasonal* or temporary wetlands. Just because they are only wet part of the year doesn't make them less important though, they provide important "rest stops" some part of the world for migrating ducks and geese as they return to their nesting grounds in the spring because of seeds and insect larvae at that time of year.

Wetlands that are wet most to all of the year are called *semi-permanent* or *permanent* wetlands. Permanent wetlands, like seasonal and semi-permanent wetlands, are also home to amphibians, insects, birds, crustaceans, mammals and many kinds of plants. All endangered and threatened species are either dependent on or associated with wetlands and riparian areas.

Plate 2:Farming in the Wetland after Drainage.

Sometimes wetlands have been drained for farming or other uses(plate2). This is usually done with small or big channels which are used to drain water from the land's surface flooded, so the farmer can grow crops on it. If the drain is plugged, then the wetland would have water again. This is often the first step in restoring a wetland.

2.2.4.1.1 Wetland Hydrology

2.2.4.1.1.1 Wetland Hydrology Primary and Second Field Indicators

Hydrology is the driving force behind the development and maintenance of wetlands, yet hydrologic observations have a limited role in wetland delineation. This is because hydrology cannot be evaluated effectively in a brief site visit. In the absence of direct hydrologic measurements, wetland hydrology decisions are usually based on field indicators. Wetland hydrology field indicators are readily observable evidence that an area was inundated or saturated recently, even though the exact timing, frequency, and duration of wet conditions may be unknown (plate3).

Plate 3:Wetland Soil Saturated

The presence of any one of these indicators is sufficient evidence of wetland hydrology for delineation purposes. However, the area is a wetland only if hydric soils and hydrophytic vegetation are also present.

Visual observation of inundation, Visual observation of soil saturation within 30cm of the surface, watermarks, drift lines ,sediment deposits - Typically, these are thin layers of silt that may settle out of standing water onto the bases of trees, surfaces of fallen leaves and twigs, or other objects on the ground. Sediment deposits include organic material, such as floating plants and algae, that may be deposited on the ground or in low vegetation after dewatering, drainage patterns within wetlands.

Most secondary indicators are intended to help in delineating groundwater-driven wetland systems that may lack primary indicators, particularly during the dry season. In_the absence of a primary indicator, at least two secondary indicators are required, oxidized rhizospheres within 30cm of the surface and water-stained leaves.

2.2.4.2 Hydric Soil Observations and Indicators

The second criteria a wetland must meet is having wetland soil. A Hydric Soil is a soil that formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part. A soil is bits of rock, dust and decaying plant matter. Having more or less of one or more of these, makes one soil different from the rest. What's on top of the soil also affects the soil underneath. Soils that have prairies on top of them have different characteristics than soils that have woodlands on top of them. Wetland soils also have characteristics that make them different from other soils. Wetland soils are called hydric soils. Using a variety of tests, we could determine what kind of soil is present (Sandy loam). The presence of a hydric soil is sometimes the first clue that a wetland was present at one time if none of the other characteristics (water or wetland plants) are at that location.(www.npwrc.usgs.gov/resource/)

Hydric soils include organic soils, mineral soils with high water tables, ponded soils, and flooded soils, and include any soil that is ponded and/or flooded continuously. Most hydric soil indicators are the result of chemical reduction of manganese (Mn), iron (Fe), or sulfur (S), or the accumulation of organic carbon (C), under anaerobic conditions.Soil colors : Soil color is the indicator used most often to recognize hydric soils and identify their boundaries. In general, hydric soils are predominantly gray due to the reduction and movement of iron and manganese under anaerobic conditions. Soil layers that are saturated nearly continuously and are neutral gray (hue N), bluish gray, or greenish gray in color. (www.npwrc.usgs.gov/resource)

2.2.4.3 Wetland Hydrophytic Plants Community

Water-loving plants are the third characteristic of a wetland. Wetland plants are specially adapted to the flooded or saturated conditions typically found in wetlands. Some plants are even adapted to the soil and water of one type of wetland.

Wetland vegetation not only slows flow and enhances sedimentation of solids but its main function is to provide a substrate or attachment area for microbes which are involved in the transformations of wastewater pollutants (Kadlec and Knight ,1996). Plants also provide a mulch/litter layer that is a porous substrate for attachment of microbes that treat wastewater. Decomposing plant matter is also a rich carbon source for microbial communities. Treatment efficiencies in wetlands are dependent on the large surface area of the plant mulch layer for attachment of microbes. Pullin and Hammer (1989) have suggested that the most important role for plants in a wetland for wastewater treatment are to grow and die, which is why treatment efficiencies between plant species are somewhat similar on a broad ecological basis.

2.2.5 Wetland Treatment

Sewage treatment plant (STP) construction in the areas typically consists of mechanical systems that can have high construction, energy and labor costs. More advanced mechanical treatment systems require higher operator grades. One of the major concerns for communities that operate such systems is the annual energy and labor cost (Plate 4). These costs are a more significant portion of the budgets for small communities. Treatment systems that require more land and have lower energy and labor costs are more attractive economically to small communities. One land-based alternative to typical treatment systems is the use of natural or constructed wetlands for wastewater treatment from one degree to another.

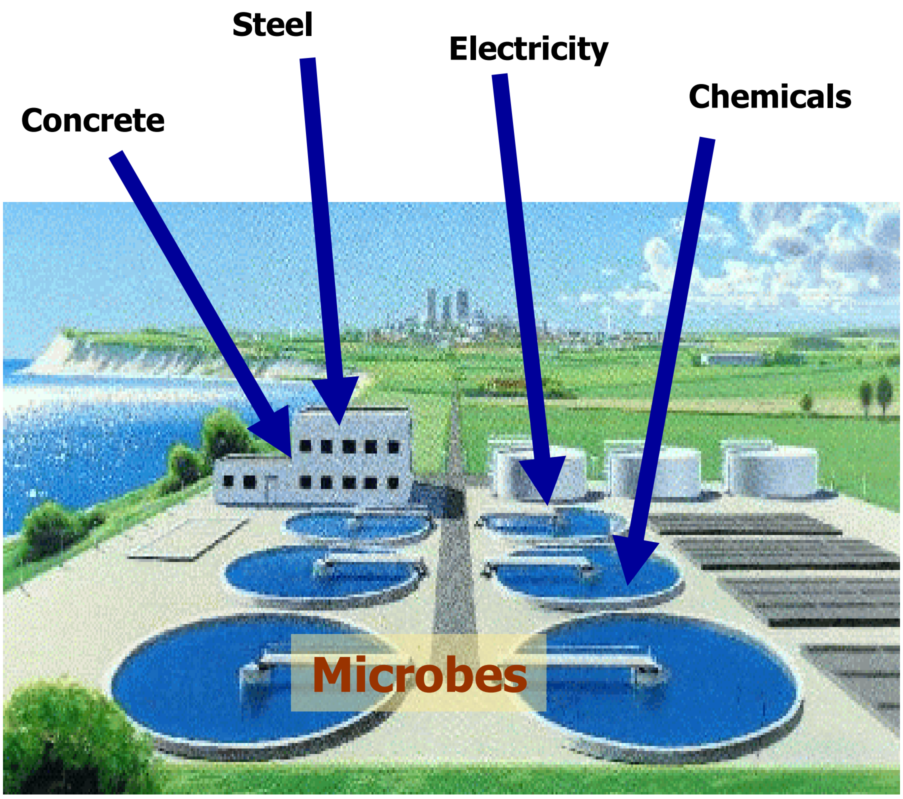


Plate4: Conventional Treatment Plant.

2.2.6 Natural Wetlands

Are land-based wastewater treatment systems that consist of shallow ponds, beds, or trenches that contain floating or emergent-rooted wetland vegetation. They rely on biological, chemical, and physical processes in a natural environment to treat greywater. Some systems are installed in indigenous soils and discharge to surface and/or groundwater. Constructed wetlands differ from natural wetlands in that operators have greater control over natural processes in the constructed wetlands because flows are more stable. Whereas, natural wetlands are subject to the variability of precipitation. Constructed wetlands have higher solids and biochemical oxygen demand (BOD) concentrations than natural wetlands (Kadlec and Knight, 1996). Natural, physical, chemical, and biological processes that occur in the soil-water-plant ecosystem provide treatment of greywater in natural systems. Natural

systems are capable of removing, at least to some degree, almost all of the major and minor constituents of wastewater that are considered pollutants—suspended solids, organic matter, nitrogen, phosphorus. trace elements, trace organic compounds, and microorganisms. Wetlands are used for solids and BOD (biochemical oxygen demand) removal.

Wetlands, when compared to mechanical treatment systems, require more land area and yet provide more diverse microenvironments using less mechanical and human labor. However microbes including algae, fungi, protozoa, and bacteria accomplish the majority of treatment in both systems.

Treatment in wetlands is accomplished by a complex combination of physical, chemical and biological mechanisms and relies upon vegetation, water depth, substrates and microbial populations according to (U.S. EPA, 1999; Hammer, 1989; Hammer 1993; Kadlec and Knight, 1996). Natural wetlands typically exhibit gradual hydroperiods, complex topographic structures, moderate to high wildlife habitat value, support few exotic species and are self-maintaining.

2.2.7 Types of wetlands

There are many types of wetlands. Some are classified depending on where the water comes from , dominant vegetation ,dominant plant lifeform ,duration of flooding and location in the catchments. As far as water source is concerned, water can come from two places. The first is surface water from precipitation (rain or snowfall) or waste water. Many seasonal and semi-permanent wetlands, and some permanent wetlands, fill with rain, melted snow or waste water. The other source of water is groundwater. Groundwater-fed wetlands are usually permanent wetlands. Sometimes it is hard to tell where a wetland gets its water. In one spot it can be fed

by rainfall or waste water flowing into it; another part of the same wetland it can be fed by groundwater. Forested wetlands are in major part of KNUST campus.

2.2.7.1 Constructed wetland

A constructed wetland is a shallow basin filled with some sort of substrate, usually soil or gravel, and planted with vegetation tolerant of saturated conditions. Water is introduced at one end and flows over the surface or through the substrate, and is discharged at the other end through a weir or other structure which controls the depth of the water in the wetland.

2.2.7.1.1 Advantages of Constructed Wetland

Constructed wetlands are a cost-effective and technically feasible approach to treating wastewater and runoff and they are the same as that of natural wetland only differ on control and prediction of constructed one are likely to be more accurate than natural one.

2.2.7.1.2 Types of Constructed Wetland

There are several types of constructed wetlands: surface flow wetlands, subsurface flow wetlands, and hybrid systems that incorporate surface and subsurface flow wetlands. Constructed wetland systems can also be combined with conventional

treatment technologies. The types of constructed wetlands appropriate for domestic wastewater, agricultural wastewater, coal mine drainage, and storm water runoff exist and are designed accordingly. Water level is above the ground surface; vegetation is rooted and emerges above the water surface: water flow is primarily above ground. Surface Flow Constructed Wetland is engineered Natural Wetland in their mode of operation.

2.2.7.1.3 Design Consideration

Despite a large amount of research and published information, the optimal design of constructed wetlands for various applications has not yet been determined (Gosselink and Mitsch,2000). Many constructed wetland systems have not been adequately monitored or have not been operating long enough to provide sufficient data for analysis. Among the systems that have been monitored, performance has varied and the influences, such as location, type of wastewater or runoff, wetland design, climate, weather, disturbance, and daily or seasonal variability affect performance.These factors are difficult to quantify. In general, wetland designs attempt to mimic natural wetlands in overall structure while fostering those wetland processes that are thought to contribute the most to the improvement of water quality. Mitsch (1992) suggests the following guidelines for creating successful constructed wetlands:

- Keep the design simple. Complex technological approaches often invite failure.
- Design for minimal maintenance.
- Design the system to use natural energies, such as gravity flow.
- Design for the extremes of weather and climate, not the average. Storms, floods, and droughts are to be expected and planned for, not feared.
- Design the wetland with the landscape, not against it. Integrate the design with the natural topography of the site.
- Avoid over-engineering the design with rectangular basins, rigid structures and channels, and regular morphology. Mimic natural systems.
- Give the system time. Wetlands do not necessarily become functional overnight and several years may elapse before performance reaches optimal

levels. Strategies that try to short-circuit the process of system development or to overmanage often fail.

- Design the system for function, not form. For instance, if initial plantings fail, but the overall function of the wetland, based on initial objectives, is intact, then the system has not failed.

2.2.7.1.4 Site Selection

Selecting an appropriate location can save significant costs. Site selection considers land use and access, the availability of the land, site topography, soils, the environmental resources of the site and adjoining land, and possible effects on any neighbors. The site should be located as close to the source of the wastewater as possible, and down gradient if at all possible so that water can move through the system by gravity. While a wetland can be fitted to almost any site, construction costs can be prohibitively high if extensive earthmoving or expensive liners are required.(Kadlec and Knight, 1996).

2.2.7.1.5 Topography

Landform considerations include shape, size, and orientation to the prevailing winds. While a constructed wetland can be built almost anywhere, selecting a site with gradual slopes that can be easily altered to collect and hold water simplifies design and construction, and minimizes costs. Previously drained wetland areas, including prior converted (PC) agricultural sites, may be well suited for a constructed wetland since the topography is usually conducive to gravity flow. The appropriate regulatory agencies must be contacted before disturbing any PC site. Since the best location for a constructed wetland is a low, flat area where water flows by gravity, it is important

to ensure that the area is not already a wetland: not all wetlands have standing water throughout the year(Kadlec and Knight, 1996).

2.2.7.1.6 Liners

Constructed wetlands must be sealed to avoid possible contamination of groundwater and also to prevent groundwater from infiltrating into the wetland. Where on-site soils or clay provide an adequate seal, compaction of these materials may be sufficient to line the wetland. Sites underlain by karst, fractured bedrock, or gravelly or sandy soils will have to be sealed by some other method. It may be necessary to have a laboratory analyze the construction material before choosing a sealing method. On-site soils can be used if they can be compacted to permeability of<108 ft/sec (<10-6 cm/sec). Soils that contain more than 15% clay are generally suitable. Bentonite, as well as other clays, provide adsorption/reaction sites and contribute alkalinity. Synthetic liners include asphalt, synthetic butyl rubber, and plastic membranes. The liner must be strong, thick, and smooth to prevent root attachment or penetration. If the site soils contain angular stones, sand bedding or geotextile cushions should be placed under the liner to prevent punctures. The liner should be covered with 3 - 4 inches of soil to prevent the roots of the vegetation from penetrating the liner. If the wetland is to be used for mine drainage, the reaction of the clay or synthetic liner should be tested before it is used since some clays and synthetics are affected by some acid mine drainages. (Kadlec and Knight, 1996)

2.2.7.1.7 Flow Control Structures

Water levels are controlled by flow control structures. Flow control structures should be simple and easy to adjust. They should allow flexibility so that processes can be optimized

2.2.7.1.8 Hydraulic Residence Time and Hydraulic Loading Rate

The hydraulic residence time (HRT) of a treatment wetland is the average time that water remains in the wetland, expressed as mean volume divided by mean outflow rate. If short-circuiting develops, effective residence time may differ significantly from the calculated residence time.

Hydraulic loading rate (HLR) refers to the loading on a water volume per plan area basis. Loading = (parameter concentration)(water volume/area)].

2.2.7.1.9 Selecting Plants

The plants that are most often used in constructed wetlands are persistent emergent plants,such as bulrushes *(Scirpus)*, spikerush *(Efeocharis)*, other sedges (Cyperus). Rushes *(Juncus)*, common reed *(Phragrnites)*, and cattails *(Typha).Thala spp* have been found to be efficient in pollutants removal in natural wetland. Not all wetland species are suitable for wastewater treatment since plants for treatment wetlands must be able to tolerate the combination of continuous flooding and exposure to wastewater or stormwater containing relatively high and often variable concentrations of pollutants.

2.2.7.1.10 Surface Flow Wetland

In wetlands constructed to treat domestic sewage, agricultural wastewaters, and other wastewaters relatively high in organic matter, bulrushes (either softstem or common threesquare) are often used because they are tolerant of high nutrient levels and because they establish readily but are not invasive. Arrowhead and pickerelweed have also been used successfully in agricultural wetlands (Gosselink and Mitsch, 2000). Blueflag iris can be planted along wetland edges to provide color. Cattails and common reed have been used frequently because of their high tolerances for

many types of wastewater, but both have disadvantages. Cattails are invasive. Since cattail tubers are a favorite food of muskrats, cattails are susceptible to damage by muskrats. Also, Surrency (1963) found that cattails were subject to attack by insects similar to army worms and suggests that cattails may not be the best choice for agricultural wetlands. Common reed is a highly aggressive species that can eliminate other species once it is introduced. It produces abundant windborne seed and spreads readily to natural wetlands. For agricultural wastewater wetlands, the ammonia tolerances of the species must be considered. Wetland species vary in their ability to tolerate ammonia. Plants may be able to tolerate higher concentrations of ammonia if the plants are slowly acclimated to it. For stormwater wetlands, the goal should be a diverse assemblage of plants. Diverse vegetation is aesthetically pleasing and may be more likely to resist invasive species, to recover from disturbance, and to resist pests than a less diverse stand. The numbers of wildlife attracted to a wetland generally increases as vegetation diversity increases. Kadlec (1995) and Webster et al. (1994) found that plant diversity declined and dominance by cattails increased as the wetlands aged. Harvesting or winter burning of above-ground. biomass is sometimes used as a means of removing nitrogen and carbon and maintaining the wetland vegetation in a log (growth) phase of high physiological activity to enhance removal, but may disrupt the wetland and the maturation of the plant community.

2.2.8 Wetland Functions

Wetlands have traditionally received a bad rap. They have been thought of as wastelands, as buggy, mucky places suitable only for murder mysteries. Nevertheless, wetlands perform a number of critical functions. They moderate impacts from flooding, control erosion, purify water, and provide habitat for fish and

wildlife. They also provide a unique natural environment for people to enjoy outdoor recreation activities etc.

2.2.8.1 Flooding

Wetlands located along the shores of oceans, lakes, rivers, and streams protect surrounding properties from flooding by acting as a sponge, temporarily storing flood water and slowly releasing it back into the system (Glossink and Miscth.2000). It is slowed down by wetland plants. Slowing the flow of water allows more time for it to percolate through the soil rather than continue downstream by so doing enrich improve the conditions in the soil.

2.2.8.2 Erosion

During a storm, the effects of rushing water can be very destructive. Fast-flowing water can carry a large load of soil particles from the land which are then washed into lakes, rivers, and streams. Excessive sediment in water is considered both a chemical and physical pollutant; it can carry bacteria and toxic particles and can alter the habitat of the receiving water for plants and animals. Wetland vegetation reduces the erosive effect of rushing water by slowing the velocity of floodwaters, binding the soil with its roots, and causing suspended soil particles to settle

2.2.8.3 Water Purification

Wetlands are particularly good water filters because of their location between land and open water. If those waters flow through a wetland before they enter a water body, some of these pollutants are filtered by the soil and plants which protect the ecosystems downstream. Research has shown that wetlands can greatly benefit water quality. Even when a wetland does not eliminate a pollutant from the water, it can

prevent it from entering a stream in one big pulse, which could overwhelm the stream's delicate web of life.

However, wetlands alone can't solve pollution problems since every wetland has a limited capacity to absorb nutrients, metals, sediments, etc. Overloading a wetland with pollution reduces its ability to serve this function. Sediment particles are often vehicles for transporting pollutants such as nutrients, pesticides, and heavy metals. Studies have shown that as much as 80-90% of sediments in the water column may be removed as they move through wetland.

Wetlands are effective in removing and storing nutrients such as nitrogen and phosphorus from waters flowing through them. Some wetlands are capable of removing 85-90% of phosphorus and nitrogen from greywater.

2.2.8.4 Groundwater Discharge and Recharge

Wetlands with a hydrological connection to groundwater can play a role in maintaining water supplies by:

1) Recharging groundwater supplies: water stored in wetlands will slowly percolate into the underlying aquifer, and

2) Discharging groundwater: water flows from the groundwater system to surface water bodies, sometimes maintaining a minimum amount of flow for rivers and streams during dry periods.

Not all wetlands perform both of these functions; some wetlands primarily recharge groundwater while others mostly discharge groundwater.

2.2.8.5 Food Webs

The vast amount of organic matter that accumulates in wetlands is the beginning of food webs for thousands of aquatic plants and animals. Because of their nutrient-rich waters, coastal marshes are among the most productive ecosystems in the world

2.2.9 Contaminant Removal Processes

Wetlands are commonly known as biological filters, providing protection for water resources such as lakes, estuaries and ground water.

The goal of wastewater treatment is the removal of contaminants from the water in order to decrease the possibility of detrimental impacts on humans and the rest of the ecosystem. The term "contaminant" is used here to refer to an undesirable constituent in the greywater that may directly or indirectly affect human or environmental health. Many contaminants, including a wide variety of organic compounds and metals, are toxic to humans and other organisms. Other types of contaminants are not toxic, but pose an indirect threat to our well-being.

A number of physical, chemical and biological processes operate concurrently in constructed and natural wetlands to provide contaminant removal. Knowledge of the basic concepts of these processes is extremely helpful for assessing the potential applications, benefits and limitations of wetland treatment systems.

2.2.9.1 Physical Removal Processes

Wetlands are capable of providing highly efficient physical removal of contaminants associated with particulate matter in the water or waste stream. Surface water typically moves very slowly through wetlands due to the characteristic broad sheet flow and the resistance provided by rooted and floating plants. Sedimentation of suspended solids is promoted by the low flow velocity and by the fact that the flow is

often laminar (not turbulent) in wetlands. Mats of plants in wetlands may serve, to a limited extent, as sediment traps, but their primary role in suspended solids removal is to limit resuspension of settled particulate matter.

