KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,
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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

ASSESSING THE IMPACT OF GHANA NUT LIMITED INDUSTRIAL DISCHARGES ON RIVER TANO IN THE TECHIMAN MUNICIPALITY

A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY, OF THE COLLEGE OF SCIENCE OF THE KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE.

BY

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DECLARATION

I, Napoleon Jackson Mensah hereby declare that except for the references to the literature, which have been duly cited herein, this thesis is the result of my own field and laboratory work towards the award of MSc. under the supervision of Dr. Bernard Fei-Baffoe of the Department of Theoretical and Applied Biology and Dr. Richard Buamah of the Department of Civil Engineering of Kwame Nkrumah University of Science and Technology. I further declare that the research has not been submitted previously either wholly or partially for a degree in the Kwame Nkrumah University of Science and Technology or elsewhere, except where due acknowledgement has been made in the text.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

This study was carried out along the Tano River (TR) and Asuotwe Stream (AS), and on the industrial effluents (EFT) emanating from Ghana Nuts Limited (GNL) for a four-month period from February to May 2012, to assess the impact of effluent from GNL on the physico-chemical and microbiological qualities of the Tano River. Seven sampling stations were selected along the Tano River, Asuotwe Stream and the GNL's effluent to give adequate spatial coverage and to represent the variety of conditions in the River, the Stream and the Factory premises. The Effluent, Asuotwe Stream and Tano River samples and *in-situ* data were collected from the stations on a monthly basis. The Effluent From GNL, Asuotwe Stream(AS) and Tano River (TR) samples were analyzed in terms of physico-chemical quality (temperature, pH, alkalinity, turbidity, total dissolved solids (TDS), total soluble solids (TSS), biological oxygen demand (BOD), oil and grease, chemical oxygen demand (COD), phosphorus and nitrate) and microbiological quality (total coliforms (TC), faecal coliforms (FC) and *Escherichia coli* (*E.coli*)). The measured parameters of the effluent were compared to EPA-Ghana guideline value for its suitability to be discharged into surface waters whereas Asuotwe stream (AS) and Tano River (TR) were compared to WHO drinking water quality guideline value. Also, the reduction of the pollutants as the Effluent (EFT) joins the Tano River (TR) at the discharge point (MS) and as the river flows from upstream to the downstream were assessed to ascertain the extent of dilution by the EFT, AS and TR as they run from a particular source to a destination. Comparing the physico-chemical parameters to the regulatory guideline values it was observed that BOD, COD, TSS, Fe and oil and grease of the EFT recorded very high mean values whilst generally the TR sampling locations recorded a higher levels in BOD, COD, Fe and turbidity. All the measurable microbiological parameters (TC, FC and *E.coli)* for the Effluent (EFT), Asuotwe (AS) and Tano River (TR) were very much above EPA-Ghana guideline value and the WHO drinking water guideline values. The percentage reduction of the contaminants of the Tano River recorded as the river flows from upstream to the discharge point of the effluent was very low as shown by the measured parameters. However there was a dilution of the contaminant levels as the river flows from the discharge point to the downstream of the river. Direct anthropogenic activities and effluent discharges from GNL were the cause of pollution of the TR and AS. Thus, polluted water from river bodies should be treated before usage. Effluents from industries should not be discharge directly into water bodies but should be treated before releasing into them. There should be education on the impact of water pollution on the health of humans as results of their own activities.

LIST OF ACRONYMS AND ABBREVIATION

AS	Asuotwe Stream
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DS 1	Downstream One (1)
DS 2	Downstream Two (2)
EFT	Industrial Effluent
EPA	Environmental Protection Agency
FRNR	Faculty of Renewable Natural Resources
GNL	Ghana Nuts Limited
GWCL	Ghana Water Company Limited
KNUST	Kwame Nkrumah University of Science and Technology
MS	Midstream/ Discharge Point
TR	Tano River
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UK	United Kingdom
UP 1	Upstream One (1)
UP 2	Upstream Two (2)
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

In the recent past, industrialization, increasing human population, intensive agricultural practices and discharges of massive amounts of wastewater into rivers and streams have resulted in deterioration of soil, biota and water qualities. The impact of these anthropogenic activities has been so extensive that the water bodies have lost their self-purification capacity to a large extent (Sood *et al.*, 2008). Edible oil mills located in urban centers also contributes significantly to waste discharges into water bodies resulting in stench, discoloration and a greasy and oily nature of such waters. These wastes pose serious threat to associated environment, including human health risk (Sood *et al.*, 2008).