Efficiency of suspended solids removal is proportional to the particle settling velocity and the length of the wetland. More commonly, resuspension results from wind-driven turbulence, bioperturbation (disturbance by animals and humans) and gas lift.

2.2.9.2 Biological Removal Processes

Biological removal is perhaps the most important pathway for contaminant removal in wetlands. Probably the most widely recognized biological process for contaminant removal in wetlands is plant uptake. Contaminants that are also forms of essential plant nutrients, such as nitrate, ammonium and phosphate, are readily taken up by wetland plants (Metcalf and Edyy,1991). The rate of contaminant removal by plants varies widely, depending on plant growth rate and concentration of the contaminant in plant tissue. Woody plants, i.e., trees and shrubs, provide relatively long-term storage of contaminants, compared with herbaceous plants. However, contaminant uptake rate per unit area of land is often much higher for herbaceous plants, or macrophytes, such as cattail. Algae may also provide a significant amount of nutrient uptake (Awuah et al. ,2002). In wetlands, as in many terrestrial ecosystems, dead plant material, known as detritus or litter, accumulates at the soil surface. Recycled contaminants may be flushed from the wetland in the surface water, or may be removed again from the water by biological uptake or other means.

In most wetlands, there is a significant accumulation of plant detritus, because the rate of decomposition is substantially decreased under the anaerobic (oxygen-depleted) conditions that generally prevail in wetland soil. If, over an extended

period of time, the rate of organic matter decomposition is lower than the rate of organic matter deposition on the soil, formation of peat occurs in the wetland. In this manner, some of the contaminants originally taken up by plants can be trapped and stored as peat. Peat may accumulate to great depths in wetlands, and can provide long-term storage for contaminants (www.wetland.com) However, peat is also susceptible to decomposition if the wetland is drained or otherwise dries up. When that happens, the contaminants incorporated in the peat may be released and either recycled or flushed from the wetland.

Microbial decomposers, primarily soil bacteria, utilize the carbon (C) in organic matter as a source of energy, converting it to carbon dioxide (CO_2) or methane (CH_4) gases. The efficiency and rate of organic C degradation by microorganisms is highly variable for different types of organic compounds.

Microbial metabolism also affords removal of inorganic nitrogen, i.e., nitrate and ammonium, in wetlands. Specialized bacteria (*Pseudomonas* spp.) metabolically transform nitrate into nitrogen gas (N_2), a process known as denitrification. The N_2 is subsequently lost to the atmosphere, thus denitrification represents a means for permanent removal, rather than storage, of nitrogen by the wetland. Removal of ammonium in wetlands can occur as a result of the sequential processes of nitrification and denitrification. Nitrification, the microbial (*Nitrosomonas* and *Nitrobacter* spp.) transformation of ammonium to nitrate, takes place in aerobic (oxygen-rich) regions of the soil and surface water. The newly-formed nitrate can then undergo denitrification when it diffuses into the deeper, anaerobic regions of the soil. The coupled processes of nitrification and denitrification are universally important in the cycling and bioavailability of nitrogen in wetland and upland soils.

2.2.9.3 Chemical Removal Processes

In addition to physical and biological processes, a wide range of chemical processes are involved in the removal of contaminants in wetlands. The most important chemical removal process in wetland soils is sorption, which results in short-term retention or long-term immobilization of several classes of contaminants. Sorption is a broadly defined term for the transfer of ions (molecules with positive or negative charges) from the solution phase (water) to the solid phase (soil). Sorption actually describes a group of processes, which includes adsorption and precipitation reactions (Metcalf and Eddy,1991).

Adsorption refers to the attachment of ions to soil particles, by either cation exchange or chemisorption. Cation exchange involves the physical attachment of cations (positively charged ions) to the surfaces of clay and organic matter particles in the soil. This a much weaker attachment than chemical bonding, therefore the cations are not permanently immobilized in the soil. Many constituents of wastewater and runoff exist as cations, including ammonium (NH_4^+) and most trace metals, such as copper (Cu^{2+}). The capacity of soils for retention of cations, expressed as cation exchange capacity (CEC), generally increases with increasing clay and organic matter content. Chemisorption represents a stronger and more permanent form of bonding than cation exchange. A number of metals and organic compounds can be immobilized in the soil via chemisorption with clays, iron (Fe) and aluminum (Al) oxides, and organic matter. Phosphate can also bind with clays and Fe and Al oxides through chemisorption. .(Kadlec and Knight,1996)

Phosphate can also precipitate with iron and aluminum oxides to form new mineral compounds (Fe- and Al-phosphates), which are potentially very stable in the soil, affording long- term storage of phosphorus.

Volatilization, which involves diffusion of a dissolved compound from the water into the atmosphere, is another potential means of contaminant removal in wetlands. Ammonia (NH_3) volatilization can result in significant removal of nitrogen, if the pH of the water is high (greater than about 8.5). However, at a pH lower than about 8.5, ammonia nitrogen exists almost exclusively in the ionized form (ammonium, NH_4^+), which is not volatile.

2.2.10 Applications and Treatment Efficiency

Constructed and natural wetlands are often used as low-tech treatment systems for domestic wastewater effluent, from single-residence septic tank effluent wetlands to large municipal wastewater treatment facilities. Similarly, wetlands may be used effectively for treatment of animal and aquaculture wastes.

Pretreatment, such as primary sedimentation or aeration stabilization, is often required for industrial effluents.

Although a broad spectrum of designs has been used for wetland treatment systems, all can be classified as either surface-flow (SF) or subsurface-flow (SSF) systems

(Fig.) Natural wetlands have also been effectively utilized as SF treatment wetlands.

2.2.11 Treatment Wetland Performance

As a case in point, the efficiency of nutrient removal will decrease as inflow concentration approaches the natural background concentration of the nutrient in the wetland, while the outflow concentration may be well within the desired range. Conversely, nutrient removal efficiency, in terms of percent mass removal, may increase substantially as the loading rate is increased to moderate levels, yet the outflow concentration may exceed the desired level. Thus, the actual performance of

treatment wetlands is dependent on a multitude of factors, including inflow concentration, mass loading rates, wetland design and climate.

2.2.11.1 Organic Carbon (BOD) Removal

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen consumed by microorganisms in the oxidation of organic matter, it includes nitrogenous and carbonaceous oxidation (Kadlec and Knight, 1996). The effectiveness of wetlands at removing BOD occurs only if the incoming BOD is greater than the natural background level.

Organic matter contains approximately 45 to 50% carbon (C), which is utilized by a wide array of microorganisms as a source of energy. A large number of these microorganisms consume oxygen (O_2) to break down organic C to carbon dioxide (CO_2), a process that provides energy for growth. Therefore, the release of excessive amounts of organic C to surface waters can result in a significant depletion of O_2, and subsequent mortality of fish and other O_2 -dependent aquatic or marine organisms.

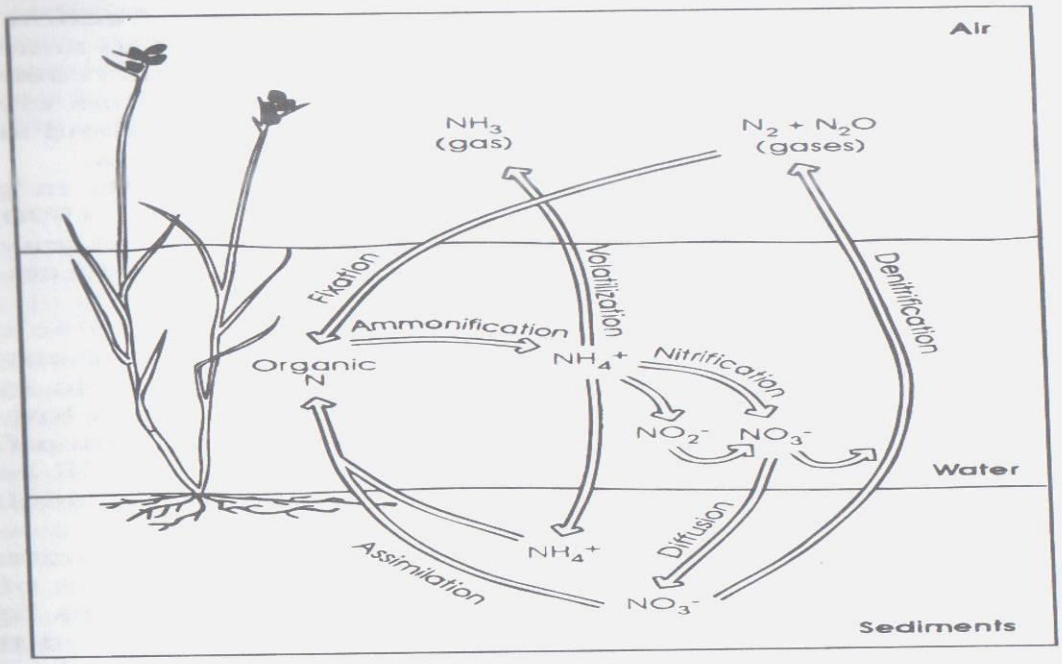
Wetlands contain vast numbers of organic C-utilizing microorganisms adapted to the aerobic (O_2-rich) surface waters and anaerobic (O_2-depleted) soils. Thus, wetlands are capable of highly effective removal of organic compounds from a variety of wastewaters. Organic C in wetlands is broken down to CO_2 and methane (CH_4), both of which are lost to the atmosphere. Wetlands also store and recycle copious amounts of organic C, contained in plants and animals, dead plant material (litter), microorganisms and peat. Therefore, wetlands tend to be natural exporters of organic C as a result of decomposition of organic matter into fine particulate matter and dissolved compounds.

A commonly-used parameter for biologically available C is biochemical oxygen demand (BOD), which is actually a measure of the rate of O_2 consumption by microorganisms utilizing the available organic C in the water or soil. The normal procedure for determining BOD in water samples measures the amount of O_2 depletion occurring over a 5-day period (BOD_5).

2.2.11.2 Nitrogen Removal

Nitrogen (N) is a major component of municipal wastewater, stormwater runoff from urban and agricultural lands, and wastewater from various types of industrial processes. High concentrations of nitrate in drinking water supplies can cause methemoglobinemia, or "blue baby" syndrome, in infants (www.who.int/water_sanitation_health/wastewater). Un-ionized ammonia (NH_3), found in certain types of wastewater effluent, is potentially toxic to many aquatic and marine organisms. In addition, eutrophication of surface waters frequently is linked with elevated N concentrations, especially in coastal and estuarine environments.

Nitrogen exists in many forms in the environment, and transformations among different forms may occur rapidly and frequently(Figure 2).



Simplified wetland nitrogen cycle

Source : Kadlec and Knight,1996

Figure 2:Simplified nitrogen cycle

In the environment, nitrate and nitrite are usually found in well-aerated waters, with nitrate being the predominant form, while ammonium is the more persistent form of inorganic N in anaerobic wetland soils.

Wetlands generally are well-suited for N removal, even though the natural background level of total N in wetland outflows is typically greater than 1 mg L^{-1}. Substantial removal of N may take place through settling of N-containing particulate matter in the wetland inflow. In addition, since N is an essential plant nutrient, it can removed through plant uptake of ammonium or nitrate, and stored in organic form in wetland vegetation. A large portion of this N may later be released and recycled, as plants die and decompose. Ammonium may be chemically bound in the soil on a

short-term basis, while organic N from dead plant material can accumulate in the soil as peat, a long-term storage mechanism.

Nitrate removal efficiency typically is extremely high in wetlands. The biological process of denitrification, i.e., conversion of nitrate to nitrogen gas, provides a means for complete removal of inorganic N from wetlands, as opposed to storage within the vegetation or soil. Denitrification usually accounts for the bulk of the inorganic N removal in wetlands (Kadlec and Knight,1996)

2.2.11.3 Phosphorus Removal

Phosphorus (P), like N, is a major plant nutrient, hence, addition of P to the environment often contributes to eutrophication of lakes and coastal waters. In many cases, wetlands do not provide the high level of long-term removal for P that they provide for N. This is due, in part, to the lack of a metabolic pathway for P removal, as compared to denitrification for N removal. Nevertheless, most wetlands can provide significant P removal from water and wastewater through a combination of physical, chemical and biological processes (Kadlec and Knight 1996) as shown on Figure 3.

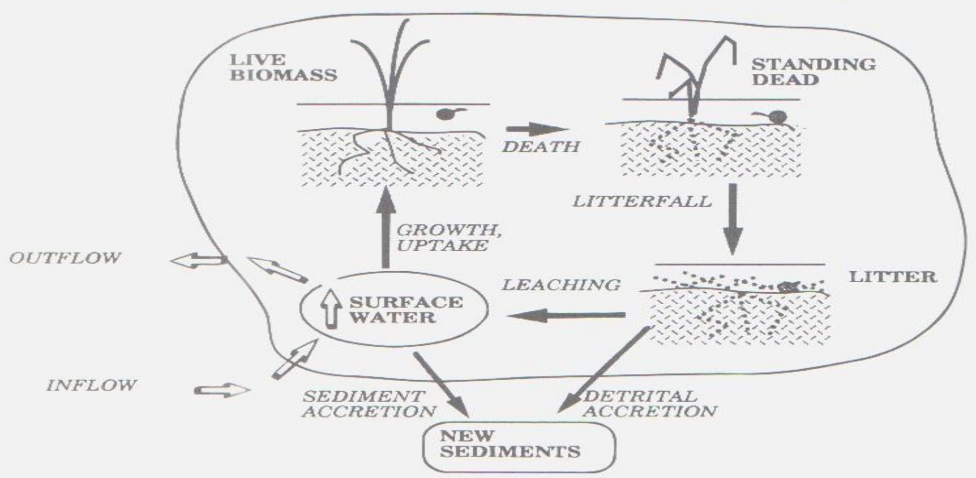


Figure 3: Phosphorus cycling in a wetland

Source: Kadlec and Knight, 1996

Orthophosphate is the predominant inorganic form of P in surface waters. This form of P readily accumulates in wetland vegetation and soils, as a result of biological uptake and chemical bonding. Formation of iron and aluminum phosphate minerals (low-pH wetlands) and calcium phosphate minerals (high-pH wetlands) is the major pathway for P removal in some wetlands. Particulate organic P may be removed by settling from the water column. Both dissolved and particulate organic P may be biologically broken down to inorganic P (mineralization), and subsequently removed through biological and chemical processes.

2.2.11.4 Trace Metals Removal

A number of metals are required in small amounts for plant or animal growth. Some of these micronutrients, such as copper, selenium and zinc etc, are toxic at higher concentrations, and may be found in certain types of wastewater.

Removal of metals in wetlands may occur through a number of processes, including plant uptake, soil adsorption (binding to soil particles) and precipitation (formation of solid compounds). Plant uptake rates and tolerance of metals varies considerably among plant species (www.wetlandplants.edu/). Some terrestrial plant species are known to be capable of storing high concentrations of metals in roots and other tissues. Metals may also tend to accumulate on the root surfaces of plants, rather than being absorbed into the plant (Gosselink and Mitsch,2000).

Wetland soils are potentially effective traps, or sinks, for metals, due to the relative immobility of most metals in wetland soils.

2.2.11.5 Total Dissolved Solids

Total dissolved solids (TDS) measurements are often used to express the degree of contamination or amount of impurities in water and wastewater. One of the reasons

for this is the relative ease of measurement -- a water sample is evaporated, and the residual solids are weighed. A wide variety of inorganic ions and organic compounds, many of which may not be considered contaminants, contribute to the sum total of dissolved solids. A number of these are biologically utilized or chemically reactive in wetlands. However, TDS often includes relatively high concentrations of "conservative", or relatively uncreative, dissolved compounds, which are not removed in wetlands

2.2.12 Wetlands and Water Quality

Good water quality consists of three closely related things: low concentrations of polluting chemicals; a good balance of the conditions that support healthy aquatic life (such as good habitat and enough oxygen); and a healthy diversity of aquatic life including fish, aquatic insects, mollusks and plants. Most of these pollutants do not enter surface water from a single point like a pipe. Instead, they are more widely spread across the landscape, and enter our surface waters in diffuse ways. These nonpoint source pollutants are a serious threat to the quality of the water. Wetlands are often the last line of defense between these nonpoint source pollutants. Wetlands vary in how effective they are at removing pollutants. Cleansing ability depends on how water moves through the wetland, what plants are present, the size of the wetland, the time of year, how long the water is held and many other factors.(Gosselink and Mitsch,2000)

2.2.12.1 Pathogens

Bacteria, viruses, protozoa, helminthes, and fungi are waterborne microorganisms found in wastewater. These organisms depend on their host for survival. The wastewater environment for pathogens is very hostile and survival of these

organisms is reduced by natural factors, such as temperature, ultraviolet radiation, unfavorable water chemistry especially anoxic conditions, sedimentation, predation, and natural die-off (Kadlec and Knight, 1995). Indicator organisms, such as coliforms, fecal coliforms, and Escherichia coli, are used as indicators of waterborne pathogen contamination to avoid the expense and technical expertise involved in analyzing for pathogens directly according to Kadlec and Knight (1995) bacteria removal efficiency is related to inflow concentrations. Removal efficiencies are high when inflow concentrations are high; removal efficiencies are nearly always greater than 90 percent for coliforms. When inflow concentrations are less than background levels, removal efficiencies are low. Removal of indicator bacteria in wetlands may be correlated with solids removal and hydraulic residence times **(**Gearheart et al., 1999; Gersberg et al., 1989.)

2.2.12.2 Human Activities and Threats

Urban & suburban development. filling and dredging wetlands for houses, commercial buildings, ports, highways, airports, waste disposal sites, and other construction projects. Paving large areas with asphalt and concrete increases the rate and amount of surface runoff which increases the likelihood of flooding. Development can also cause fragmentation of large wetland systems. Erosion, sea level rise, droughts, hurricanes, and overgrazing by wildlife can also impact wetlands

3 CHAPTER III: METHODOLOGY

3.1 Study Area description

The Natural Wetland under study is located at the centre of KNUST Campus at an altitude of 280m above sea level. The greywater was been discharged in it more than thirty years ago through four gutters connected to the three halls of residence ,namely Africa hall, Queen's hall and one part of Republic hall. The effluent water is discharged into Wiwi stream after it flows through soils and vegetations of a natural valley (figure 4). Only Greywater is conveyed into this natural wetland whiles the blackwater is chanalised in sewer network to the University sewage Treatment plant.

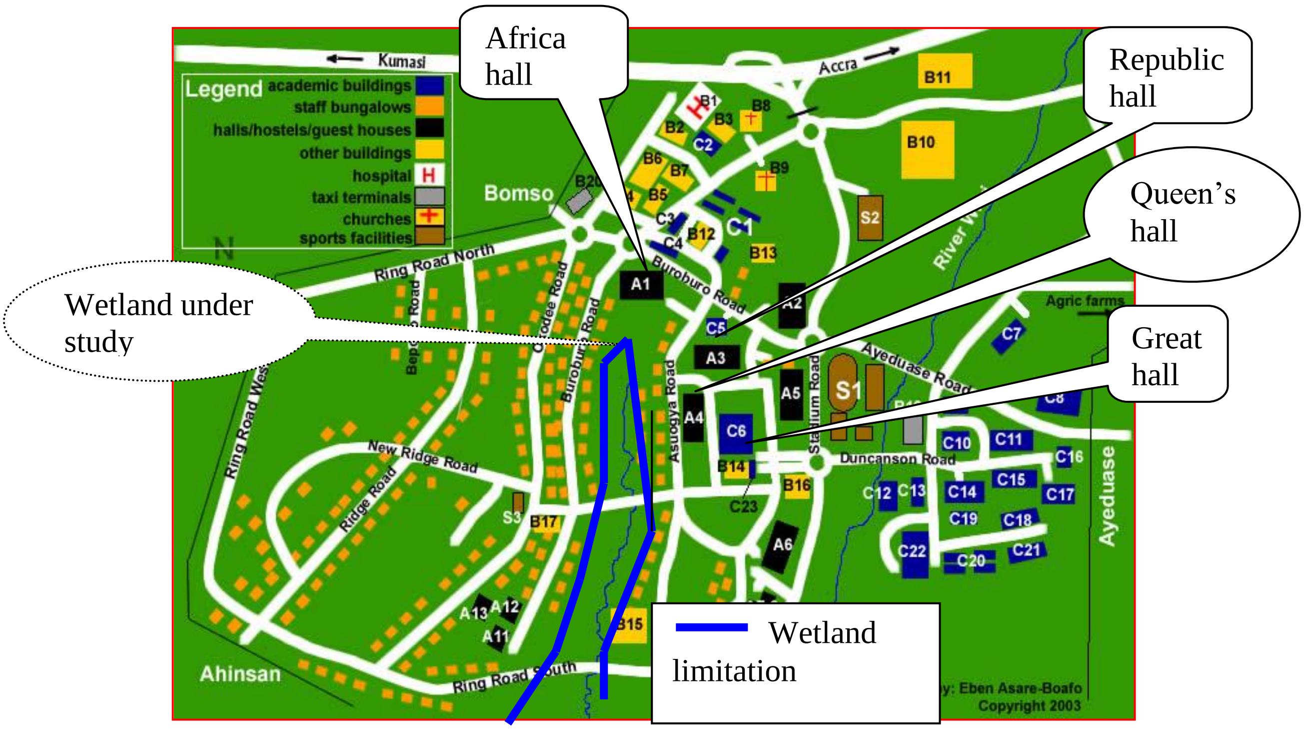


Figure 4: Map of KNUST Campus

During nine weeks, different samples on greywater, soils and plants; were taken and analysed in various Laboratories in Kumasi. The composite samples , of three samples collected two hours time of interval, were collected once a week at eight

locations GQ1,GQ2,GQ1,GQ2,JUNC,MID ,EFF., and STR for laboratory analysis , Appendix V 3rd figure. For the purpose of this study, the sampling locations in the wetland were designated as follows:

Four Inlet Points,

GA1 = influents from the Africa residential student hall.