As urban and industrial development increases, the quantity of waste generated also increases. These wastes pose a serious threat to public health when they are not readily disposed off. When these wastes are removed by water carriage system, they are termed wastewater. Wastewater is the used water or liquid waste of a community, which includes human and household waste together with street washings. Industrial waste, ground and storm water may be mixed with it. Nevertheless, it must be borne in mind that although the sediment is an excellent adsorbent for most soluble pollutants, domestic wastewater must be treated before it can be discharged into water bodies to prevent the risk to both public and the environment (Mohammed, 2006). In view of this, the research sought to assess the impact of effluent from Ghana Nuts Limited on the physico- chemical and microbiological qualities of the Tano River.

1.1 PROBLEM STATEMENT

The pollution of water bodies through discharges from industries and domestic sources have been a major concern in the country lately. Many water bodies are losing their capacity to host aquatic fauna and flora because of the extent of pollution. Aside rendering the extinction of some aquatic species, the effect of the water pollution on resident downstream of the water bodies is enormous and poses a major health risk (Holdgates, 1979). In recognition of these probable challenges, it becomes very necessary to take inventory and evaluate the possible impacts of the wastewater discharges from the Ghana Nuts Limited (GNL) on its environs and the residents within the Techiman catchment area.

To date very limited documented information exists with regards to the impact of the GNL discharges although some media houses in the country, the EPA of Ghana and some of the Techiman residents have raised some concern about the situation. Also, during the celebration of the World Water Day 2011, at Techiman, the Officer In-charge of Tanoso Water Headwork's of the Ghana Water Company disclosed in an interview that the Tano river is polluted which was attributed to the production discharges unto the surrounding environment by the GNL at Hansua a suburb of Techiman. The company (GNL), promised to treat its waste in order not to pollute the Tano River (Boateng, 2012). The disposal of industrial wastewater is a serious problem as it affects the freshwater resources, human health and agricultural productivity. The problem is more critical in the urban and industrial areas where rapid water quality deterioration has caused widespread water-borne diseases and other irrecoverable damages to the environment (Paraveen *et al.*, 2010).

It is against this background that the present assessment was conducted into the quality of the receiving water bodies within the catchment area of the GNL.

1.2 AIM AND OBJECTIVES

AIM

The research sought to assess the impact of effluent from Ghana Nuts Limited on the physico- chemical and microbiological quality of the Tano River.

SPECIFIC OBJECTIVES

The research had the following specific objectives:

1. To assess the physico-chemical quality (TDS, TSS, NO^{-1}_3, PO^{-2}_4, SO^{-2}_4, Colour, turbidity, Temp. alkalinity, conductivity, pH, oil and grease, total hardness, COD, BOD) of Ghana Nuts Limited effluent, Asuotwe Stream discharges and water samples from Tano River.
2. To assess microbiological quality (Faecal Coliforms, Total Coliforms, *E. coli*) of Ghana Nuts Limited effluent, Asuotwe Stream discharges, and water samples of Tano River.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 GHANA NUT LIMITED

The Ghana Nuts Limited (GNL) was established in 2001 and commenced operations as a commodity trader in soya, groundnuts, cashew, shea butter and sesame seeds, *Voacanga Africana, Griffoniaspp* to Europe, UK, India and Japan (GNL, 2011).

The production of edible oil by the GNL leaves in its trail waste, both solid and liquid. The waste water generated, very probable contain organic oil and waxes that when discharged untreated, could have a number of negative impacts on the aquatic life of receiving water bodies. In the Techiman Municipality, one of the receiving water bodies directly affected includes the Tano River (Boateng, 2012).

The disposal of industrial wastewater is a serious problem as it affects the freshwater resources, human health and agricultural productivity. The problem is more critical in the urban and industrial areas where rapid water quality deterioration has caused widespread water borne diseases and other irrecoverable damages to the environment. Rapid development and growth in industrialization has adversely affected the environment and the surrounding ecosystem (Paraveen *et al.*, 2010).

The discharged effluent may impact on soil, sediments, biota and water quality, besides its socio-economic dimensions. It was against this background that necessitated the study into the efficiency of mitigation measure adopted by a commercial edible oil factory for treating its effluent in Ghana (Boateng, 2011).

Ghana Nut Limited has grown over the years to become the leading agro processor, manufacturer and exporter of edible oils (including bleached and deodorized soybean and cotton seed cooking oils), animal feed input material and shea butter. Exports of these products amount to over 30000 tons per annum. GNL employs a high infrastructure, state of the art solvent extraction facility and refinery plant and operates in accordance with good manufacturing practice (Boateng, 2011).

2.2 Surface Water

Precipitation that does not evaporate or infiltrate into the ground runs as surface water, which may accumulate to form streams, and streams join to form rivers. Lakes are inland depressions that hold standing freshwater. Ponds are generally considered to be small temporary or permanent bodies of water shallow enough for rooted plants to grow over and at the bottom. While lakes contain nearly as much as one hundred times water as all rivers and streams combined, they are still a major component of total world water supply (Mallard, 1982).

2.3 Water Quality

Water quality is a term used here to express the suitability of water to sustain various uses or processes. Water quality is affected by a wide range of natural and anthropological (human) influences. The most important of the natural influences are geological, hydrological and climatic, since these affect the quality and quantity of water available. It is important to understand how the water upstream and downstream is being used because the downstream use will often dictate the overall water quality. The utilization of water for a wide diversity of desirable purposes affects water quality and the wastewater generated must be treated to save the environments from being polluted (Russell, 2006).

2.3.1 Water Quality Monitoring

The main elements of water quality monitoring are on-site measurements, the collection and analysis of water samples, the study and evaluation of the analytical results and the reporting of the findings. Some of the common water qualities monitoring strategies are Ambient Monitoring, Baseline Monitoring and Compliance or regulatory monitoring (Igbinosa and Okoli, 2009).

2.4 Some Parameters Used to Determine Effluent and Water Quality

2.4.1 pH

By definition pH, is the negative logarithm of the hydrogen ion concentration of a solution and it is thus a measure of whether the liquid is acid or alkaline. The pH scale (derived from the ionization constant of water) ranges from 0 (very acid) to 14 (very alkaline). The

range of natural pH in fresh waters extends from around 4.5, for acid, peaty upland waters, to over 10.0 in waters where there is intense photosynthetic activity by algae. However, the most frequently encountered range is 6.5-8.0. In waters with low dissolved solids, which consequently have a low buffering capacity (i.e. low internal resistance to pH change), changes in pH induced by external causes may be quite dramatic. The effect of pH on fish is also an important consideration and values which depart increasingly from the normally found levels will have a more and more marked effect on fish, leading ultimately to mortality. The range of pH suitable for fisheries is considered to be 5.0-9.0, though 6.5-8.5 is preferable (Ireland EPA, 2001).

Campbell and Stokes (1985) have described two contrasting responses of an organism to metal toxicity with a decrease in pH

1. If there is little change in speciation and metal binding is weak at the biological surface, a decrease in pH will decrease toxicity due to competition for binding sites from hydrogen ions.
2. Where there is a marked effect on speciation and strong binding of the metal at the biological surface the dominant effect of a decrease in pH will be to increase metal availability.