GA2 = influents from the Africa hall mainly kitchen.

GQ1 = influents from the Queen's annex and part of the republic Hall main.

GQ2 = influent greywater from Queen's hall main.

JUNC=Meeting point of greywater from four gutters above mentioned.

and other three for monitoring points ,

MID=Middle course of greywater under treatment

EFF=Exit point of the greywater after treatment in the wetland.

STR=stream receiving effluent after wetland treatment.

Parameters analyzed included BOD,COD, pH, nitrates and nitrites, total phosphorus, Total coliforms, suspended solids, turbidity, and heavy metals.

Soils samples as well as that of predominant species in the natural wetland under study were collected and identified in the laboratories. Soil sampling points were taken from site A,B,C,D and E (Appendix V 3rd figure) ; each site has three locations; Low slope (LS), Middle slope (MS), and Upper slope (USp) .sample were taken between 0-65cm deep at each of these location across and along the wetland.

Plants samples were taken over the whole wetland area and identified.

Methods of analytical procedures are provided in Table 1

Table 1: Methods and Instruments used

Parameter	Method used	Instrument
BOD	Winkler Modification	Appendix V:B
COD	Open Reflux Method	Appendix V:A
Turbidity	APHA Standard Method(USEPA)	HACH Model 2100P Turbidimeter
Conductivity	Tetra Con® 325,330i	Tetra Con® 325,330i
Suspended Solid	Gravimetric Method	Appendix V:C
Nitrate	Cadmium Reduction Method (Nitra Ver Powder Pillows)	HACH type DREL/2010 Spectrophotometer
Nitrite	Diazotization Method (Powder Pillows)	HACH type DREL/2010 Spectrophotometer
Phosphorus	Orthophosphate Phos Ver® 3 (Ascorbic Acid) Method {Pillow Powder}	HACH type DREL/2010 Spectrophotometer
Chemical and Physical of the Soil	U.S E.P.A Methods 3050,7130. Test Methods for evaluating Solid Waste: Laboratory Manual – Physical/chemical Methods.SW-846,3rd edition (Washington ,DC U.S E.P.A, November 1986)	A.A.S*
Total coliforms	Spread Plate Method	Plate media (chromocult)

Site characteristics studied included topography , a narrowed wetland at the upstream of it and increase width at the downstream side .(Fig.4), soil characteristics, existing land use, and climate.

The wetland is used mainly for farming, different vegetables are cultivated there .Sugar cane makes major part of land use of the area and is among the plants contributing to wastewater purification.

3.2 *Flow rate measurement*

A 24hour flow measurement of incoming greywater was carried out four times and average were made in order to assess the effect of loading on treatment .

Direct determination of the discharge was done using volumetric or weight measurements. Container(bucket) placed on scales allows the weighing of the water entering the container in a measured time interval (Plate 4).

The measured weight, divided by the unit weight of water and by the measured time interval, gives the flow rate in volume per unit time.

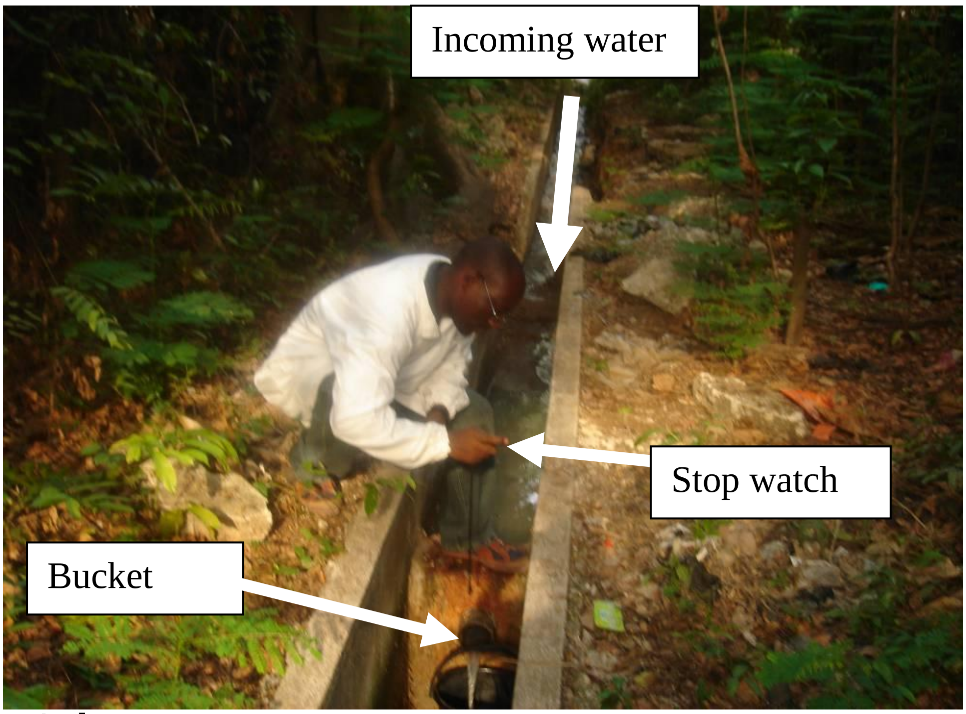


Plate 4:Flow Rate Measurement

4 CHAPTER IV: RESULTS AND DISCUSSIONS

4.1 Greywater Characteristics

Ever since the operational of KNUST Campus , greywater has been discharged into wetland under study, no control or monitoring of the pollutants limits have been recorded at the site. Pollutants removal by the vegetative and soil components of the wetland treatment system occur at natural rate and the Natural Wetland System has ability of self maintenance (Kadlec and Knight,1996) .

Incoming greywater concentrations were above permissible limits according to the EPA Ghana guidelines during the period of study (Table.2). After passage through the wetland treatment, the concentrations of all sample were well within permit limits, except lead which were slightly above the limit(Table 2). This removal process from the greywater were occurring very rapidly in the Natural wetland system, with most removal of suspended solids. Soil testing results for heavy metals, indicated that the Iron is the most prevalent in the soil .The pollutants levels in the greywater are reduced as the water passes through the wetland treatment system. The final concentration has been steadily falling within the range required. The details of the results are summarized in the Table 2.

The values of Junction (meeting point) are taken as influent to the natural wetland under study. Table 2.gives the values also for effluent , those of receiving water body (Wiwi stream),maximum permissible and gives efficiency removal of the parameters measured.

Table 2:Greywater Characteristics

Parameter	Units	Influent *	Effluent *	Stream*	% Removal	Max. Perm
pH	—	6.83±0.29	6.97±0.15	6.99±0.2	—	6-9
Turbidity	NTU	279.89±131.30	5.83±1.54	121.12±100.86	97.9	75
Conductivity	(μS/cm)	656.42±192.85	339.11±62.46	462.12±171.50	48.3	1500
SS	mg/l	222.83±94.97	2.59±1.32	51.67±23.57	98.8	50
COD	mg/l	707.28±29218	100±51.37	454±219.91	85.9	1000
BOD	mg/l	420.22±159.19	48.89±11.73	240.89±137.34	88.4	200
Nitrate –N	mg/l	12.91±3.62	7.5±1.9	12.19±3.01	41.9	100
Nitrite-N	mg/l	0.19±0.14	0.03±0.02	0.04±0.02	81.8	—
Phosphates	mg/l	12.43±4.46	3.48±3.28	9.74±7.45	72	10
Total Coliforms	MPN/100ml	5.5E+05 ±0.3E+06	3.3E+04 ± 3.4E+04	5E+5 ± 1.3E+5	94	4.00E+08
Heavy Metals in Greywater						
Parameter	Units	Influent	of Effluent	Stream	% Removal	Max. Perm
Cd	mg/L	0.015±0.002	0.031±0.015	0.025±0.008	-51.0	<0.1
Pb	mg/L	0.316±0.224	0.298±0.327	0.277±0.095	5.6	0.1
Cu	mg/L	0.135±0.092	0.064±0.022	0.095±0.108	52.6	2.5
Zn	mg/L	0.151±0.140	0.032±0.012	0.027±0.022	78.8	5
Mn	mg/L	0.098±0.064	0.065±0.046	0.055±0.022	33.7	2.5

**Mean ± Standard error 99%*

4.2 Biochemical Oxygen Demand *(BOD)* Removal

The average Inlet value of Biochemical Oxygen Demand (BOD) 420mg/l was higher compared to EPA Ghana guidelines for wastewater 50mg/L. The ratio of COD: BOD was 1.7 (Table.2&3) This indicates that the extent of biodegradation of the Greywater from the resident halls in KNUST campus is more than 50%.

Table 3: Biochemical Oxygen Demand (BOD)mg/l

Source of sample	**Mean*** (mg/L)	**Max.** (mg/L)	**Min.** (mg/L)	**SD**
GA1	356.67±258.25	1040.00	80.00	300.29
GA2	637.33±317.36	1160.00	330.00	369.02
GQ1	323.56±115.51	502.00	120.00	134.31
GQ2	363.33±137.06	720.00	220.00	159.37
Av. Inf.	420.22±207.04	855.50	187.50	183.94
JUN	153.89±60.11	310.00	100.00	69.90
MID	84.67±34.16	146.00	30.00	39.72
EFF	48.89±11.73	70.00	30.00	13.64
STR	240.89±137.34	550.00	60.00	159.69

**Mean ± Standard error 99%*

The removal of organic matter is between 50-90 percent of substrate biodegradation if the COD: BOD ratio ranges between 2 and 3.5 (Quano et al., 1978). The percentage BOD reduction achieved here was in the range of 83.9% - 91.8%. Comparison of BOD_5 levels as the Greywater moves through wetland soils and plants is shown on the Figure 6**,** and shows that there is BOD5 removal as the greywater moves through wetland soils and plants. Fifty percent of the applied BOD is removed within few meters of the treatment slope and the remaining in colloidal and dissolved forms as the wastewater comes in contact with attached microbial growth in the system. (Crites et al, 2005).

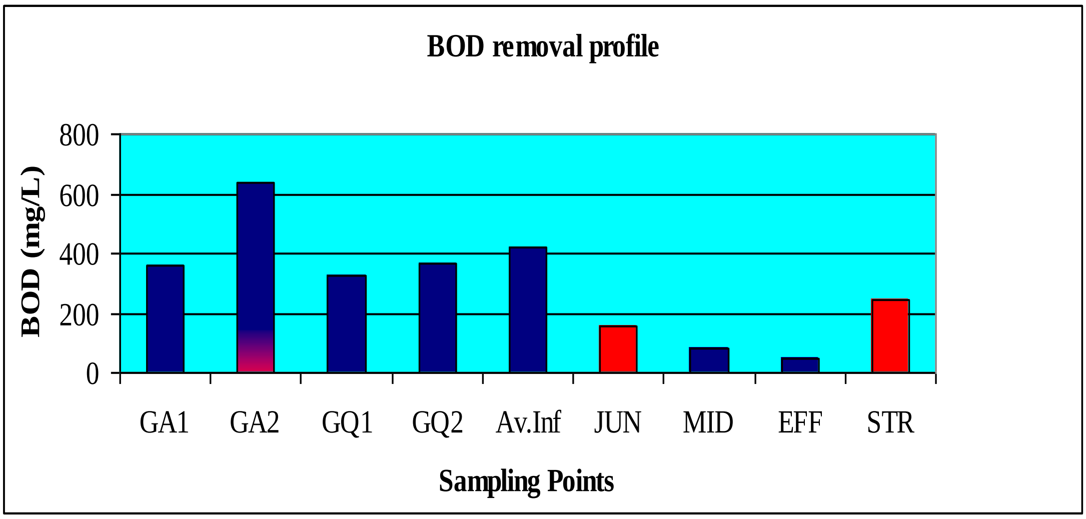


Figure 5: BOD removal profile into wetland

For example, at the points JUNC,MID and EFF, the removal efficiency of BOD_5 was about 72.4% ; 83.1% and 88.4% respectively(Table 2 &Figure 5). These variations may be due to different bio-activity of microbes and also with changes in temperature because the study was carried out in the warm season (January-April). In rain season the weather is cold, the metabolism and bio-activity of microbes are low; whereas, with the higher temperature, the biomasses and activities of microbes increase at high speed, which resulted in higher BOD_5 removal (Steinmann et al., 2003).

4.3 Chemical Oxygen Demand Removal

The results in the Table 4 Shows that COD values were 707 mg/l and 100mg/l respectively at inlet and effluent, the latter below 250mg/L for EPA Ghana guidelines (Appendix II: Table A1).The removal efficiency varied in different stages time and with the distance were ranged between 73.1%-93.6% and the figure 7 gave the profile of the efficiency removal**.** Actually, the natural wetland treatment system contributed to more than 85% of COD removal and the values are higher than that of BOD. There is COD removal potential in the wetland environment, due to the presence of humic materials (Kadlec and Knight, 1996). The relative oxygen

depletion effect of effluent greywater were low thus there is no pollution to the receiving water body. Also the seasonal variations might have significant potential effect on COD removal. The study was carried out in warm season, the removal efficiency for COD is greater than that in cold season (Steinmann et al., 2003).

Table 4:Chemical Oxygen Demand(COD)mg/l

Source of sample	**Mean*** (mg/L)	**Max.** (mg/L)	**Min.** (mg/L)	**SD**
GA1	532.36±221.00	1040.00	192.00	256.98
GA2	1127.22±399.84	1835.00	464.00	464.93
GQ1	537.56±190.90	784.00	168.00	221.97
GQ2	632.00±356.98	1688.00	304.00	415.10
Av. Inf.	707.28±292.18	1336.75	282.00	199.76
JUN	364.33±144.80	600.00	160.00	168.37
MID	149.78±77.70	344.00	56.00	90.35
EFF	100.00±51.37	232.00	40.00	59.73
STR	460.54±219.91	736.00	64.00	255.71

**Mean ± Standard error 99%*

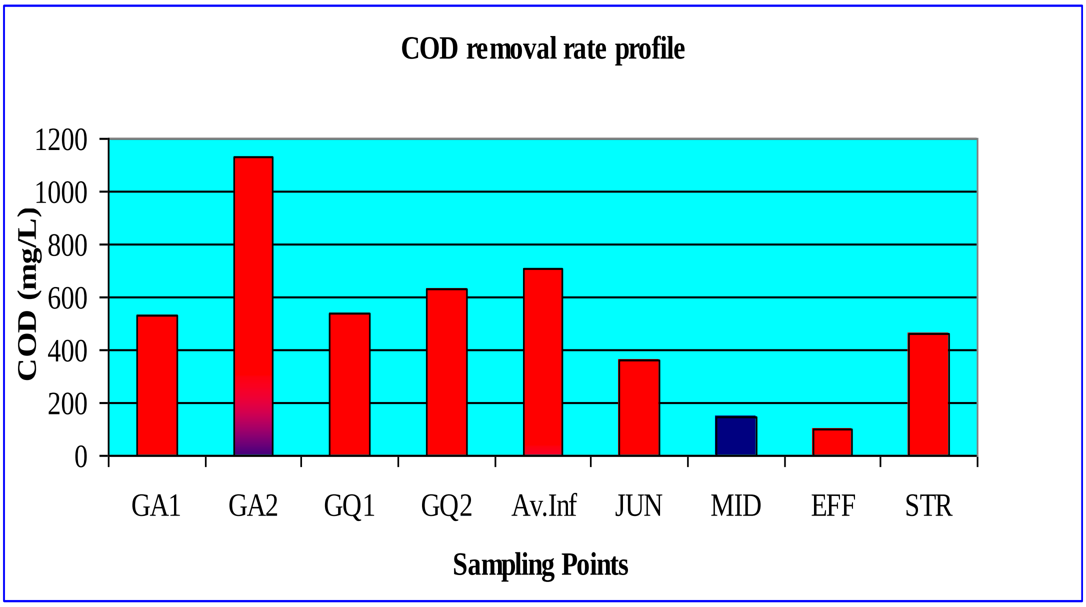


Figure 6: COD Removal profile into wetland

4.4 Nutrients Removal

4.4.1 Nitrogen removal

Table 5 shows that the effluent greywater nitrate concentration value were 7.15 mg/L below EPA Ghana recommended value of 75mg/L. The efficiency removal were 41.9%, means that inlet concentration is also below EPA Ghana guidelines .

Table 5: Nitrate -Nitrogen (NO^{-}_{3} –N)mg/L

Source of sample	**Mean*** (mg/L)	**Max.** (mg/L)	**Min.** (mg/L)	**SD**
GA1	10.88±3.18	17.00	6.50	3.70
GA2	15.75±5.80	31.00	9.50	6.74
GQ1	13.31±4.14	22.00	9.00	4.81
GQ2	11.69±3.26	20.00	8.00	3.79
Av. Inf.	12.91±3.62	22.50	8.25	4.21
JUN	10.25±2.14	13.00	6.50	2.49
MID	9.06±2.89	14.00	4.00	3.36
EFF	7.50±1.90	11.00	4.50	2.20
STR	12.19±3.01	18.00	7.50	3.50

**Mean ± Standard error 99%*

The low percentage removal, is due to the application of chemicals by the farmers and also the rate of ammonification, nitrification and denitrification which generated more stable Nitrate –Nitrogen , as shown on the figure 7 . The reactions rate producing Nitrate -Nitrogen within wetland change from one location to another. The percentage efficiency removal were ranged between 6.38% and 63.64%(Table5). (Crites, et al., 2005) reported that the plant uptake accounts only 10% for Nitrogen removal .

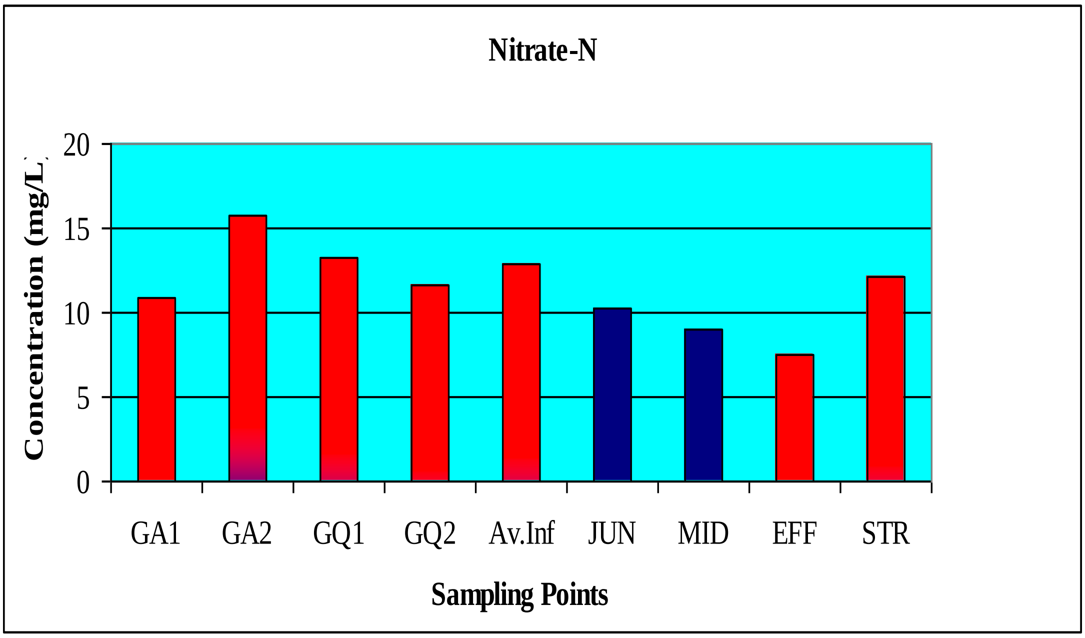


Figure 7: Nitrate Removal Profile

The removal nitrite in natural wetland treatment system is presented in (Table 6) which shows that inlet and outlet concentration values were 0.18,g/l and 0.03mg/l respectively .Nitrification rate accounted for higher part of the Nitrite-Nitrogen and the efficiency removal up to 81.8% were influenced by ambient temperature of 29.86ºC favorable to microbial activity nitrite removal profile is shown on Figure 8. Low in the wetland, usually a detectable level of it indicates incomplete nitrogen assimilation and the presence of anthropogenic nitrogen source (Kadlec and Knight,1996). Organic nitrogen were converted into NH_3 -N under both aerobic and anaerobic conditions present in the wetland. The aerobic being the most common.