2.4.2 Temperature

Temperature is important because it not only influences the metabolic activity and behavior of organisms, which may affect their exposure to a pollutant, but it may also alter the physical and chemical state of the pollutant. In general, toxicity increases with

temperature, as is the case for metals (Felts and Heath, 1984; Khangarot and Ray, 1987). There are, however, many exceptions to the increase in toxicity with temperature. The effect of temperature, and especially changes in temperature, on living organisms can be critical and the subject is a very wide and complex one. The temperature of surface waters is influenced by latitude, altitude, and season, time of day, air circulation, cloud cover and the flow and depth of the water body. In turn, temperature affects physical, chemical and biological processes in water bodies and, therefore, the concentration of many variables. As water temperature increases, the rate of chemical reactions generally increases together with the evaporation and volatilization of substances from the water. Increased temperature also decreases the solubility of gases in water, such as O_2, CO_2, N_2, CH_4 and others. The metabolic rate of aquatic organisms is also related to temperature, and in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter. Growth rates also increase (this is most noticeable for bacteria and phytoplankton which double their populations in very short time periods) leading to increased water turbidity, macrophyte growth and algal blooms, when nutrient conditions are suitable. Surface waters are usually within the temperature range 0°C to 30°C, although "hot springs" may reach 40°C or more. These temperatures fluctuate seasonally with minima occurring during winter or wet periods, and maxima in the summer or dry seasons, particularly in shallow waters. Abnormally high temperatures in surface water can arise from thermal discharges, usually from power plants, metal foundries and sewage treatment plants (Chapman, 1996).

2.4.3 Total suspended solids

The significance of suspended solids in water is great, on a number of grounds. The solids may in fact consist of algal growths and hence be indicative of severely eutrophic conditions; they may indicate the discharge of washings from sandpits, quarries or mines; they will reduce light penetration in surface waters and interfere with aquatic plant life; they will seriously damage fishery waters and may affect fish life; they may form deposits on the bed of rivers and lakes which will in turn give rise to septic and offensive conditions; and they may indicate the presence of unsatisfactory sewage effluent discharges (Ireland EPA, 2001).

Domestic wastewater usually contains large quantities of suspended solids that are organic and inorganic in nature. These solids are measured as Total Suspended Solids or TSS and are expressed as mg TSS/ liter of water. Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life (Mitchell and Stapp, 1992).

High TSS can block light from reaching submerged vegetation. As the amount of light passing through the water is reduced, photosynthesis slows down. Reduced rates of photosynthesis causes less dissolved oxygen to be released into the water by plants. If light is completely blocked from bottom dwelling plants, the plants will stop producing oxygen and will die. As the plants are decomposed, bacteria will use up even more oxygen from

the water. Low dissolved oxygen can lead to fish kills. High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This can cause dissolved oxygen levels to fall even further (because warmer waters can hold less DO), and can harm aquatic life in many other ways (Mitchell and Stapp, 1992).

The decrease in water clarity caused by TSS can affect the ability of fish to see and catch food. Suspended sediment can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. When suspended solids settle to the bottom of a water body, they can smother the eggs of fish and aquatic insects, as well as suffocate newly hatched insect larvae. Settling sediments can fill in spaces between rocks which could have been used by aquatic organisms for homes (Mitchell and Stapp, 1992).

High TSS in a water body can often mean higher concentrations of bacteria, nutrients, pesticides, and metals in the water. These pollutants may attach to sediment particles on the land and be carried into water bodies with storm water. In the water, the pollutants may be released from the sediment or travel farther downstream. High TSS can cause problems for industrial use, because the solids may clog or scour pipes and machinery (Mitchell and Stapp, 1992).

2.4.4 Nitrate

The nitrate ion (NO_3^-) is the common form of combined nitrogen found in natural waters. It may be biochemically reduced to nitrite (NO_2^-) by denitrification processes, usually under anaerobic conditions. The nitrite ion is rapidly oxidised to nitrate. Natural sources of

nitrate to surface waters include igneous rocks, land drainage and plant and animal debris. Nitrate is an essential nutrient for aquatic plants and seasonal fluctuations can be caused by plant growth and decay. Natural concentrations, which seldom exceed 0.1 mg/ L. NO_3N, may be enhanced by municipal and industrial waste-waters, including leachates from waste disposal sites and sanitary landfills. In rural and suburban areas, the use of inorganic nitrate fertilizers can be a significant source. When influenced by human activities, surface waters can have nitrate concentrations up to 5 mg/ L NO_3N, but often less than 1 mg/ L NO_3N. Concentrations in excess of 5 mg/ L NO_3N usually indicate pollution by human or animal waste, or fertilizer run-off. In cases of extreme pollution, concentrations may reach 200 mg/ L NO_3N. In lakes, concentrations of nitrate in excess of 0.2 mg/ L NO_3N tend to stimulate algal growth and indicate possible eutrophic conditions (Chapman, 1996).