Biological nitrification/denitrification may be most important factor in NH_3-N removal compared to that chemical removal usually carried out through reaction ammonia with negative charges of the clays particles ,which were 7% as against at least 15% needed for a better wetland soil to treat efficiently wastewater and organic

Table 6: Nitrite -Nitrogen (NO^-_2–N)mg/L

Source of sample	**Mean*** (mg/L)	**Max.** (mg/L)	**Min.** (mg/L)	**SD**
GA1	0.11±0.16	0.55	0.02	0.74
GA2	0.12±0.21	0.68	0.00	1.24
GQ1	0.35±0.32	0.80	0.01	0.95
GQ2	0.15±0.12	0.40	0.01	0.85
Av. Inf.	0.18±0.14	0.61	0.01	0.95
JUN	0.03±0.01	0.05	0.01	1.13
MID	0.06±0.05	0.19	0.02	1.04
EFF	0.03±0.02	0.08	0.01	1.20
STR	0.04±0.01	0.06	0.02	1.03

**Mean ± Standard error 99%*

matter. Because of aerobic condition the nitrification rate increased and ammonia nitrogen is lower in high-oxygen wetland and the optimum pH range of ammonification is between 6.5 and 8.5 (Reddy and Patrick,1984)

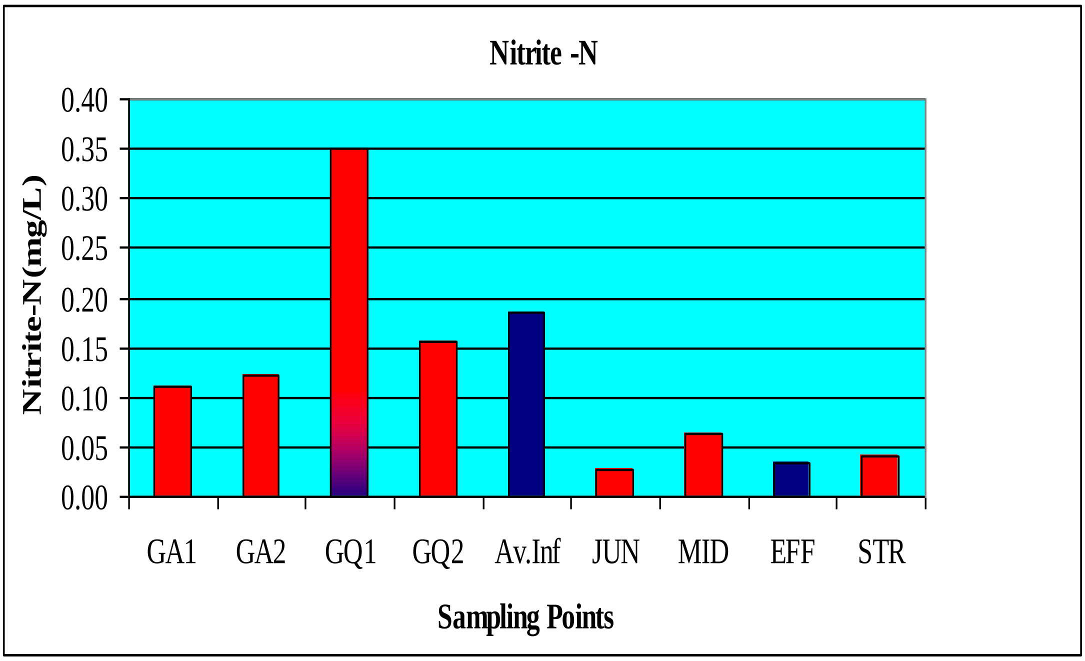


Figure 8:Nitrite Removal profile

Results of this study showed NO_2 -N had higher efficiency removal of 81.8% after wetland treatment system of and on other side Nitrate efficiency removal was low , less than 50%(table 5) ,probably due to the rate of nitrification/denitrification process in wetland. The nitrate and nitrite are important in water quality control because their toxicity cause methylglobanemia to infants. (For US drinking water is 10mg/L)

4.4.2 Phosphates removal

The influent and effluent greywater phosphate concentration were averagely 12.43mg/l and 3.48mg/l respectively Table 7 and EPA Ghana recommended value for effluent is 10mg/L .Figure.10 compares phosphate removal in natural wetland of the study as the greywater moves from inlet to down stream outlet. As indicated in Appendix V,TableA.10), the removal efficiency of phosphates were ranged between 27%and 91.7%. Phosphates removal variation after wetland treatment system could be due mainly to the fluctuation of students activities.

Table 7:Phosphate – Phosphorus (PO^{3-}_4-P)mg/L

Source of sample	Mean* (mg/L)	Max. (mg/L)	Min. (mg/L)	SD
GA1	8.46±5.26	18.60	1.15	5.77
GA2	11.50±9.16	32.40	3.10	10.04
GQ1	14.19±5.63	23.40	4.15	6.17
GQ2	15.58±9.07	39.00	10.35	9.94
Av. Inf.	12.43±7.28	28.35	4.69	4.89
JUN	10.48±5.06	22.60	4.95	5.54
MID	9.15±4.35	16.50	1.50	4.76
EFF	3.48±3.28	12.00	0.90	3.60
STR	9.74±7.45	23.80	0.70	8.17

**Mean ± Standard error 99%*

The results show that temperature had no significant effects on phosphates removal in the wetland rather depend on incoming greywater load throughout the study processes. These results indicated that the natural system had much effect on phosphates removal through vegetation community and hydric soils performance (Figure9) .

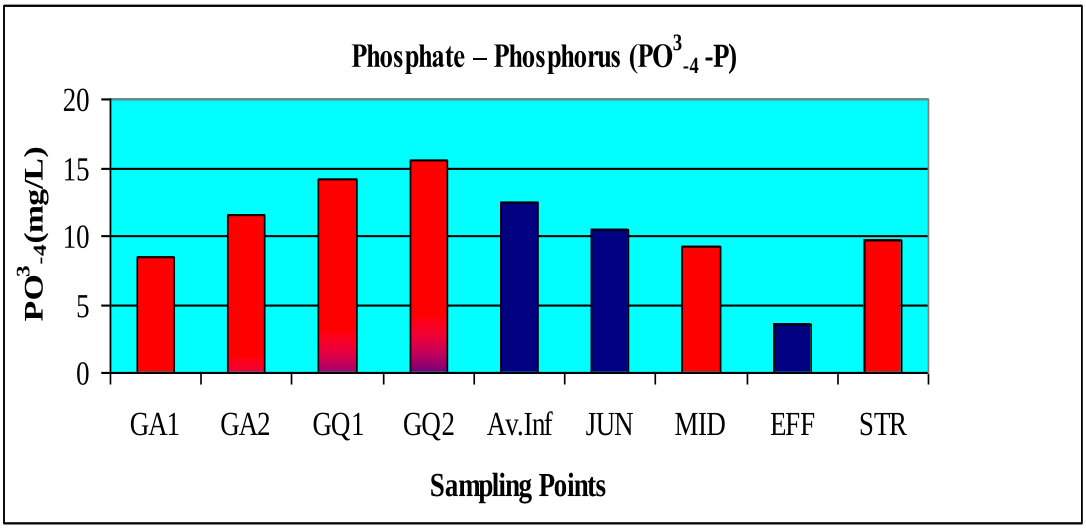


Figure 9: Phosphates Removal profile

In natural system, adsorption of phosphates to sedimentary particles is an important removal process. The adsorption capacity is mainly dependent on the presence of Fe^{3+}, Ca^{2+} or Al^{3+} in sediments (Verhoeven and Arthur, 1999) and the higher Fe concentration in the wetland soil contributed to the efficiency removal**.** Additionally, phosphates can also be precipitated with Fe^{3+}, Ca^{2+} or Al^{3+} contained in greywater. The uptake of plant was also considered as one important removal pathway of phosphates.

4.5 Suspended Solid

The inflow and outflow greywater SS concentration were 222.83 mg/L and 2.59 mg/L respectively ,the latter being far below recommended value of 50mg/L (Table 8 and appendix V:Table A6) .More than 98.8% of SS efficiency removal were

observed in this natural system ,effluent concentration was not varying so much ;about from 1mg/l-5mg/L. The good performance of SS removal may be due to the low velocity, coupled with the presence of the luxuriant vegetation and gravel substrate Plat 6 (Kadlec and Knight, 1996).

Table 8: Suspended Solid (mg/L)

Source of Sample	**Mean*** (mg/L)	**Max.** (mg/L)	**Min.** (mg/L)	**SD**
GA1	239.46±230.77	723.00	73.30	236.65
GA2	306.33±282.44	1036.70	93.00	289.64
GQ1	198.17±97.57	440.00	110.00	100.06
GQ2	147.37±56.89	220.00	50.00	58.34
Av.Inf	222.83±94.97	604.93	81.58	97.39
JUN	155.62±139.51	433.30	33.00	143.06
MID	6.30±3.68	12.00	1.00	3.77
EFF	2.59±1.32	5.00	1.00	1.35
STR	51.67±23.57	84.00	4.00	24.17

**Mean ± Standard error 99%*

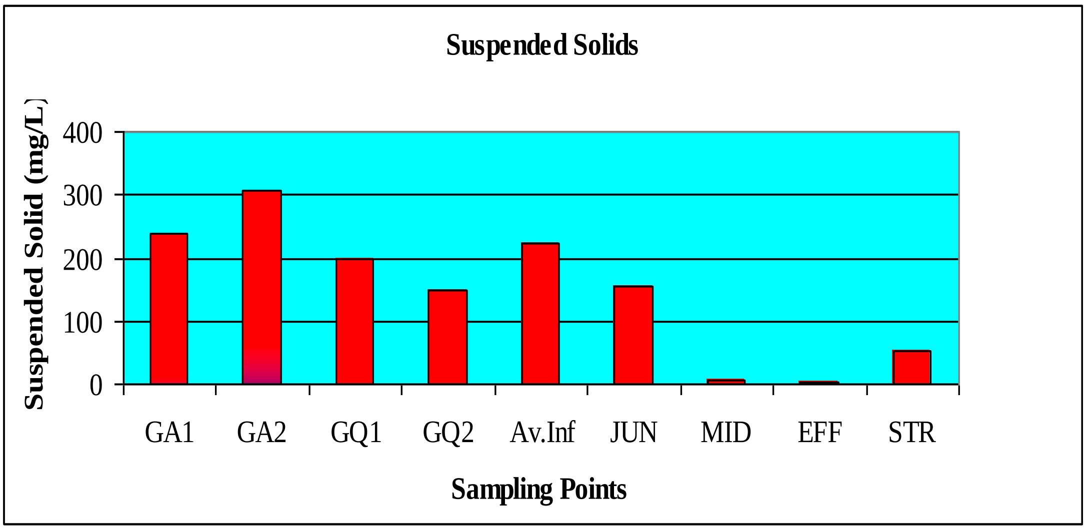


Figure 10: Suspended Solid removal profile

Indeed, the overgrowth of plants would therefore influence the characteristics of SS removal in this natural wetland system. Figure 10 compares SS removal profile between different points from upstream inlet flow and downstream at outlet flow point, showing that SS in this system is substantially removed as greywater moves towards effluent point was higher even at the first stage MID about 300m from JUNC with efficiency removal of 96%. The SS reduction in the process greatly influence other pollutants removal like BOD,COD, heavy metals and compared to the ordinary conventional system, this natural system may effectively reduce the adverse effect of SS ensure effluent quality at the low cost.

Plate 5:Luxuriant vegetation at the study site

4.6 Turbidity

The turbidity readings were ranged between 5.83 NTU and 279.89 NTU respectively for the effluent and influent values. The recommended effluent value was 75 NTU(EPA Ghana guidelines for wastewater) .The effluent was in range of 2.8 to 7.9 NTU, and the receiving Wiwi stream readings ranging between 11.88 and 329.674 NTU. Table8 indicates that there is no pollution in both cases .

Figure 12 gave the turbidity removal profile, shows that at early stages of greywater wetland treatment the turbidity reduction is observed within few meters. Turbidity; as the same as suspended solid; were removed in the short distance into wetland compared to other parameters removal progress, this essentially due to the abundant vegetation and important ingredient in turbidity and suspended solid removal at the site.

Table 9: Turbidity (mg/L)

Source of Sample	Mean* NTU	Max .NTU	Min. NTU	SD
GA1	214.65±105.26	445.30	61.10	122.40
GA2	298.72±160.26	755.00	167.90	186.34
GQ1	255.04±71.53	414.70	155.60	83.17
GQ2	351.16±188.17	908.60	187.10	218.80
Av.Inf	279.89±131.30	630.90	142.93	152.68
JUN	181.05±176.20	703.00	53.20	204.88
MID	11.16±3.42	16.20	5.70	3.98
EFF	5.83±1.54	7.90	2.80	1.80
STR	121.12±100.86	329.67	11.88	117.28

**Mean ± Standard error 99%*

High turbidity readings imply low clarity and may indicate erosion and sedimentation problems. Rainfall and runoff can increase the suspended solid load in a river and make the river appear cloudy or muddy. High biological productivity related to increases in nutrients can result in increases of diatoms and other algae that contribute to turbidity.

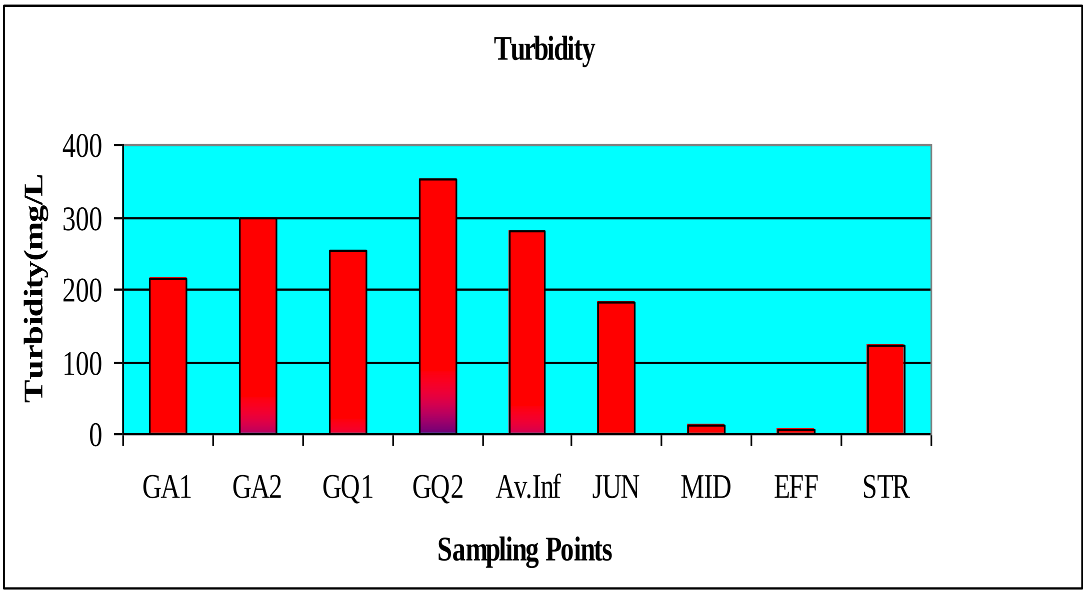


Figure 11:Turbidity Removal Profile

.Elevated turbidity can cause an increase in temperature since suspended particles absorb heat. Reduction of light penetrating the water column due to turbidity can decrease the rate of photosynthesis. This, in turn, can decrease the amount of dissolved oxygen in the water. As suspended particles settle, they can impair the habitat needed for fish spawning and aquatic macroinvertebrates. They can also clog the gills of fish and the breathing apparatus of invertebrates. Particles serve as places of attachment for harmful microorganisms and toxic materials. Turbidity in drinking water is decreased through the process of flocculation, which involves addition of alum or a mixture of iron, lime, and chloride to cause solids to settle out , while in the natural system were done by the vegetation and soils.(Metcalf and Eddy,1991)

4.7 Conductivity removal

The EPA Ghana guidelines recommends 1500 µS/cm(appendix V:Table A.4), in the both case influent and effluent flow the values were 656.42 µS/cm and 339.11 µS/cm respectively and below guidelines recommendation as well as that of receiving body Wiwi stream were 462.12 µS/cm (Table 10). The mean efficiency removal were less

than 50% the highest recorded were 69, 6 %.Figure 13 shows low variation in conductivity removal in course of the natural wetland treatment system.

Table 10:Conductivity levels of a natural wetland at KNUST receiving greywater (in µS/cm)

Source of sample	**Mean*** (µS/cm)	**Max.** (µS/cm)	**Min.**(µS/cm)	**SD**
GA1	429.33±162.89	860.00	253.00	189.41
GA2	687.78±257.24	1206.00	471.00	299.11
GQ1	791.89±161.52	1118.00	592.00	187.82
GQ2	716.67±189.75	1235.00	450.00	220.64
Av.Inf	656.42±192.85	1104.75	441.50	224.25
JUN	555.28±98.48	772.50	429.00	114.51
MID	429.67±67.97	543.00	306.00	79.03
EFF	339.11±62.46	426.00	235.00	72.63
STR	462.12±171.50	700.25	146.80	199.42

** Mean ± Standard error 99%*

Conductivity determinations are useful in aquatic studies because they provide an estimate of dissolved ionic matter in the water. Low values of specific conductance are characteristic of high-quality, oligotrophic (low nutrient) for waters. Very high

values are good indicators of possible pollution sites..

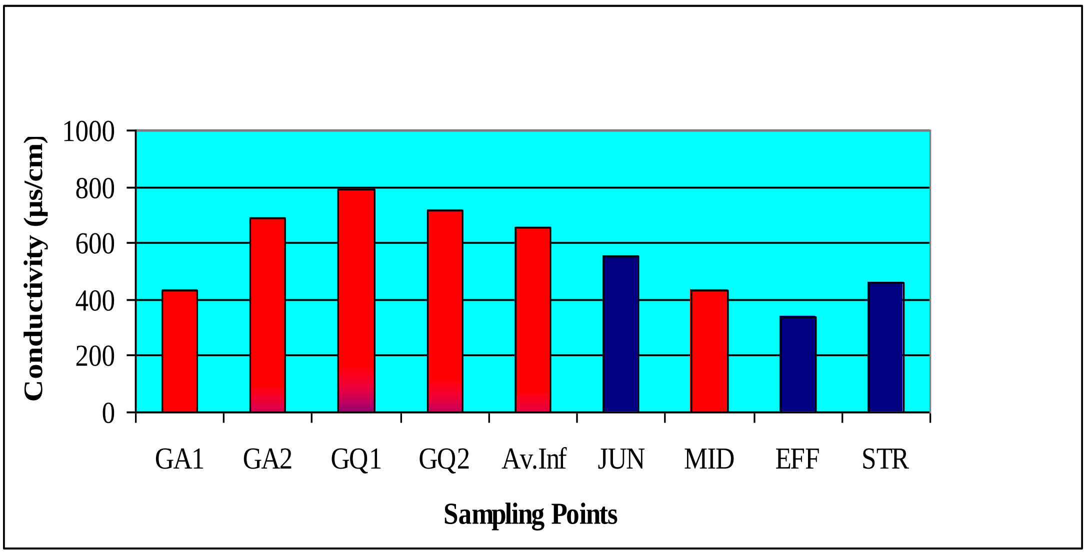


Figure 12:Conductivity Removal Profile of natural wetland at KNUST.

For instance, road salt can raise conductivity. A sudden change in conductivity can indicate a direct discharge or other source of pollution into the water .Conductivity readings do not provide information the specific ionic composition and concentrations. Water, itself, contains hydrogen (H+) and hydroxide ions (OH-) with relative amounts reflected in the pH readings. Chloride, phosphate, sulfate, and nitrate anions (negative ions) as well as calcium, magnesium, iron, aluminum, and sodium cations (positive ions) contribute to overall conductivity as well (Gosselink and Mitsch,2000) . Mostly they are removed by attachment (chemical removal) ,the plant uptake does not greatly contribute to ions and cations removal, ,their size permit to escape and move with water molecules. Figure 12 clarifies little change of conductivity removal profile .

4.8 Total Coliforms

The total coliform in the effluent greywater quality for were in the range of 3.29±3.85(at 10^{-4} dilution) Table.11 and efficiency removal were ranged from 55.1 - 100% .The values fall under the EPA Ghana guidelines for wastewater being

discharged in the waterbodies (MPN/100mL) of 400. Figure14 shows considerable reduction of total coliforms from JUN , MID and EFF.

Table 11:Total coliforms 10^{-4}

Source of sample	Mean* Counts after10^{-4}dilution	Max.	Min.	SD
GA1	40.71±33.44	104.00	6.00	34.29
GA2	81.14±46.37	142.00	10.00	47.55
GQ1	46.57±42.54	135.00	11.00	43.62
GQ2	50.29±21.53	78.00	13.00	22.08
Av.Inf	54.68±19.32	88.75	22.25	19.82
JUN	31.86±36.24	115.00	11.00	37.16
MID	10.00±6.37	19.00	1.00	6.53
EFF	3.29±3.85	10.00	0.00	3.95
STR	50.43±14.89	71.00	29.00	15.27

**Mean ± Standard error 99%*

The following factors are the most important that might have affected microbial concentrations in the greywater effluent: Temperature, sunlight and Physical process (sedimentation filtration and sorption) the study was carried out in the warm season .

Much of the earliest works on bacterial removal assumed that temperature was the most important factor controlling the removal mechanism, Marais and Shaw (1961). Recent investigations considered bacterial removal as a more complex mechanism involving interactions between the physical, chemical and biological systems present in wetlands and retention ponds, although temperature clearly remains an important parameter, Polprasert *et al.* (1994), Pearson *et al.* (1987a, b). All found that removal rates of fecal coliforms increased with increasing temperature. No matter which indicator organism is tested, temperature clearly affects indicator bacteria. Canteras

et al. (1995) reported that sunlight was the most important factor affecting die-off of *Eschericia coli* with 90% concentration reductions within about 1h.

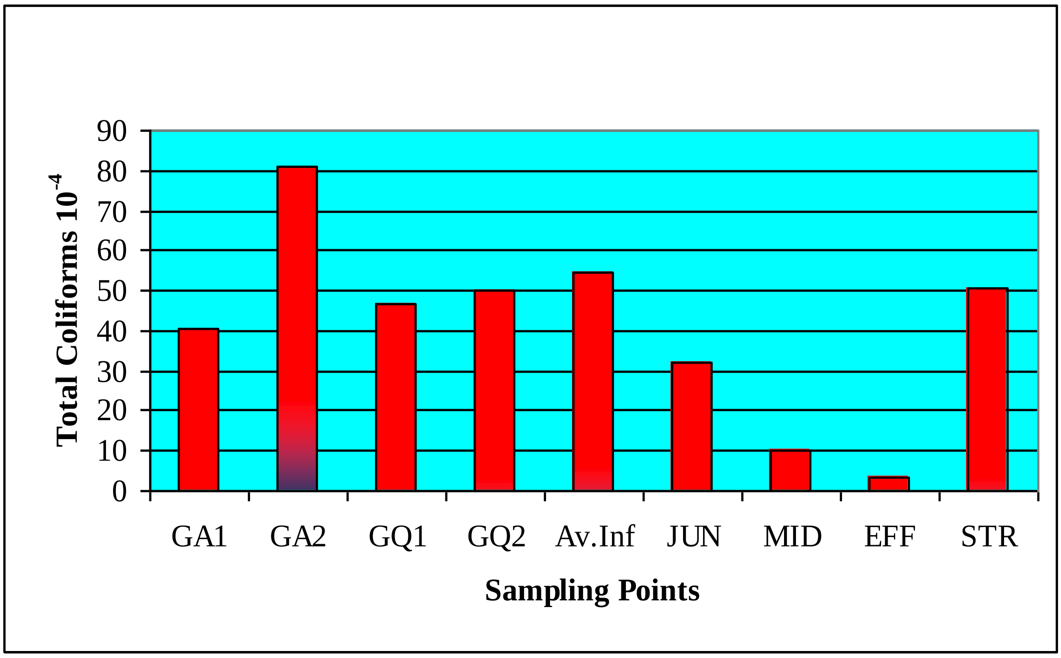


Figure 13: Coliforms removal profile

Microbes in the water column may associate with particles or remain in the ‘‘free’’ or unassociated phase. Microbes associated with particles, particularly denser inorganic particles, will tend to settle from the water column more quickly than free organisms or those associated with less dense particles that remain more mobile in the environment. Howell *et al*., 1996 and Sherer *et al*., 1992 observed that microbes associated with particles tend to survive longer in natural waters than free microbes.

4.9 Heavy Metals

Table 12: Heavy Metal Concentration in Greywater

Parameter	*Units*	*Influent**	*Effluent**	*Stream**	*% Removal*	*Max. Perm*
Fe	mg/l	0.670±0.426	0.337±0.177	0.407±0.280	49.7	-
Cd	mg/l	0.015±0.002	0.031±0.015	0.025±0.008	-51.0	<0.1
Pb	mg/l	0.316±0.224	0.298±0.327	0.277±0.095	5.6	0.1
Cu	mg/l	0.135±0.092	0.064±0.022	0.095±0.108	52.6	2.5
Zn	mg/l	0.151±0.140	0.032±0.012	0.027±0.022	78.8	5
Mn	mg/l	0.098±0.064	0.065±0.046	0.055±0.022	33.7	2.5

**Mean ± Standard error 99%*

The ranges of metal levels in water and soil during the study period are shown in Table 12. The Pb were above the recommended value (Table 2) and due probably to the discharge of wastewater containing heavy metals into wetland over more than thirty years , concentration of certain metal might have accumulated. Example of Cd in coming Greywater and outlet flow were 0.015±0.002mg/l and 0.031±0.015mg/l respectively. Means that there were addition of Cd within wetland but still effluent were below the recommended value (Table 2). Adsorption and chemical precipitation are the mechanisms of heavy metal removal vary with the constituent metal from 50 to about 80 %(Crites et al. 2005) Only Cu and Zn were in this range while others were below (Table 12), this shows that the heavy metal efficiency removal in the natural wetland treatment system is low.

4.10 Characteristics of the wetland soil

- Physical aspects

The Soil moisture at field capacity were between 11.18% and 59.56% in the wetland soil(LS and MS). The type of soil for natural wetland was Sandy loam with sand 65.41%, silt 27.88% and clay content were 6.72%. Soil type classification from silt, silt loam, loam sandy loam to loamy sand are reported by Metcalf and Eddy ,1991; 15% of clay is generally suitable and recommended for wetland treatment systems, (Kadlec and Knight,al.1996)**.** Hydraulic conductivity ranges between 1.2-2.4 m/d.

- Chemical Aspects

Top soils were mostly organic soils for at least 5cm ,this may be especially contribute to phosphorus and metals removal by adsorption and precipitation, because the chemical reactivity relate to the surface electrical charge of the soil particle ;and soil charge is typical highest in clays and organic soil particle, Kadlec and Knight,1996.

Table 14 and 15 shows higher value of micronutrients present the soil and that may occur at trace to high concentrations within wetland. Iron concentration is the highest. Surface waters , sediments and plant roots contain a higher proportion of Iron than stems or leaves (Wetzel, 1978).The pH value was 5.55 which is moderately acidic (Soil Research Institute of Kwadaso,2007) and the range of 5.55-8 is suitable for most crops (.Crites et al. 2005) . Available P and K were 16.3 ppm and 92.6 ppm respectively found to be medium (11-20ppm and 50-100ppm); Organic matter were high 2.8%>0.2 (Table 14) higher range probably due to the falling of leaves from present luxuriant vegetation; Cu and Zn were high and very high respectively, and

exchangeable micronutrients varied within natural wetland system and from different location (Figure 14,15)

Table 13: Heavy metals Concentration in the Soil of wetland receiving greywater at the site understudy.

Parameter	Concentration
Mn	84.34mg/kg±10.72mg/kg
Cd	68.15mg/kg±4.63mg/kg
Cu	6.01mg/kg±1.82mg/ kg
Pb	41.62mg/kg±4.71mg/kg
Zn	34.22mg/kg±5.22mg/kg
Fe	1890.69mg/kg±163.8 mg/kg

Table 14:Exchangeable Cations me/100g

Parameter	LS	MS	Av. WL	US
Higher concentration in Wetland				
NH_4-N(PPm)	49	43.5	46.25	35.8
CEC(me/100g)	9.9	5.2	7.55	5.9
pH	5.7	5.4	5.55	5.2
OC%	2.8	1.O	2.8	0.7
Ca(me/100g)	6.4	2.5	4.45	2.9
K(me/100g)	0.6	0.3	0.45	0.3
Na(me/100g)	0.9	0.6	0.75	0.6
Higher concentration up land				
A.P(PPm)	5.9	26.7	16.3	47.6
A.K(PPm)	100.7	84.5	92.6	106.9
NO_3-N(PPm)	6.7	6.5	6.6	8.2
Exch.Al	0.6	0.7	0.65	0.7
Mg(me/100g)	1.5	1	1.25	1.3

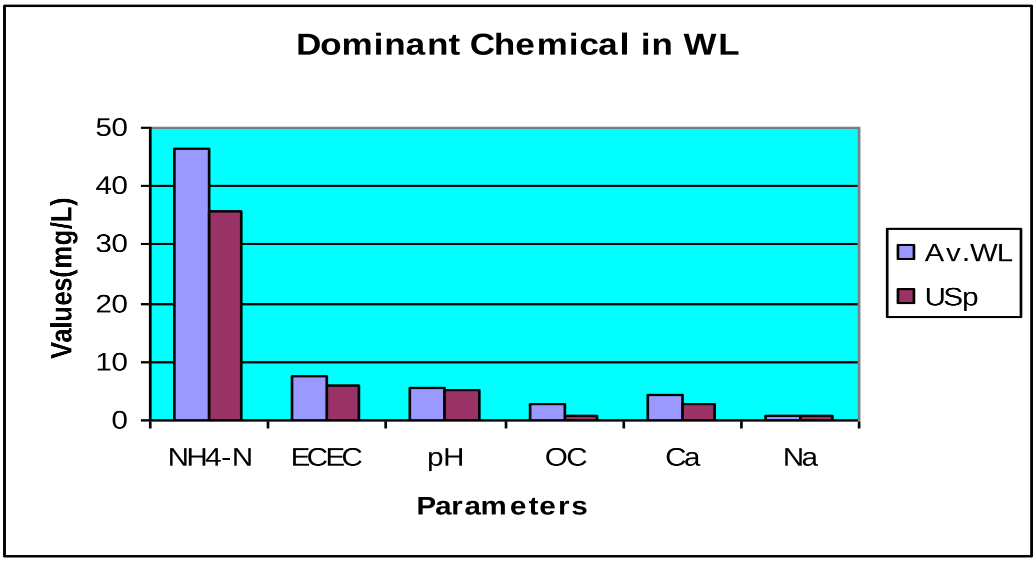


Figure 14:Chemicals Concentration in the Soil A

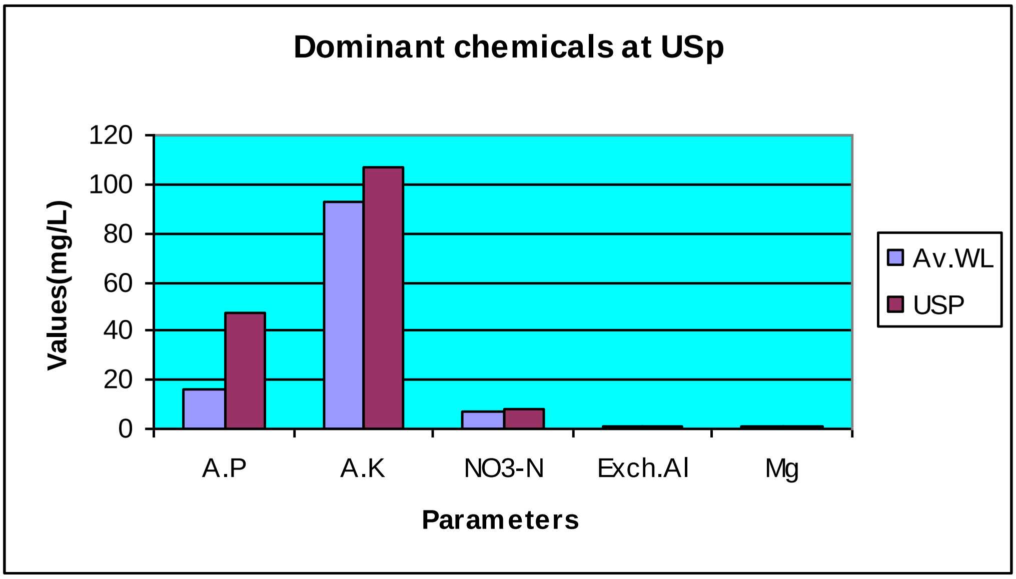


Figure 15:Chemicals Concentration in the Soil B

4.11 Flow rate

Influent flows to the Wetland were up at 618m^3/d for the daily average. The average is made up by four source of Greywater :GA1,GA2.GQ1 and GQ2.respectively1.94 l/s,1.41 l/s,2.27 l/s, and 1.54 l/s. The adjacent graph plots flow (daily average) and rainfall (for total study period).The data shows a continuous fluctuations in the flows. It appears that the rain within the period does not influence incoming flows from various gutters of sampling points collection. The fluctuation were due to the

students activities in and around campus . In GQ1, the flow is permanently higher compared to other gutters this because it collects Queen's annex and a part of Republic hall main. The regression part of the line would show a decrease in flow rates due to low consumption of the water by students at that time of resting and in contrary it shows peak flow between 7am -10am and 3pm-9pm (Figure 16). There is not significant correlation between rainfall and flow rates. Since the total weekly rainfall values from January to May were small for four twenty four hours flow measurements(appendix III: Table A and appendix V:Table A13)

The average Inlet flow (Q in. av.)was 0.0072 m^3 /s and average outflow(Q out. av.) was 0.0032m^3 /s. This means that Qout average was 45% of Q in average imply that evaporation, evapotranspiration ,percolations, and storage within wetland had effect on greywater flowing through the natural wetland treatment system. The wetland area were 866702 m^2 thus the hydraulic loading rate was 0.07cm/d during the dry season no rain effect were observed. The big area compared to discharge flow resulted to the low HLR and might have influenced greywater treatment .

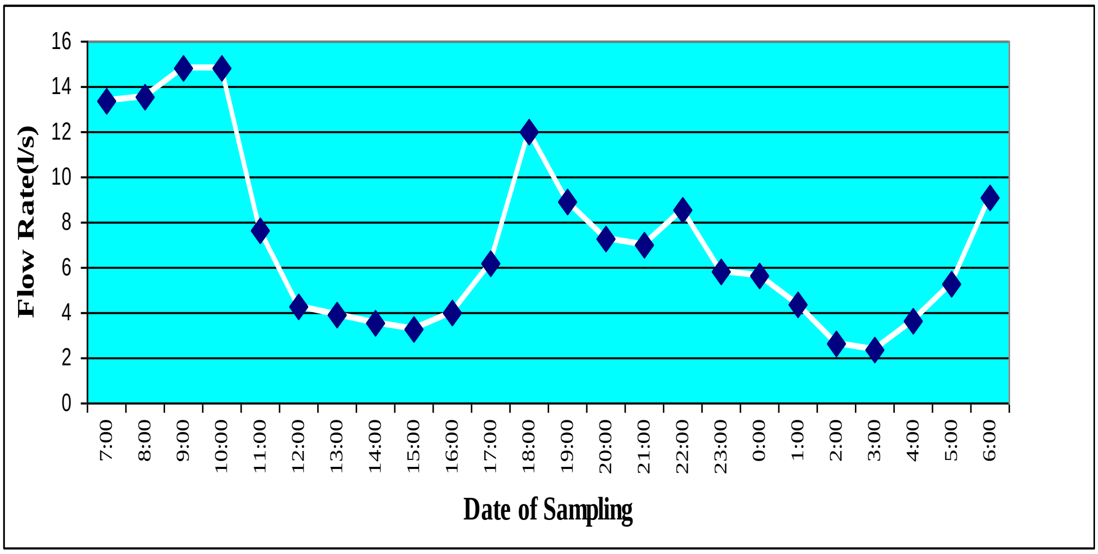


Figure 16: Average 24 hour Flow Measurement of incoming greywater

4.12 Wetland Species Identification

The amount of emergent plants present and healthy in the wetland treatment system is one of the most important requirements for pollutants assimilation. The plants serve as hosts for a variety of attached growth organisms, and it this microbial activity that is primarily responsible for the organic decomposition (Crites et al., 2005) . A Wetland without emergent plants will have limited potential for dissolved and particulate pollutants reductions (Kadlec and Knight,1996;Gosselink and Mitsch,2000) .The following species were found to be dominant in the wetland under study and apparently contributed to the pollutants removal.

- *Arundiniria gigantea (cane),Nymphaea nouchal(water lily)i,Saccharum efficinarum(Sugar canne), Aspillia Africana,Justicia flava ,Nephrolepis biserrata (ferns)*
- *Panicum maximum,Nauclea latifolia,Piptandencastrum africanum.*
- Supoa (twi), Hwedeɛ (twi)

Those most closer to the wetland channel generally are:

Eleis guineensis, Colocasia esculenta, Xanthosoma sp, Saccharum afficinarum, Thala sp and *Coix lacryma (Job's tears).*

The Natural Wetlands differ from one wetland to another in shape, hydrology, plant species ,for a new engineered wetland the following have found to be also efficient in pollutants removal(Table 15).

Table 15:Natural wetland plants communities that may be compatible with final polishing of wastewaters .

General wetland type Communities	specific wetland	Typical dominants
Marsh	Cattail marsh	*Typha sp.*
	Mixed emergent	*Potenderia sp.*
		Sagittaria sp.
	Bulrush marsh	*Scirpus sp.*
	Wet prairie	*Sedges*
Scrub shrub	Buttonbush swamp	*Cephalanthus occidentalis*
	Titi swamp	*Cyrilla racemiflora*
Swamps	Cypress/gum	*Taxodium sp, Nyssa sp.*
	Palm	*Sabal minor*
	Melaleuca	*Melaleuca quinquinerva*

Source:Kadlec and Knight,1996

5 CHAPTER V: CONCLUSION

The conclusions drawn from this study are these:

Greywater effluent quality after treatment in natural wetland meet EPA Ghana guidelines , except Pb (appendix V: Table A1; appendix II: Table A1).

- The best performance was obtained at suspended solid removal efficiency of 98.8%. Turbidity, Suspended Solids, COD, BOD, Total Coliform were ranged between 85-99%; Phosphates and Nitrite-N ranged between 70-85% ;Conductivity and Nitrate –N were less than 50% ; heavy metals (Mn and Pb) were less than 50%,Cu and Fe ranged between 50-70% , Zn was 78.8%, and Cd increased by 51.These results show that the greywater has less pollution potentials after treatment in the natural wetland.
- COD to BOD ratio of 1.7:1, means that, the extent of biodegradation of the greywater from these halls is more than 50%.
- However, removal efficiency is low for heavy metals .Cd increases in levels.
- The soil were sandy loam and the heavy metals concentrations in the soil were higher
- The in flow rate was 7.16 l/s and outlet flow rate was 45% of inlet flow rate. The Hydraulic loading rate was 1.4cm/d,Flow rate and wetland surface area ratio assessed show positive effect on treatment and the hydraulic Loading Rate of 1,4cm/d fall within range of 0.5cm- 4cm/d (Kadlec and Knight, 1996).
- The plants species that are likely to influence on the pollutants removal efficiency in the natural wetland treatment system are *Coix lachryma, Colocasia esculenta* and *Thala* sp.
- Successful operation of a natural wetland treatment may require careful site selection.

6 CHAPTER VI: RECOMMENDATIONS

- The present study results were compared with EPA Ghana guidelines for wastewater being discharged into environment. It is recommended that comparison with guidelines for other purpose be done.
- The establishment of standards and guidelines for greywater being discharged in the wetland should be done.
- To avoid short circuiting (chanalised) flow into Natural wetland treatment system and to increase detention time, the greywater should be evenly distributed.
- Use of *Coix lachryma, Colocasia esculenta* and *Thala* sp. Plants are recommended with further research on their potential treatment of greywater for different seasons at other site.
- The Natural wetland can be used to improve water quality for reuse

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8 APPENDICES

APPENDIX I

A.CHEMICAL OXYGEN DEMAND (COD)

Open Reflux Method

1. General Discussion

a. Principle: Most types of organic matter are oxidized by a boiling mixture of chromic and sulfuric acids. A sample is refluxed in strongly acid solution with a known excess of potassium dichromate ($K_2Cr_2O_7$). After digestion, the remaining unreduced $K_2Cr_2O_7$ is titrated with ferrous ammonium sulfate to determine the amount of $K_2Cr_2O_7$ consumed and the oxidizable matter is calculated in terms of oxygen equivalent. Keep ratios of reagent weights, volumes, and strengths constant when sample volumes other than 50 mL are used. The standard 2-h reflux time may be reduced if it has been shown that a shorter period yields the same results. Some samples with very low COD or with highly heterogeneous solids content may need to be analyzed in replicate to yield the most reliable data. Results are further enhanced by reacting a maximum quantity of dichromate, provided that some residual dichromate remains.

2. Apparatus

a. Reflux apparatus, consisting of 500- or 250-mL erlenmeyer flasks with ground-glass 24/40 neck and 300-mm jacket Liebig, West, or equivalent condenser with 24/40 ground-glass joint, and a hot plate having sufficient power to produce at least 1.4 W/cm^2 of heating surface, or equivalent.

b. Blender.

c. Pipets, Class A and wide-bore.

3. Reagents

a. Standard potassium dichromate solution, 0.04167*M*: Dissolve 12.259 g $K_2Cr_2O_7$, primary standard grade, previously dried at 150°C for 2 h, in distilled water and

dilute to 1000 mL. This reagent undergoes a six-electron reduction reaction; the equivalent concentration is 6 X 0.04167*M* or 0.2500*N*.

b. Sulfuric acid reagent: Add Ag_2SO_4, reagent or technical grade, crystals or powder, to conc H_2SO_4 at the rate of 5.5 g Ag_2SO_4 /kg H_2SO_4. Let stand 1 to 2 d to dissolve. Mix.

c. Ferroin indicator solution: Dissolve 1.485 g 1,10-phenanthroline monohydrate and 695 mg $FeSO_4 \cdot 7H_2O$ in distilled water and dilute to 100 mL. This indicator solution may be purchased already prepared.*

d. Standard ferrous ammonium sulfate (FAS) titrant, approximately 0.25*M*: Dissolve 98 g $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in distilled water. Add 20 mL conc H_2SO_4, cool, and dilute to 1000 mL. Standardize this solution daily against standard $K_2Cr_2O_7$ solution as follows:

Dilute 25.00 mL standard $K_2Cr_2O_7$ to about 100 mL. Add 30 mL conc H_2SO_4 and cool. Titrate with FAS titrant using 0.10 to 0.15 mL (2 to 3 drops) ferroin indicator.