2.4.5 Phosphate

Phosphorus occurs widely in nature in plants, in micro-organisms, in animal wastes and so on. It is widely used as an agricultural fertilizer and as a major constituent of detergents, particularly those for domestic use. Run-off and sewage discharges are thus important contributors of phosphorus to surface waters. The significance of phosphorus is principally in regard to the phenomenon of eutrophication (over-enrichment) of lakes and, to a lesser extent, rivers. Phosphorus gaining access to such water bodies, along with nitrogen as nitrate, promotes the growth of algae and other plants leading to blooms, littoral slimes, diurnal dissolved oxygen variations of great magnitude and related problems (Ireland EPA, 2001). Natural sources of phosphorus are mainly the weathering of phosphorus-bearing rocks and the decomposition of organic matter. Domestic waste-waters (particularly those

containing detergents), industrial effluents and fertilizer run-off contribute to elevated levels in surface waters. Phosphorus associated with organic and mineral constituents of sediments in water bodies can also be mobilized by bacteria and released to the water column. Phosphorus is rarely found in high concentrations in freshwaters as it is actively taken up by plants. As a result there can be considerable seasonal fluctuations in concentrations in surface waters. In most natural surface waters, phosphorus ranges from 0.005 to 0.020 mg/ L PO_4^-P. Concentrations as low as 0.001 mg/ L PO_4^-P may be found in some pristine waters and as high as 200 mg/ L PO_4^-P in some enclosed saline waters (Chapman, 1996).

2.4.6 Conductivity

Conductivity, or specific conductance, is a measure of the ability of water to conduct an electric current. It is sensitive to variations in dissolved solids, mostly mineral salts. The degrees to which these dissociate into ions, the amount of electrical charge on each ion, ion mobility and the temperature of the solution all have an influence on conductivity. Conductivity is expressed as microsiemens per centimeter (µS/cm) (Igbinosa and Okoh 2009). The conductivity of most freshwaters ranges from 10 to 1,000 µS/cm but may exceed 1,000 µS/ cm, especially in polluted waters, or those receiving large quantities of land run-off. In addition to being a rough indicator of mineral content when other methods cannot easily be used, conductivity can be measured to establish a pollution zone, e.g. around an effluent discharge, or the extent of influence of run-off waters. The ability of the water o conduct a current is very temperature dependent (Chapman, 1996).

2.4.7 Total dissolved solids

Total Dissolved Solids (TDS) refer to any minerals, metals, salts, cations or anions dissolved in water. This includes anything present in water other than the pure water (H_2O) molecule and suspended solids (suspended solids are any particles / substances that are neither dissolved nor settled in the water, such as wood pulp). In general, the total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) ions in the water. Parts per million (ppm) is the weight-to-weight ratio of any ion to water (APHA, 2005).

Total dissolved solids (TDS) are naturally present in water or are the result of mining or some industrial treatment of water. TDS contain minerals and organic molecules that provide benefit such as nutrients or contaminants such as toxic metals and organic pollutants. Current regulations require the periodic monitoring of TDS, which is a measurement of inorganic salts, organic matter and other dissolved materials in water. Measurements of TDS do not differentiate among ions. The amount of TDS in a water sample is measured by filtering the sample through a 2.0 µm pore size filter, evaporating the remaining filtrate and then drying what is left to a constant weight at 180^{0}C. The concentration and composition of TDS in natural waters is determined by the geology of the drainage, atmospheric precipitation and the water balance (evaporation-precipitation). Changes in TDS concentration in natural waters often result from industrial effluent, changes to the water balance (by limiting inflow, by increased water use or increased precipitation), or by salt-water intrusion (APHA, 2005).