Molarity of FAS solution

$$= \frac{\text{Volume } 0.04167M\ K_2Cr_2O_7 \text{ solution titrated, mL}}{\text{Volume FAS used in titration, mL}} \times 0.2500$$

e. Mercuric sulfate, $HgSO_4$, crystals or powder.

f. Sulfamic acid: Required only if the interference of nitrites is to be eliminated (see 5220A.2 above).

g. Potassium hydrogen phthalate (KHP) standard, $HOOCC_6H_4COOK$: Lightly crush and then dry KHP to constant weight at 110°C. Dissolve 425 mg in distilled water and dilute to 1000 mL. KHP has a theoretical COD[1] of 1.176 mg O_2/mg and this solution has a theoretical COD of 500 µg O_2/ mL. This solution is stable when

refrigerated, but not indefinitely. Be alert to development of visible biological growth. If practical, prepare and transfer solution under sterile conditions. Weekly preparation usually is satisfactory

4. Procedure

a. Treatment of samples with COD of >50 mg O_2/L: Blend sample if necessary and pipet 50.00 mL into a 500-mL refluxing flask. For samples with a COD of >900 mg O_2/L, use a smaller portion diluted to 50.00 mL. Add 1 g $HgSO_4$, several glass beads, and very slowly add 5.0 mL sulfuric acid reagent, with mixing to dissolve $HgSO_4$. Cool while mixing to avoid possible loss of volatile materials. Add 25.00 mL 0.04167*M* $K_2Cr_2O_7$ solution and mix. Attach flask to condenser and turn on cooling water. Add remaining sulfuric acid reagent (70 mL) through open end of condenser. Continue swirling and mixing while adding sulfuric acid reagent. CAUTION: *Mix reflux mixture thoroughly before applying heat to prevent local heating of flask bottom and a possible blowout of flask contents.*

Cover open end of condenser with a small beaker to prevent foreign material from entering refluxing mixture and reflux for 2 h. Cool and wash down condenser with distilled water. Disconnect reflux condenser and dilute mixture to about twice its volume with distilled water. Cool to room temperature and titrate excess $K_2Cr_2O_7$ with FAS, using 0.10 to 0.15 mL (2 to 3 drops) ferroin indicator. Although the quantity of ferroin indicator is not critical, use the same volume for all titrations. Take as the end point of the titration the first sharp color change from blue-green to reddish brown that persists for 1 min or longer. Duplicate determinations should agree within 5% of their average. Samples with suspended solids or components that are slow to oxidize may require additional determinations. The blue-green may reappear. In the same manner, reflux and titrate a blank containing the reagents and a volume of distilled water equal to that of sample.

b. Determination of standard solution: Evaluate the technique and quality of reagents by conducting the test on a standard potassium hydrogen phthalate solution.

5. Calculation

$(A - B) \times M \times 8000$

COD as mg O_2/L =

mL sample

where:

A = mL FAS used for blank,

B = mL FAS used for sample,

M = molarity of FAS, and

8000 = milliequivalent weight of oxygen X 1000 mL/L.

B. Biochemical Oxygen Demand (BOD)

Section 1: GENERAL

In the presence of free oxygen, aerobic bacteria use the organic matter found in wastewater as "food". The BOD test is an estimate of the "food" available in the sample. The more "food" present in the waste, the more Dissolved Oxygen (DO) will be required. The BOD test measures the strength of the wastewater by measuring the amount of oxygen used by the bacteria as they stabilize the organic matter under controlled conditions of time and temperature.

Section 2: BOD INTRODUCTION

The BOD test is used to measure waste loads to treatment plants, determine plant efficiency (in terms of BOD removal), and control plant processes. It is also used to determine the effects of discharges on receiving waters. A major disadvantage of the BOD test is the amount of time (5 days) required to obtain the results.

When a measurement is made of all oxygen consuming materials in a sample, the result is termed "Total Biochemical Oxygen Demand" (TBOD), or often just simply

"Biochemical Oxygen Demand" (BOD). Because the test is performed over a five day period, it is often referred to as a "Five Day BOD", or a BOD_5.

In many biological treatment plants, the facility effluent contains large numbers of nitrifying organisms which are developed during the treatment process. These organisms can exert an oxygen demand as they convert nitrogenous compounds (ammonia and organic nitrogen) to more stable forms (nitrites and nitrates). At least part of this oxygen demand is normally measured in a five day BOD.

Sometimes it is advantageous to measure just the oxygen demand exerted by organic (carbonaceous) compounds, excluding the oxygen demand exerted by the nitrogenous compounds. To accomplish this, the nitrifying organisms can be inhibited from using oxygen by the addition of a nitrification inhibitor to the samples. The result is termed "Carbonaceous Biochemical Oxygen Demand", or CBOD.

EQUIPMENT AND REAGENTS

REAGENTS

Test reagents are as follows:

1. Phosphate buffer solution
2. Magnesium sulfate solution ($MgSO_4$ $7H_2O$) *
3. Calcium chloride solution ($CaCl_2$) *
4. Ferric chloride solution ($FeCl_3$) *
5. Sodium hydroxide (NaOH), 1 N *
6. Sulfuric acid (H_2SO_4), 1 N *
7. Sodium sulfite (Na_2SO_3), 0.025 N
8. Potassium iodide solution (KI), 10%

9. Acetic acid solution (CH_3CO_2H), (1+1) *
10. Sulfuric acid solution (H_2SO_4), (1+50) *
11. Starch indicator solution
12. Glucose-glutamic acid solution
13. Nitrification inhibitor (2-chloro-6-(trichloromethyl) pyridine) *
14. Distilled water.

NOTE: Use only high-grade distilled or deionized water. The water must contain less than 0.01 mg/L copper, and be free of chlorine, chloramines, caustic alkalinity, organic material, or acids.

*These reagents are poisonous or corrosive

EQUIPMENT

1. BOD meter with probe for measurement of dissolved oxygen in 300 mL BOD bottles
2. 300 mL BOD bottles
3. Incubator, capable of maintaining 20 +/- 1°C
4. 250 mL graduated cylinders
5. 100 mL graduated cylinders
6. 25 mL measuring pipettes (wide-mouth)
7. 10 mL measuring pipettes (wide-mouth)
8. 100 mL beaker
9. 1000 mL beaker
10. 250 mL Erlenmeyer flask
11. Burette graduated to 0.1 mL
12. Dilution water bottle of suitable volume for the number of tests to be performed
13. Pipette but
14. Magnetic stirrer and stirring bars **

LABORATORY PROCEDURE

1. Completely fill two BOD bottles with dilution water

2. Into additional BOD bottles, partially filled with dilution water, carefully measure out the proper volume of sample. Add dilution water until the bottles are completely filled.

NOTE: If the modified Winkler procedure is to be used for DO measurements, two BOD bottles should be prepared for each dilution; one for determination of the initial DO and one for incubation and final DO measurement. If the meter method is used for DO measurements the initial and final DO determinations can be performed on the same bottle.

3. Stopper each bottle taking care to avoid trapping air bubbles inside the bottles as the bottle stoppers are inserted.

4. Fill the top of each bottle neck around the stopper with dilution water.

5. Determine the initial DO content on one of each set of duplicate bottles, including the dilution water blank by one of the approved methods and record data on the lab sheet.

6. Place the remaining bottles in the incubator at 20°C and incubate for five days.

7. At the end of exactly five days (+/-3 hours), test the DO content of the incubated bottles.

8. Calculate the BOD for each dilution. The most accurate BOD will be obtained from those dilutions that have a depletion of at least 2 mg/L DO and at least 1.0 mg/L DO residual. If there is more than one dilution that meets these criteria, the BOD results should be averaged to obtain a final BOD value.

9. The dilution water blanks are used only to check the quality of the dilution water. If the quality of the water is good and free from impurities, the depletion of

DO should be less than 0.2 mg/L. In any event, do not use the depletion obtained as a blank correction.

10. If nitrification inhibition is used, the BOD test must also be performed on a series of sample dilutions which have not been inhibited.

11. Report the results of the nitrification inhibited samples as $CBOD_5$ and uninhibited samples as BOD_5.

CALCULATIONS

To determine the value of the BOD in mg/L, use the following formula:

BOD, mg/L = [(Initial DO - Final DO) x 300]/mL sample

For example:

Initial DO = mg/L

Final DO = mg/L

Sample size = mL

BOD mg/L = mg/L

Whenever a sample is dechlorinated, it must be seeded. If the sample is seeded, a correction factor must be calculated to determine the effects that the seed material has on the DO depletion. A number of BOD's must be run on the seed material to determine the seed correction factor.

C. Suspended Solids

1. Weigh filter paper and place it in the filtration apparatus
2. Mix the sample thoroughly and filter an appropriate volume (say 100 ml)
3. Dry the residue retained on the filter paper to a constant weight at 103 to 105°C
4. Cool in a dessicator
5. Weigh filter paper and dried residue

6. Calculate suspended solids (SS) from the relation:

$$SS = \frac{(W_2 - W_1)}{V} \text{ x } 1000 \qquad \text{(mg/l)}$$

W_1 = weight of filter paper (mg)

W_2 = weight of filter paper and dried residue (mg)

V = volume of sample (ml)

APPENDIX II:TABLE A1 SCHEDULE 1

(Regulation 2)

Wastewater Quality Guidelines for Discharges into Water Bodies or Water Course

	COLUMN 1 PARAMETER/DESCRIPTION	COLUMN 2 MAXIMUM PERMISSIBLE LEVEL (new Facilities)	COLUMN 3 MAXIMUM TARGET (PERMISSIBLE) LEVEL (Existing Facilities)
1.	pH	6 - 9(in the range of)	6 – 9
2.	Temperature*	<3^{o}C above ambient	<3^{o}C above ambient
3.	Colour (TCU)	20	100
4.	Oil and Grease (mg/l)	20	20
5.	Oil	No visible floating oil	No visible floating oil
6.	BOD (mg/l)**	50	200
7.	COD (mg/l)**	250	1000
8.	Total Dissolved Solids (mg/l)	1000	1000
9.	Total Suspended Solids (mg/l)	50	50
10.	Turbidity (NTU) **	75	75
11.	Conductivity (μS/cm)**	1500	1500
12.	Total Coliforms (MPN/100ml)	400	400
13.	E. Coli (MPN/100ml)	10	10
14.	Ammonia as N (mg/l)**	1.0	10
15.	Nitrate (mg/l)**	75	100
16.	Flouride (mg/l)**	10	20
17.	Phenol (mg/l)	1.0	1.0
18.	Sulphide (mg/l)	1.5	1.5
19.	Total phosphorus (mg/l)**	2.0	10.0
20.	Total Cyanide (mg/l)	1.0	1.0
21.	Free Cyanide (mg/l)	0.2	0.2
22.	Cyanide as Weak Acid Dissociable (mg/l)	0.6	0.6
23.	Total Arsenic (mg/l)	0.5	0.5
24.	Soluble Arsenic (mg/l)	0.1	0.1
25.	Cadmium (mg/l)	<0.1	<0.1
26.	Chromium (+6) mg/l	0.1	0.1
27.	Total chromium (mg/l)	0.5	0.5
28.	Copper (mg/l)	2.5	2.5
29.	Lead (mg/l)	0.1	0.1

Source : EPA Ghana Guidelines 2000

TABLE A2:Soil test analysis	
Soil pH	
<5	Very acidic
5.1 – 5.4	Acidic
5.5 - 6.4	Moderately acidic
6.1 – 6.4	slightly acidic
6.5 – 7.0	Neutral
7.1 – 7.4	slightly alkaline
7.5 – 8.0	moderately alkaline
>8.0	Alkaline
Units: ➢ **ppm = mkg** **The SI units for ppm = kg soil** ➢ **m.e/100g soil = cmol (+) kg soil K.Na (monovalent cations)** **e,g. 5 m.e K/100g/100 soil = 5 cmol (+) kg soil** ➢ **For divalent cations (Ca and MG)** **5 m.e.K.100g soil = 5 cmol(+)kg soil**	
Extractable Cu	
<0.3mg/kg	very low
0.3 – 1.5	low
2.0 – 3.0	moderate
4.0 – 7	very high
Extractable Zn	
< 0.2 mg/kg	very low
0.2 – 1.0	Low
2.0 – 3.0	Moderate
4.0 – 5.0	High
> 5.0	very high
>5.0	Very high

Source: SRI (Soil Research Institute)

TABLE A3:Soil test analysis	
Total nitrogen: <0.1 %	Low
0.1 – 0.2	Medium
> 0.2	adequate
Organic matter: < 1.5%	Low
1.5 – 3.0	Medium
> 3.0	High
Bray's No. 1P :< 3.0ppm	Very low
3 - 10	Low
11- 20	Medium
> 20	High
Bray's K: <50 mg/kg soil	Low
50 -100	Medium
>100	High
Exchangeable Ca: <5.0 m.e./100g soil	Low
50-100	Medium
>10.0	High
Exch :Mg :<1.0 m.e./100g soil	Low
1.0 – 3.0	Medium
>4.0	High
Exch: K :< 0. 15 m.e./100g	Low
0.15 – 0.25	Medium
>0.25	High
Base saturation	
<50%	Low
50 – 70	Medium
70 - 90	High
>90	Very high

Source: SRI (Soil Research Institute)

TABLE B :Heavy metals concentration in Greywater

Zn	sple1	sple2	sple3	sple4	sple5	sple6	Av.	Max.	Min.	SE(99%)	SD
A1	0.045	0.042	0.017	0.011	0.048	0.046	0.035	0.048	0.011	0.017	0.016
A2	0.062	0.053	0.411	0.407	0.095	0.097	0.187	0.411	0.053	0.182	0.172
Q1	0.049	0.044	0.165	0.162	0.061	0.061	0.090	0.165	0.044	0.060	0.057
Q2	0.058	0.060	0.706	0.701	0.109	0.114	0.291	0.706	0.058	0.337	0.320
AV.	0.053	0.050	0.325	0.320	0.078	0.080	0.151	0.325	0.050	0.140	0.133
JUNC	0.040	0.039	0.018	0.012	0.026	0.029	0.027	0.040	0.012	0.012	0.011
MID	0.048	0.060	0.036	0.031	0.031	0.032	0.040	0.060	0.031	0.012	0.012
EFF	0.063	0.056	0.016	0.024	0.017	0.019	0.032	0.063	0.016	0.022	0.021
STR	0.046	0.042	0.019	0.019	0.019	0.020	0.027	0.046	0.019	0.013	0.013

Cu	sple1	sple2	sple3	sple4	sple5	sple6	Av.	Max.	Min.	SE (99%)	SD
A1	0.054	0.046	0.045	0.055	0.248	0.260	0.118	0.260	0.045	0.111	0.106
A2	0.046	0.046	0.138	0.176	0.338	0.364	0.185	0.364	0.046	0.146	0.139
Q1	0.025	0.040	0.060	0.026	0.271	0.293	0.119	0.293	0.025	0.134	0.127
Q2	0.086	0.067	0.185	0.211	0.075	0.079	0.117	0.211	0.067	0.067	0.063
Av.	0.053	0.050	0.107	0.117	0.233	0.249	0.135	0.249	0.050	0.092	0.087
JUNC	0.018	0.017	0.202	0.156	0.187	0.200	0.130	0.202	0.017	0.093	0.089
Mid	0.038	0.047	0.028	0.017	0.124	0.125	0.063	0.125	0.017	0.051	0.049
Eff	0.041	0.042	0.079	0.095	0.060	0.067	0.064	0.095	0.041	0.022	0.021
STR	0.020	0.014	0.016	0.072	0.223	0.226	0.095	0.226	0.014	0.108	0.103

Pb	sple1	sple2	sple3	sple4	sple5	sple6	Av.	Max.	Min.	SE(99%)	SD
A1	0.130	0.180	0.700	0.745	0.188	0.201	0.357	0.745	0.130	0.299	0.284
A2	0.095	0.095	0.455	0.376	0.097	0.099	0.203	0.455	0.095	0.175	0.167
Q1	0.250	0.164	0.360	0.500	0.228	0.242	0.291	0.500	0.164	0.127	0.121
Q2	0.180	0.273	1.035	0.520	0.228	0.232	0.411	1.035	0.180	0.346	0.328
av.A15	0.164	0.178	0.638	0.535	0.185	0.194	0.316	0.638	0.164	0.224	0.212
JUNCt	0.170	0.123	0.330	0.380	0.208	0.226	0.239	0.380	0.123	0.103	0.098
Mid	0.190	0.280	0.715	0.328	0.101	0.115	0.288	0.715	0.101	0.239	0.227
Eff	0.180	0.193	0.720	0.653	0.014	0.028	0.298	0.720	0.014	0.327	0.311
STR	0.205	0.270	0.450	0.284	0.215	0.236	0.277	0.450	0.205	0.095	0.090

Cd	sple1	sple2	sple3	sple4	sple5	sple6	Av.	Max.	Min.	SE(99%)	SD
A1	0.015	0.018	0.018	0.022	0.023	0.018	0.019	0.023	0.015	0.003	0.003
A2	0.006	0.012	0.019	0.014	0.015	0.018	0.014	0.019	0.006	0.005	0.005
Q1	0.020	0.019	0.019	0.016	0.008	0.005	0.014	0.020	0.005	0.007	0.006
Q2	0.013	0.018	0.012	0.016	0.011	0.011	0.013	0.018	0.011	0.003	0.003
av.	0.013	0.017	0.017	0.017	0.014	0.013	0.015	0.017	0.013	0.002	0.002
JUNCt	0.025	0.021	0.018	0.014	0.017	0.021	0.019	0.025	0.014	0.004	0.004
Mid	0.006	0.009	0.029	0.026	0.018	0.019	0.018	0.029	0.006	0.009	0.009
Eff	0.041	0.055	0.020	0.017	0.026	0.027	0.031	0.055	0.017	0.015	0.014
STR	0.021	0.020	0.017	0.026	0.033	0.034	0.025	0.034	0.017	0.008	0.007

Mn	sple1	sple2	sple3	sple4	sple5	sple6	Av.	Max.	Min.	SE(99%)	SD
A1	0.103	0.099	0.041	0.067	0.027	0.025	0.060	0.103	0.025	0.037	0.035
A2	0.042	0.047	0.087	0.052	0.059	0.058	0.057	0.087	0.042	0.017	0.016
Q1	0.088	0.096	0.162	0.170	0.031	0.033	0.097	0.170	0.031	0.063	0.060
Q2	0.052	0.052	0.498	0.302	0.075	0.079	0.176	0.498	0.052	0.194	0.184
av.	0.071	0.074	0.197	0.148	0.048	0.049	0.098	0.197	0.048	0.064	0.061
JUNCt	0.099	0.119	0.067	0.059	0.040	0.032	0.069	0.119	0.032	0.035	0.034
Mid	0.125	0.119	0.090	0.059	0.017	0.019	0.071	0.125	0.017	0.050	0.047
Eff	0.103	0.116	0.068	0.076	0.012	0.014	0.065	0.116	0.012	0.046	0.044
STR	0.084	0.079	0.052	0.033	0.040	0.045	0.055	0.084	0.033	0.022	0.021

Fe	sple1	sple2	sple3	sple4	sple5	sple6	Av.	Max.	Min.	SE(99%)	SD
A1	0.382	0.484	1.526	1.759	0.207	0.211	0.761	1.759	0.207	0.731	0.694
A2	0.121	0.144	0.777	1.058	0.492	0.478	0.511	1.058	0.121	0.382	0.363
Q1	0.383	0.427	1.307	1.362	0.282	0.304	0.677	1.362	0.282	0.539	0.512
Q2	0.122	0.137	0.618	0.833	1.302	1.363	0.729	1.363	0.122	0.572	0.543
av.	0.252	0.298	1.057	1.253	0.571	0.589	0.670	1.253	0.252	0.426	0.405
JUNCt	0.185	0.182	0.210	0.346	1.216	1.201	0.557	1.216	0.182	0.536	0.509
Mid	0.075	0.072	0.221	0.148	0.714	0.724	0.326	0.724	0.072	0.326	0.310
Eff	0.213	0.149	0.241	0.596	0.377	0.444	0.337	0.596	0.149	0.177	0.168
STR	0.210	0.186	0.238	0.317	0.743	0.746	0.407	0.746	0.186	0.280	0.265

APPENDIX III

TABLE A: Flow Rate Measurement

TABLE A.1 1st measurement 02/03/07

Hour	GA1(l/s)	GA2(l/s)	GQ1(l/s)	GQ2(l/s)	Composite(l/s)
7:00	1.57	0.50	0.34	1.38	3.79
8:00	2.20	0.31	0.46	1.10	4.07
9:00	2.20	0.41	0.50	0.48	3.59
10:00	2.75	0.65	0.48	0.41	4.28
11:00	2.75	0.20	0.61	0.46	4.02
12:00	0.22	0.18	0.55	0.26	1.20
13:00	0.12	0.08	0.41	0.34	0.95
14:00	0.04	0.12	0.28	0.28	0.71
15:00	0.09	0.14	0.17	0.31	0.71
16:00	0.28	0.15	0.20	0.50	1.13
17:00	1.38	0.14	0.26	0.37	2.15
18:00	2.75	0.31	0.52	0.61	4.19
19:00	1.22	0.17	0.38	0.50	2.27
20:00	0.61	0.17	0.37	0.34	1.49
21:00	0.38	0.23	0.50	0.14	1.26
22:00	0.31	0.05	0.42	0.26	1.04
23:00	0.33	0.15	0.58	0.37	1.43
0:00	0.09	0.08	0.55	0.42	1.14
1:00	0.21	0.03	0.50	0.44	1.18
2:00	0.24	0.03	0.24	0.20	0.71
3:00	0.03	0.03	0.28	0.13	0.47
4:00	0.58	0.04	0.24	0.12	0.97
5:00	0.20	0.04	0.61	0.55	1.40
6:00	0.69	0.24	0.55	0.92	2.39