2.4.8 Colour

Colour in water may result from the presence of natural metallic ions (irons and manganese), humus and peats materials, plankton, weeds and industrial waste. In some highly coloured industrial waste water, colour is contributed principally by colloidal or suspended materials. In general, colour is removed to make water suitable for domestic and industrial application (APHA, 2005). The colour of water is the result of the different wavelengths that is not absorbed by the water itself or the results of particulate and dissolved substances present (Chapman and Kimstach, 1992). The colour of the waste is an indication that it contains contaminants of different materials and in varying concentrations. Some of these materials are chemical in nature. These are mostly industrial effluents discharged from factories. In such cases, the metallic ions present in these effluents impart different colours and in different hues depending on the strength and polluting potential (Runion, 2010).

2.4.9 Alkalinity

Alkalinity of natural water is generally due to the presence of bicarbonates formed in reactions in the soils through which the water percolates. It is a measure of the capacity of the water to neutralize acids and it reflects its so-called *buffer capacity* (its inherent resistance to pH change). Poorly-buffered water will have a low or very low alkalinity and will be susceptible to pH reduction by atmospheric, acid deposition (Chapman, 1996). At times, however, river alkalinity values of up to 400 mg/l $CaCO_3$ may be found; they are without significance in the context of the quality of the water. There is little known sanitary significance attaching to alkalinity (even up to 400 mg/l $CaCO_3$), though

unpalatability may result in highly alkaline waters. Alkalinity is involved in the consequential effects of eutrophication [over-enrichment] of waters (Ireland EPA, 2001).

2.4.10 Turbidity

Water turbidity, although due primarily to the presence of suspended material with its concomitant scattering, it is also affected by absorption. The measurement of turbidity by image extinction methods such as the candle turbidimeter recognizes the effects of scattering (particularly forward scattering) and absorption. Most of the presently used nephelometric techniques for assessing turbidity in water quality work ignore the effect of absorption and make a turbidity determination proportional to the volume scattering function at some large angle (or range of angles) from the direction of propagation. In addition, these instruments are calibrated in units of little physical significance (WTS, 2012). According to WHO (2011) high level of the turbidity can protect microorganisms from the effects of disinfection, stimulate the growth of bacteria and exerts a significant chlorine demand. In all processes in which disinfection is practised, therefore, the turbidity must always be low, preferably below 1 NTU for effective disinfection (WHO, 2011).

2.4.11 Total hardness

Hardness of water is caused principally by the elements: calcium and Magnesium and sometimes by Iron and Aluminum. It must be noted that iron and aluminum are seldom present in sufficient amounts that can impact significantly in the hardness determination. Hence, it is most of the Calcium and Magnesium is present in natural waters as

bicarbonates, carbonate, and sulphate and sometimes as chlorides and nitrates(APHA, 2005).

Hardness-producing substances react with soaps forming insoluble compounds before lather is produced. They are thus a measure of the soap-consuming power of water. They also deposit scales in boilers and water-heating systems. Hardness can be classified as temporary or permanent. Temporary hardness is caused by the presence of bicarbonates of Calcium and Magnesium and can be removed by boiling. Permanent hardness is caused primarily by calcium sulphate and remains even after boiling. Compounds causing permanent hardness are often termed "incrustants"(APHA, 2005).

Hardness can also be grouped under carbonate or non-carbonate hardness. Carbonate hardness is due to the presence of Calcium and Magnesium carbonates and bicarbonates. Non-carbonate hardness includes the Calcium and Magnesium sulphates, chlorides and nitrates. Sulphates are often the only non-carbonate hardness compound present.

2.4.12 Calcium

Calcium dissolves out from practically all rocks, and is consequently detected in all waters. Waters associated with granite or siliceous may contain less than 10mg of calcium per litre and those associated with gypsiferious shale may contain several hundred mg of calcium per litre. Appreciable calcium salts precipitate on heating to form scales in boilers, pipes and cooking utensils. Calcium also contributes to the hardness of water (APHA, 2005).