TABLE A.2: 2nd Measurement 05/04/07

Hour	GA1(l/s)	GA2(l/s)	GQ1(l/s)	GQ2(l/s)	SUMM(l/s)
7:00	0.28	1.00	1.38	0.50	3.16
8:00	0.37	1.57	0.48	0.55	2.97
9:00	0.46	2.75	0.46	0.55	4.22
10:00	0.30	2.20	0.42	0.61	3.53
11:00	0.42	0.24	0.34	0.32	1.33
12:00	0.20	0.32	0.22	0.27	1.02
13:00	0.19	0.26	0.21	0.25	0.91
14:00	0.18	0.20	0.15	0.29	0.82
15:00	0.17	0.17	0.28	0.31	0.94
16:00	0.11	0.44	0.48	0.37	1.40
17:00	0.34	0.28	0.35	0.33	1.31
18:00	0.25	0.61	0.39	0.69	1.94
19:00	0.28	1.00	0.42	0.41	2.11
20:00	0.31	0.19	0.32	0.21	1.03
21:00	0.11	0.19	0.34	0.28	0.92
22:00	0.11	0.22	0.18	0.17	0.67
23:00	0.11	0.16	0.17	0.17	0.61
0:00	0.10	0.15	0.15	0.15	0.56
1:00	0.10	0.11	0.14	0.16	0.51
2:00	0.10	0.14	0.14	0.14	0.51
3:00	0.08	0.09	0.09	0.09	0.35
4:00	0.08	0.09	0.14	0.32	0.63
5:00	0.04	0.04	0.23	0.28	0.59
6:00	0.08	0.16	0.92	0.55	1.71

TABLE A.3: 3rd measurement 04/05/07

Hour	GA1(l/s)	GA2(l/s)	GQ1(l/s)	GQ2(l/s)	Composite(l/s)
7:00	2.20	0.37	0.55	0.61	**3.73**
8:00	2.20	0.25	0.35	0.79	**3.59**
9:00	2.75	0.21	0.31	0.69	**3.95**
10:00	2.20	0.21	0.22	0.30	**2.93**
11:00	0.31	0.18	0.16	0.20	**0.85**
12:00	0.27	0.17	0.21	0.19	**0.84**
13:00	0.52	0.09	0.35	0.20	**1.16**
14:00	0.58	0.08	0.19	0.20	**1.05**
15:00	0.16	0.15	0.26	0.18	**0.75**
16:00	0.14	0.15	0.15	0.25	**0.70**
17:00	0.42	0.17	0.35	0.55	**1.50**
18:00	2.75	0.29	0.46	0.65	**4.14**
19:00	2.20	0.30	0.37	0.52	**3.39**
20:00	2.75	0.35	0.26	0.30	**3.66**
21:00	1.57	0.41	0.24	0.22	**2.44**
22:00	3.67	0.27	0.14	0.14	**4.21**
23:00	1.83	0.20	0.11	0.11	**2.25**
0:00	2.75	0.19	0.09	0.11	**3.13**
1:00	1.83	0.14	0.11	0.09	**2.18**
2:00	0.50	0.14	0.15	0.11	**0.90**
3:00	0.58	0.16	0.15	0.11	**1.00**
4:00	0.69	0.17	0.24	0.22	**1.31**
5:00	0.85	0.19	0.69	0.26	**1.98**
6:00	1.38	0.22	0.92	0.35	**2.87**

TABLE A.4: 4th measurement 13/05/07

Hour	GA1(l/s)	GA2(l/s)	GQ1(l/s)	GQ2(l/s)	Composite(l/s)
7:00	1.00	0.55	0.55	0.61	2.71
8:00	1.38	0.39	0.35	0.79	2.91
9:00	1.83	0.20	0.31	0.69	3.02
10:00	2.75	0.79	0.22	0.30	4.06
11:00	0.42	0.65	0.16	0.20	1.42
12:00	0.23	0.58	0.21	0.19	1.21
13:00	0.18	0.13	0.35	0.20	0.86
14:00	0.31	0.26	0.19	0.20	0.97
15:00	0.17	0.22	0.26	0.18	0.84
16:00	0.28	0.13	0.15	0.25	0.80
17:00	0.15	0.15	0.35	0.55	1.20
18:00	0.46	0.13	0.46	0.65	1.69
19:00	0.12	0.14	0.37	0.52	1.15
20:00	0.18	0.33	0.26	0.30	1.07
21:00	1.83	0.12	0.24	0.22	2.42
22:00	2.20	0.11	0.14	0.14	2.59
23:00	1.22	0.11	0.11	0.11	1.55
0:00	0.55	0.10	0.09	0.11	0.84
1:00	0.24	0.09	0.11	0.09	0.53
2:00	0.16	0.08	0.15	0.11	0.51
3:00	0.18	0.09	0.15	0.11	0.53
4:00	0.20	0.09	0.24	0.22	0.75
5:00	0.27	0.09	0.69	0.26	1.31
6:00	0.46	0.37	0.92	0.35	2.10

APPENDIX IV

TABLE A.1:Physical Characteristics of the Soil Under Study Area

Point	Labels	horizon(cm)	%soil moisture at field capacity	%sand	%Silt	%Clay	Type of Soil
A	**LS**	0-15	24.61	51.52	42.38	6.1	**Sandy loam**
		15-30	21.31	60.7	31.19	8.11	**»**
		30-45	18.88	67.44	22.46	10.1	**»**
	MS	0-15	19.13	75	21	4	**loamy sand**
		15-30	7.36	84.78	13.21	2.01	**»**
	US	0-15	19.09	68.1	23.79	8.11	**Sandy loam**
		15-30	17.3	72.24	19.67	8.09	**»**
		30-45	12.49	78.94	13.03	8.03	**»**
		45-60	8.22	73.94	14.02	12.04	**»**
B	**LS**	0-15	46.44	6.16	85.71	8.13	**Silt**
		15-30	10.64	27.26	64.65	8.09	**silt loam**
		30-45	39.86	69.62	24.28	6.1	**sandy loam**
	MS	0-15	19.01	92.3	3.64	4.06	**Sand**
		15-30	7.36	67.3	26.64	6.06	**Sand loamy**
		30-45	44.77	80.12	17.79	2.09	**loamy sand**
	US	0-15	10.29	77.08	18.86	4.06	**loamy sand**
		15-30	5.73	80.66	13.27	6.07	**»**
		30-45	5.22	79.68	16.31	4.01	**»**
C	**LS**	0-20	37.22	48.72	41.22	10.06	**Loam**
		20-40	43.85	60.36	27.5	12.14	**Sandy loam**
		40-65	25.9	73.98	22.01	4.01	**»**

	MS	0-15	12.2	69.64	24.26	6.1	**Sandy loam**
		15-30	11.16	70.68	19.3	10.02	**»**
		30-45	12.48	64.22	19.65	16.13	**»**
	US	0-15	7.03	65.72	26.21	8.07	**Sandy loam**
		15-30	10.66	56.18	19.74	24.08	**Sandy C L**
		30-45	7.95	61.48	22.45	16.07	**sand loam**

D	**LS**	0-15	51.37	53.5	42.46	4.04	**sandy loam**
		15-30	77.75	57.44	38.39	4.17	**»**
		30-45	49.56	41.46	44.41	14.13	**loam**
	MS	0-15	12.15	77.5	18.38	4.12	**loamy sand**
		15-30	10.02	78.24	15.65	6.11	**»**
		30-45	11.37	75.82	18.07	6.11	**sandy loam**
	US	0-15	6	71.82	24.12	4.06	**sandy loam**
		15-30	8.28	73.1	18.67	8.23	**»**
		30-45	8.85	66.34	19.53	14.13	**»**
E	**LS**	0-15	43.73	64.22	31.64	4.14	**sandy loam**
		15-30	65.38	72.5	23.41	4.09	**»**
		30-45	36.96	84.32	11.58	4.1	**loamy sand**
	MS	0-15	43.23	74.78	21.12	4.1	**sandy loam**
		15-30	20.81	73.78	20.13	6.09	**»**
		30-45	20.43	73.54	16.27	10.19	**»**
	US	0-15	5.31	76.78	19.09	4.13	**loamy sand**
		15-30	7.76	83.62	10.18	6.2	**»**
		30-45	7.6	78.58	11.32	10.1	**sandy loam**
	Average		**22.06**	**68.03**	**24.41**	**7.56**	**sandy loam**

APPENDIX V

TABLE A.1:Greywater Characteristics

Parameter	Units	Influent(SE)	Effluent(SE)	Stream(SE)	% Removal	*Max. Perm
pH		6.83±0.29	6.97±0.15	6.99±0.2		6→9
Turbidity	NTU	279.89±131.30	5.83±1.54	121.12±100.86	97.9	75
Conductivity	(μS/cm)	656.42±192.85	339.11±62.46	462.12±171.50	48.3	1500
SS	mg/l	222.83±94.97	2.59±1.32	51.67±23.57	98.8	50
COD	mg/l	707.28±29218	100±51.37	454±219.91	85.9	1000
BOD	mg/l	420.22±159.19	48.89±11.73	240.89±137.34	88.4	200
Nitrate –N	mg/l	12.91±3.62	7.5±1.9	12.19±3.01	41.9	100
Nitrite-N	mg/l	0.19±0.14	0.03±0.02	0.04±0.02	81.8	
Phosphates	mg/l	12.43±4.46	3.48±3.28	9.74±7.45	72	10
T.Coliforms	MPN/100ml	5.5E+05 ±0.3E+06	3.3E+04 ± 3.4E+04	5E+5 ± 1.3E+5	94	4.00E+08
Heavy Metals in Greywater						
Fe	mg/l	0.670±0.426	0.337±0.177	0.407±0.280	49.7	–
Cd	mg/l	0.015±0.002	0.031±0.015	0.025±0.008	-51.0	<0.1
Pb	mg/l	0.316±0.224	0.298±0.327	0.277±0.095	5.6	0.1
Cu	mg/l	0.135±0.092	0.064±0.022	0.095±0.108	52.6	2.5
Zn	mg/l	0.151±0.140	0.032±0.012	0.027±0.022	78.8	5
Mn	mg/l	0.098±0.064	0.065±0.046	0.055±0.022	33.7	2.5

Mean ± Standard error 99%

TABLE A.2:Temperature (ºC)

Source of sample	Date of sampling									Av.	Max.	Min.	SE (99%)	SD
	22/02	01/03/07	08/03/07	15/03/07	28/03/07	04/04/07	13/04/07	19/04/07	28/04/07					
GA1	30.00	30.60	30.60	28.60	29.70	30.60	29.10	30.20	29.20	29.84	30.60	28.60	0.64	0.74
GA2	31.50	30.90	30.80	27.60	29.20	30.70	29.00	30.00	29.10	29.87	31.50	27.60	1.06	1.24
GQ1	30.00	31.10	31.50	29.60	28.90	30.60	29.00	30.00	29.00	29.97	31.50	28.90	0.81	0.95
GQ2	30.50	31.20	30.80	29.20	29.20	30.50	29.00	30.10	29.00	29.94	31.20	29.00	0.73	0.85
Av.Inf	30.50	30.95	30.93	28.75	29.25	30.60	29.03	30.08	29.08	29.91	31.20	28.53	0.81	0.95
JUN	30.00	31.00	30.50	28.40	27.70	30.50	28.70	30.00	28.90	29.52	31.00	27.70	0.97	1.13
MID	30.80	30.30	30.80	28.60	28.20	30.60	28.70	30.10	29.00	29.68	30.80	28.20	0.90	1.04
EFF	30.00	31.50	32.30	29.80	28.90	30.60	28.80	30.20	29.00	30.12	32.30	28.80	1.03	1.20
STR	30.60	30.20	31.50	29.80	28.40	30.70	29.10	30.10	28.60	29.89	31.50	28.40	0.88	1.03

TABLE A.3 :pH

Source of sample	Date of sampling									Av.	Max.	Min/	SE(99%)	SD
	22/02/07	03/01/07	08/03/07	15/03/07	28/03/07	04/04/07	13/04/07	19/04/07	28/04/07					
GA1	6.45	6.90	6.62	6.51	7.21	7.21	7.24	6.39	6.46	6.78	7.24	6.39	0.31	0.36
GA2	5.74	6.23	6.20	6.23	7.12	7.05	6.62	5.71	6.59	6.39	7.12	5.71	0.43	0.50
GQ1	6.95	6.71	7.19	6.84	7.06	6.46	7.33	6.93	7.35	6.98	7.35	6.46	0.25	0.29
GQ2	7.01	7.29	7.21	6.95	7.55	6.91	7.34	7.14	7.17	7.17	7.55	6.91	0.18	0.20
Av. nf.	6.54	6.78	6.81	6.63	7.24	6.91	7.13	6.54	6.89	6.83	7.32	6.37	0.29	0.34
JUN	6.73	6.68	6.90	6.66	7.21	6.87	7.13	6.87	6.86	6.88	7.21	6.66	0.16	0.19
MID	7.00	6.93	6.80	6.80	7.00	6.87	7.13	7.02	6.89	6.94	7.13	6.80	0.09	0.11
EFF	7.06	6.92	6.92	7.29	7.13	6.81	6.80	7.03	6.73	6.97	7.29	6.73	0.15	0.18
STR	7.02	6.96	6.88	7.39	7.31	6.73	6.96	7.02	6.68	6.99	7.39	6.68	0.20	0.23

TABLE A.4:Conductivity(µS/cm)

Source of sample	Date of sampling									Av.	Max.	Min.	SE(99%)	SD
	22/02/07	03/01/07	08/03/07	15/03/07	28/03/07	04/04/07	13/04/07	19/04/07	28/04/07					
GA1	405.00	490.00	523.00	425.00	268.00	860.00	259.00	253.00	381.00	429.33	860.00	253.00	162.89	189.41
GA2	1206.00	537.00	471.00	502.00	733.00	1189.00	527.00	547.00	478.00	687.78	1206.00	471.00	257.24	299.11
GQ1	703.00	889.00	694.00	592.00	656.00	1118.00	884.00	593.00	998.00	791.89	1118.00	592.00	161.52	187.82
GQ2	776.00	780.00	679.00	708.00	657.00	559.00	606.00	450.00	1235.00	716.67	1235.00	450.00	189.75	220.64
Av.Inf	772.50	674.00	591.75	556.75	578.50	931.50	569.00	460.75	773.00	656.42	1104.75	441.50	192.85	224.25
JUN	772.50	621.00	605.00	651.00	467.00	497.00	513.00	442.00	429.00	555.28	772.50	429.00	98.48	114.51
MID	543.00	487.00	497.00	476.00	399.00	418.00	414.00	327.00	306.00	429.67	543.00	306.00	67.97	79.03
EFF	424.00	426.00	365.00	421.00	294.00	308.00	315.00	264.00	235.00	339.11	426.00	235.00	62.46	72.63
STR	700.25	613.00	605.00	662.00	364.00	260.00	300.00	508.00	146.80	462.12	700.25	146.80	171.50	199.42

TABLE A.5:Turbidity (mg/l)

Source of sample	Date of sampling									Av.	Max.	Min.	SE (99%)	SD
	22/02/07	03/01/07	08/03/07	15/03/07	28/03/07	04/04/07	13/04/07	19/04/07	28/04/07					
GA1	206.80	242.00	186.70	226.70	110.10	445.30	103.87	61.10	349.30	214.65	445.30	61.10	105.26	122.40
GA2	755.00	284.00	194.27	193.30	246.50	400.30	278.00	167.90	169.20	298.72	755.00	167.90	160.26	186.34
GQ1	175.00	339.00	289.30	155.60	192.00	255.70	218.20	255.90	414.70	255.04	414.70	155.60	71.53	83.17
GQ2	336.30	415.00	271.67	291.70	265.70	234.00	250.40	187.10	908.60	351.16	908.60	187.10	188.17	218.80
Av.Inf	368.28	320.00	235.49	216.83	203.58	333.83	212.62	168.00	460.45	279.89	630.90	142.93	131.30	152.68
JUN	87.00	143.87	201.54	217.70	53.20	97.50	69.40	703.00	56.20	181.05	703.00	53.20	176.20	204.88
MID	14.21	15.20	16.20	12.90	5.70	8.60	13.13	6.30	8.20	11.16	16.20	5.70	3.42	3.98
EFF	7.90	7.60	5.86	7.90	4.50	4.11	5.57	2.80	6.20	5.83	7.90	2.80	1.54	1.80
STR	243.81	220.83	329.67	11.88	15.10	26.20	90.40	29.40	122.80	121.12	329.67	11.88	100.86	117.28

TABLE A.6:Suspended Solid (mg/l)

Source of sample	Date of sampling									Av.	Max.	Min.	SE (99%)	SD
	22/02/07	03/01/07	08/03/07	15/03/07	28/03/07	04/04/07	13/04/07	19/04/07	28/04/07					
GA1	543.00	277.00	163.30	136.70	83.30	74.30	81.21	73.30	723.00	239.46	723.00	73.30	230.77	236.65
GA2	93.00	333.00	1036.70	156.70	196.70	210.21	187.23	396.70	146.70	306.33	1036.70	93.00	282.44	289.64
GQ1	140.00	440.00	236.70	153.30	110.00	184.32	145.87	230.00	143.30	198.17	440.00	110.00	97.57	100.06
GQ2	197.00	207.00	220.00	160.00	150.00	76.24	112.80	153.30	50.00	147.37	220.00	50.00	56.89	58.34
Av.Inf	243.25	314.25	414.18	151.68	135.00	136.27	131.78	213.33	265.75	222.83	604.93	81.58	94.97	97.39
JUN	57.27	145.00	356.70	150.00	49.00	67.30	109.00	433.30	33.00	155.62	433.30	33.00	139.51	143.06
MID	12.00	9.00	3.00	3.00	1.00	6.00	5.00	6.70	11.00	6.30	12.00	1.00	3.68	3.77
EFF	5.00	3.00	4.00	2.00	1.00	1.00	2.00	3.30	2.00	2.59	5.00	1.00	1.32	1.35
STR	56.00	67.00	84.00	43.00	4.00	28.00	63.00	70.00	50.00	51.67	84.00	4.00	23.57	24.17

TABLE A.7: Nitrate -Nitrogen (NO^{-}_{3} –N)mg/l

Source of sample	Date of sampling)									Av.	Max.	Min.	SE (99%)	SD
		03/01/07	**08/03/07**	**15/03/07**	**28/03/07**	**04/04/07**	**13/04/07**	**19/04/07**	**28/04/07**					
GA1		10.00	6.50	9.50	6.50	17.00	11.50	11.00	15.00	10.88	17.00	6.50	3.38	3.70
GA2		10.50	16.00	12.00	9.50	31.00	16.00	14.00	17.00	15.75	31.00	9.50	6.15	6.74
GQ1		10.50	9.00	9.00	10.50	19.00	12.50	14.00	22.00	13.31	22.00	9.00	4.39	4.81
GQ2		13.00	12.00	10.50	9.00	20.00	9.00	8.00	12.00	11.69	20.00	8.00	3.46	3.79
Av.Inf		11.00	10.88	10.25	8.88	21.75	12.25	11.75	16.50	12.91	22.50	8.25	3.84	4.21
JUN		7.50	9.00	9.50	6.50	13.00	11.50	13.00	12.00	10.25	13.00	6.50	2.27	2.49
MID		7.00	8.50	8.00	7.00	14.00	11.00	13.00	4.00	9.06	14.00	4.00	3.07	3.36
EFF		6.00	7.50	6.50	4.50	10.00	8.50	11.00	6.00	7.50	11.00	4.50	2.01	2.20
STR		11.00	16.00	18.00	7.50	10.00	14.00	11.00	10.00	12.19	18.00	7.50	3.20	3.50

TABLE A.8:Nitrite -Nitrogen (NO^{-}_{2} –N)mg/l

Source of sample	Date of sampling									Av.	Max.	Min.	SE (99%)
		03/01/07	08/03/07	15/03/07	28/03/07	04/04/07	13/04/07	19/04/07	28/04/07				
GA1		0.05	0.02	0.06	0.55	0.05	0.05	0.06	0.05	0.11	0.55	0.02	0.16
GA2		0.06	0.01	0.06	0.68	0.00	0.06	0.04	0.07	0.12	0.68	0.00	0.21
GQ1		0.06	0.02	0.80	0.50	0.01	0.55	0.07	0.80	0.35	0.80	0.01	0.32
GQ2		0.06	0.15	0.40	0.09	0.30	0.04	0.01	0.19	0.15	0.40	0.01	0.12
Av.Inf		0.05	0.05	0.33	0.46	0.09	0.17	0.05	0.28	0.18	0.61	0.01	0.14
JUN		0.03	0.02	0.01	0.03	0.01	0.04	0.03	0.05	0.03	0.05	0.01	0.01
MID		0.04	0.04	0.05	0.07	0.02	0.05	0.04	0.19	0.06	0.19	0.02	0.05
EFF		0.03	0.05	0.02	0.04	0.01	0.03	0.01	0.08	0.03	0.08	0.01	0.02
STR		0.04	0.06	0.04	0.03	0.02	0.04	0.04	0.06	0.04	0.06	0.02	0.01

TABLE A.9:Coliform 10^{-4}

Source of sample	Date of sampling							Av.	Max.	Min.	SE (99%)	SD
	22/02/07	01/03/07	08/03/07	28/03/07	13/04/07	19/04/07	28/04/07					
GA1	18.00	19.00	28.00	104.00	6.00	43.00	67.00	40.71	104.00	6.00	33.44	34.29
GA2	10.00	128.00	112.00	68.00	142.00	52.00	56.00	81.14	142.00	10.00	46.37	47.55
GQ1	48.00	11.00	26.00	16.00	135.00	23.00	67.00	46.57	135.00	11.00	42.54	43.62
GQ2	13.00	38.00	44.00	60.00	72.00	78.00	47.00	50.29	78.00	13.00	21.53	22.08
Av.Inf	22.25	49.00	52.50	62.00	88.75	49.00	59.25	54.68	88.75	22.25	19.32	19.82
JUN	16.00	21.00	28.00	115.00	11.00	21.00	11.00	31.86	115.00	11.00	36.24	37.16
MID	12.00	19.00	17.00	4.00	1.00	9.00	8.00	10.00	19.00	1.00	6.37	6.53
EFF	10.00	4.00	0.00	0.00	0.00	7.00	2.00	3.29	10.00	0.00	3.85	3.95
STR	29.00	48.00	41.00	42.00	71.00	69.00	53.00	50.43	71.00	29.00	14.89	15.27

TABLE A.10:Phosphate – Phosphorus (PO^{3-}_4-P)mg/l

Source of sample	Date of sampling									Av.	Max.	Min.	SE (99%)	SD
		03/01/07	08/03/07	15/03/07	28/03/07	04/04/07	13/04/07	19/04/07	28/04/07					
GA1		7.50	18.60	5.15	1.15	14.90	9.46	4.00	6.90	8.46	18.60	1.15	5.26	5.77
GA2		6.65	7.25	4.80	5.90	32.40	11.40	20.50	3.10	11.50	32.40	3.10	9.16	10.04
GQ1		4.15	13.50	12.85	9.75	23.40	12.73	21.60	15.50	14.19	23.40	4.15	5.63	6.17
GQ2		10.55	11.15	10.35	11.90	11.10	11.01	19.60	39.00	15.58	39.00	10.35	9.07	9.94
Av.Inf		7.21	12.63	8.29	7.18	20.45	11.15	16.43	16.13	12.43	28.35	4.69	7.28	4.89
JUN		8.25	13.00	8.10	4.95	6.80	8.21	11.90	22.60	10.48	22.60	4.95	5.06	5.54
MID		7.39	12.69	8.26	4.55	1.50	10.66	16.50	11.70	9.15	16.50	1.50	4.35	4.76
EFF		3.20	1.40	4.25	0.90	1.70	2.29	12.00	2.10	3.48	12.00	0.90	3.28	3.60
STR		12.25	9.43	18.50	4.00	0.70	7.73	23.80	1.50	9.74	23.80	0.70	7.45	8.17

TABLE A.11:Chemical Oxygen Demand(COD)mg/l

Source of sample	Date of sampling									Av.	Max.	Min.	SE (99%)	SD
	22/02/07	03/01/07	08/03/07	15/03/07	28/03/07	04/04/07	13/04/07	19/04/07	28/04/07					
GA1	584.00	560.00	583.20	432.00	400.00	1040.00	256.00	192.00	744.00	532.36	1040.00	192.00	221.00	256.98
GA2	1512.00	1250.00	1404.00	464.00	616.00	1835.00	1008.00	1384.00	672.00	1127.22	1835.00	464.00	399.84	464.93
GQ1	168.00	234.00	612.00	592.00	384.00	712.00	720.00	632.00	784.00	537.56	784.00	168.00	190.90	221.97
GQ2	368.00	416.00	608.00	488.00	504.00	640.00	672.00	304.00	1688.00	632.00	1688.00	304.00	356.98	415.10
Av.Inf	658.00	615.00	801.80	494.00	476.00	1056.75	664.00	628.00	972.00	707.28	1336.75	282.00	292.18	199.76
JUN	395.00	404.00	560.00	512.00	232.00	600.00	192.00	160.00	224.00	364.33	600.00	160.00	144.80	168.37
MID	210.00	162.00	144.00	120.00	176.00	56.00	64.00	72.00	344.00	149.78	344.00	56.00	77.70	90.35
EFF	80.00	68.00	64.00	48.00	128.00	136.00	104.00	40.00	232.00	100.00	232.00	40.00	51.37	59.73
STR	496.88	624.00	728.00	64.00	480.00	736.00	120.00	640.00	256.00	460.54	736.00	64.00	219.91	255.71

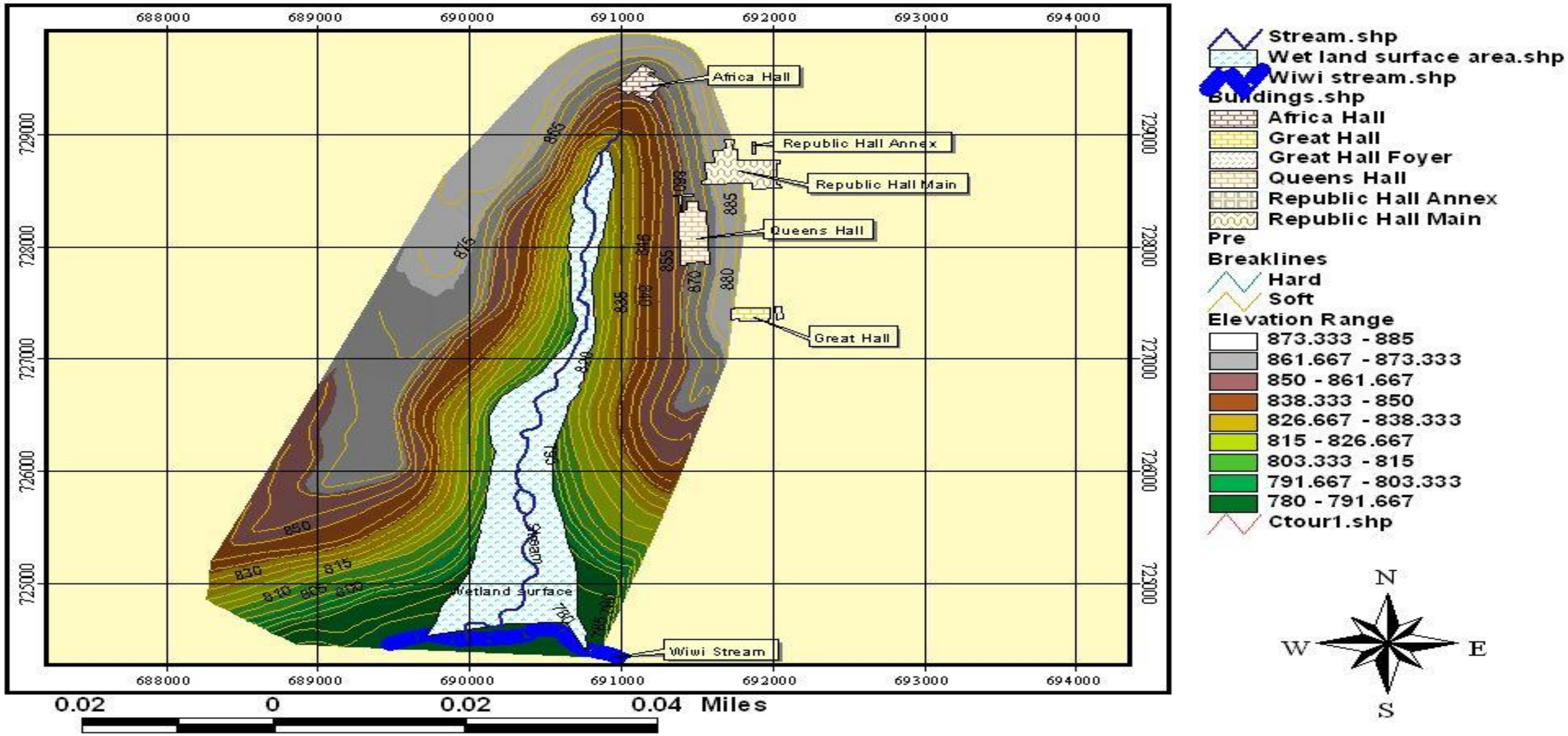
TABLE A.12:Biochemical Oxygen Demand(BOD)mg/l

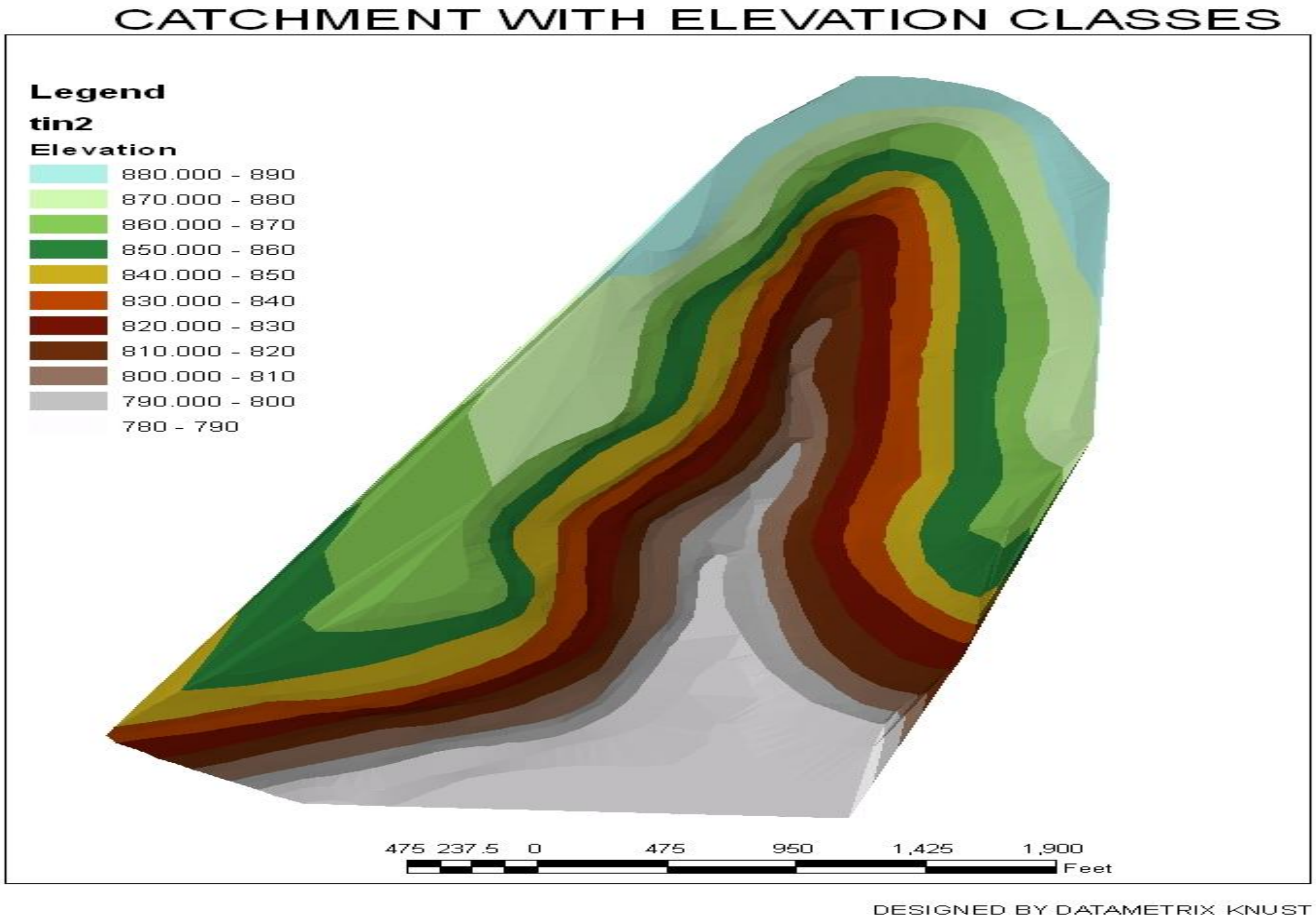
Source of sample	Date of sampling									Av.	Max.	Min.	SE (99%)	SD
	22/02/07	03/01/07	08/03/07	15/03/07	28/03/07	04/04/07	13/04/07	19/04/07	28/04/07					
GA1	550.00	250.00	400.00	150.00	200.00	1040.00	80.00	120.00	420.00	356.67	1040.00	80.00	258.25	300.29
GA2	1150.00	550.00	1050.00	340.00	380.00	1160.00	330.00	420.00	356.00	637.33	1160.00	330.00	317.36	369.02
GQ1	120.00	250.00	500.00	280.00	220.00	440.00	360.00	240.00	502.00	323.56	502.00	120.00	115.51	134.31
GQ2	300.00	350.00	520.00	240.00	280.00	340.00	300.00	220.00	720.00	363.33	720.00	220.00	137.06	159.37
Av.Inf	530.00	350.00	617.50	252.50	270.00	745.00	267.50	250.00	499.50	420.22	855.50	187.50	207.04	183.94
JUN	220.00	165.00	310.00	110.00	100.00	140.00	120.00	100.00	120.00	153.89	310.00	100.00	60.11	69.90
MID	130.00	80.00	120.50	75.50	80.00	30.00	50.00	50.00	146.00	84.67	146.00	30.00	34.16	39.72
EFF	40.00	60.00	40.00	40.00	60.00	40.00	60.00	30.00	70.00	48.89	70.00	30.00	11.73	13.64
STR	360.00	280.00	550.00	60.00	220.00	340.00	60.00	140.00	158.00	240.89	550.00	60.00	137.34	159.69

TABLE A.13:Rainfall Data (mm)

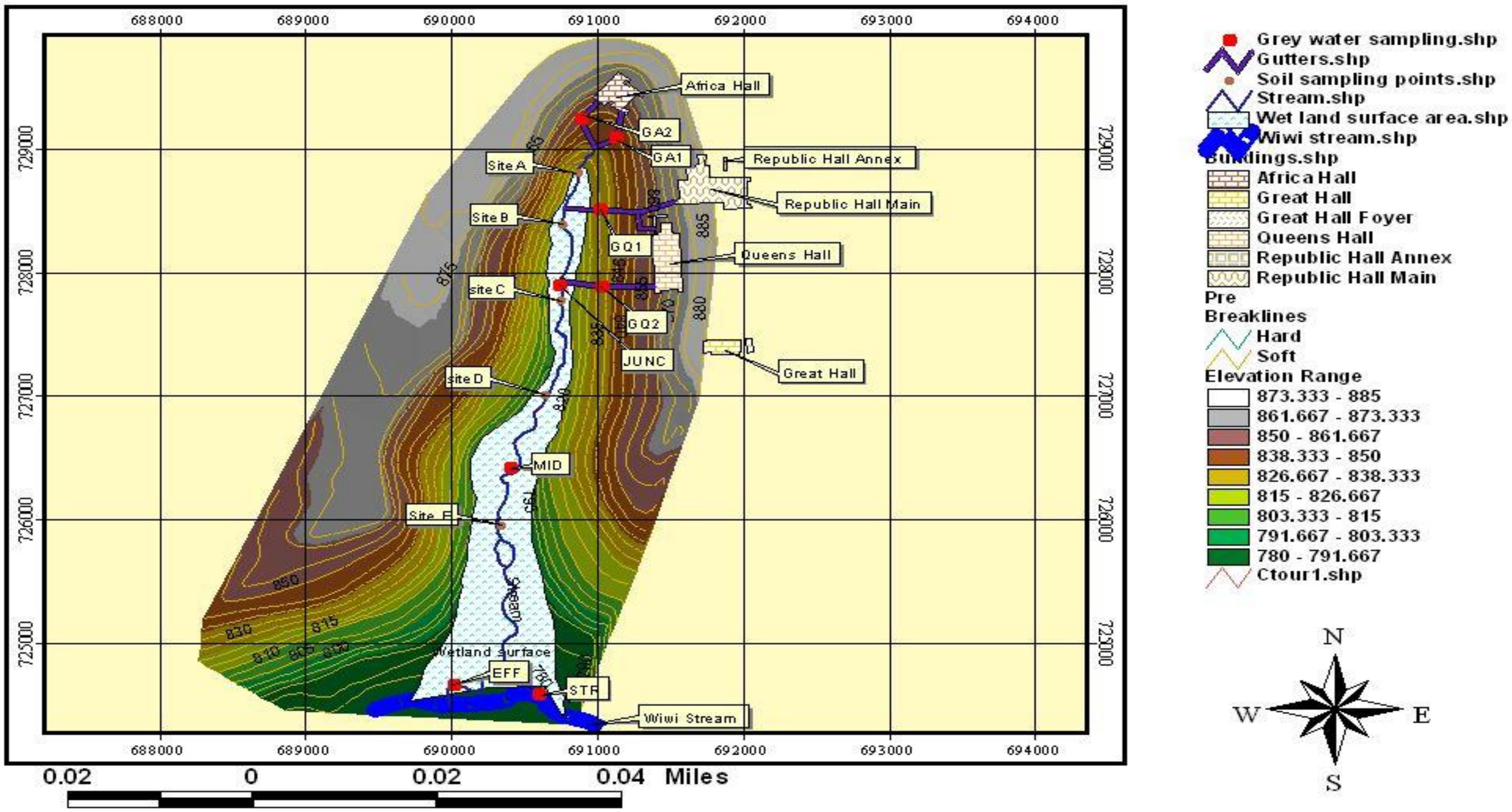
Weeks	1	2	3	4	5	6	7	8	9	10	11	12
Value	0.17	2.2	0.03	0.03	0.03	0.03	2.11	4.6	16.77	0.03	8.86	14.61

Catchment and Wetland



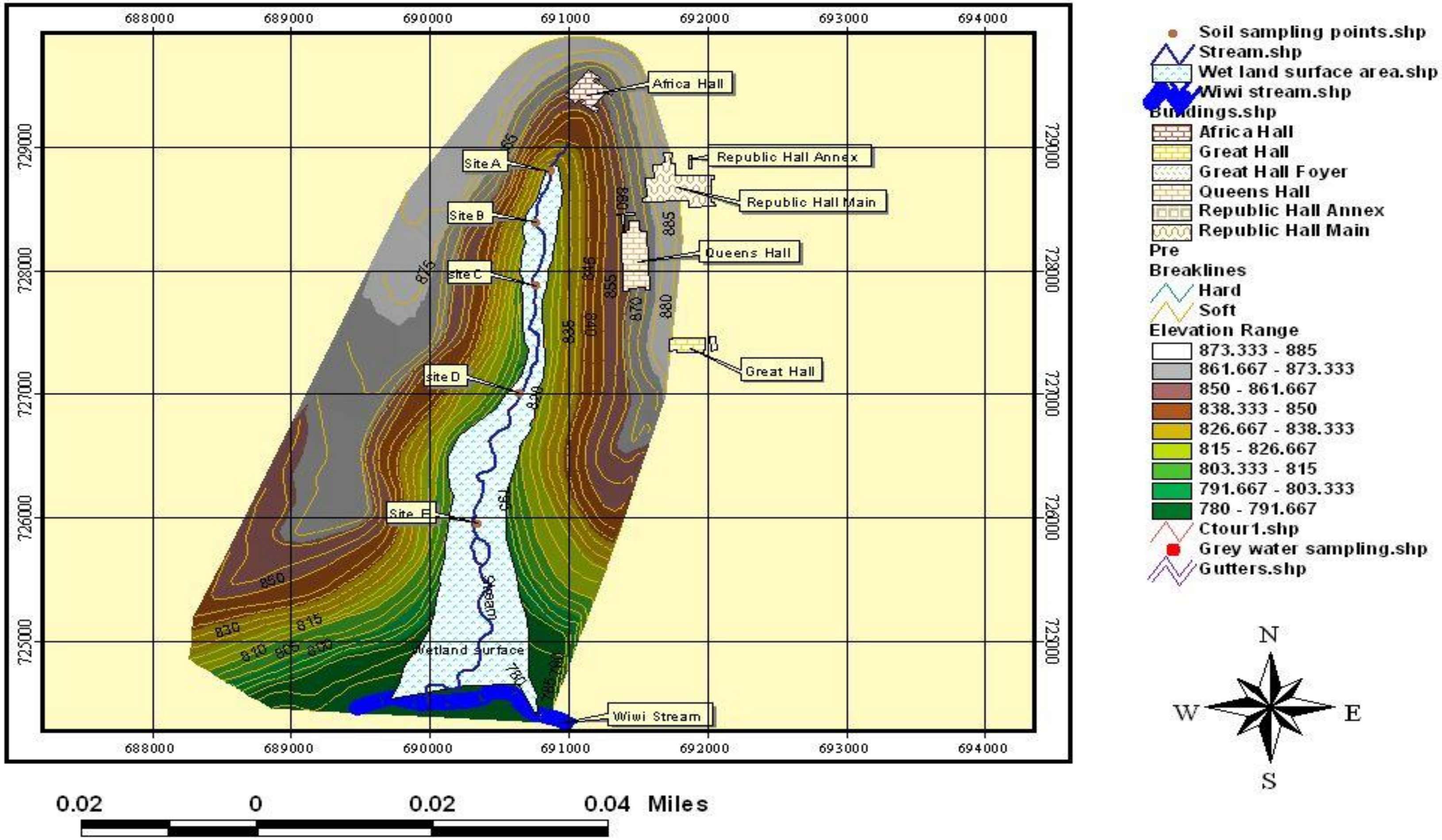

CATCHMENT WITH ELEVATION CLASSES
Legend
tin2
Elevation
880.000 - 890
870.000 - 880
860.000 - 870
850.000 - 860
840.000 - 850
830.000 - 840
820.000 - 830
810.000 - 820
800.000 - 810
790.000 - 800
780 - 790
475 237.5 0 475 950 1,425 1,900
Feet
DESIGNED BY DATAMETRIX KNUST

Grey Water and Soil Sampling Sites



A

Soil Sampling Sites



Grey Water Sampling