2.4.13 Iron

Iron, one of the most abundant metals on earth, is essential to most life forms and to normal human physiology. Iron is an integral part of many proteins and enzymes that maintain good health. In humans, iron is an essential component of proteins involved in oxygen transport. It is also essential for the regulation of cell growth and differentiation. A deficiency of iron limits oxygen delivery to cells, resulting in fatigue, poor work performance, and decreased immunity. On the other hand, excess amounts of iron in man can result in toxicity and even death (Ram *et al.*, 2011).

2.4.14 Biological oxygen demand

The biochemical oxygen demand (BOD) is an approximate measure of the amount of biochemically degradable organic matter present in a water sample. It is defined by the amount of oxygen required for the aerobic micro-organisms present in the sample deoxidize the organic matter to a stable inorganic form. The method is subject to various complicating factors such as the oxygen demand resulting from the respiration of algae in the sample and the possible oxidation of ammonia (if nitrifying bacteria are also present). The presence of toxic substances in a sample may affect microbial activity leading to a reduction in the measured BOD (Kanu and Achi, 2011).

2.4.15 Chemical oxygen demand

The chemical oxygen demand (COD) is a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant, such as dichromate. The COD is widely used as a measure of the susceptibility to oxidation of

the organic and inorganic materials present in water bodies and in the effluents from sewage and industrial plants. The test for COD is non-specific, in that it does not identify the oxidisable material or differentiate between the organic and inorganic material present. Similarly, it does not indicate the total organic carbon present since some organic compounds are not oxidised by the dichromate method whereas some inorganic compounds are oxidised. Nevertheless, COD is a useful, rapidly measured, variable for many industrial wastes and has been in use for several decades (Kanu and Achi, 2011).

2.4.16 Pathogens

Pathogens are disease-causing organisms that grow and multiply within the host. They are divided into categories with the most common groups associated with water pollution being bacteria, viruses, protozoa, helminthes (intestinal worms) and algae. Wastewater often contains representatives of the different pathogen categories and colonization of water by pathogens generally occurs through faeces. The usage of contaminated water therefore results in transmission of pathogens to animals and man. Measurement of coliforms have been identified that they are easy to monitor and correlate with populations of pathogenic organisms. The coliform bacteria group is one of the most common indicator organisms. Coliforms are frequently monitored as total or faecal coliforms. Total coliform (TC) is defined as a large group of anaerobic, non-spore forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C (Chapra, 1997). They originate most often in the intestinal tract of warm-blooded animals, including humans, but also exist in soils. *E. coli* is a common member of this group. Some pathogens enter the human body through the skin but more commonly they are ingested with drinking water. Faecal

coliform (FC) is a subset of TC that comes from the intestines of warm-blooded animals. However, since they do not include soil organisms, they are preferable to TC as an indicator organism. They are measured by running the standard total coliform test at an elevated temperature (44°C) (Chapra, 1997).

Loading concentrations of coliforms depend on the extent of use of water use in a region. For instance, in the United States, where per capita water use is high, the coliform concentration of raw sewage is approximately $20x10^6$ TC per 100 ml in a country like Brazil, however, where water consumption is lower, concentrations of $200x10^6$ TC per 100 ml have been measured (Chapra, 1997). The concentration standards for water use in the United States may give a general idea of acceptable coliform counts. Drinking water has a zero-tolerance limit form both TC and FC. Contact recreation has a TC limit of 1000-5000 per 100 ml and a FC limit of 100-1000 ml (Chapra, 1997)

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Location

Ghana Nuts Limited (GNL) as shown in plate 1 is an edible oil refinery in the Techiman Municipality, which is one of the administrative districts in the Brong Ahafo region of Ghana. It is located at geographical coordinates latitude 7^0 34' 60N, longitude 1^0 55' 60W. It shares common boundaries with Wenchi district to the north and west, Kintampo south district to the north east, Nkoranza south district to the south east and Offinso district in the Ashanti region to the south (Fig 3.1). Techiman, the municipal capital is the second largest town in the region. It is 126km North West of Kumasi and 392km from Accra (Kortatsi and Quansah, 2004)

The municipality is home to the famous Techiman market, the largest food crop market in Ghana. Its strategic location as a commercial centre and a major transit point attracts a large number of people in and out of the municipality daily for business (Kortatsi and Quansah, 2004)

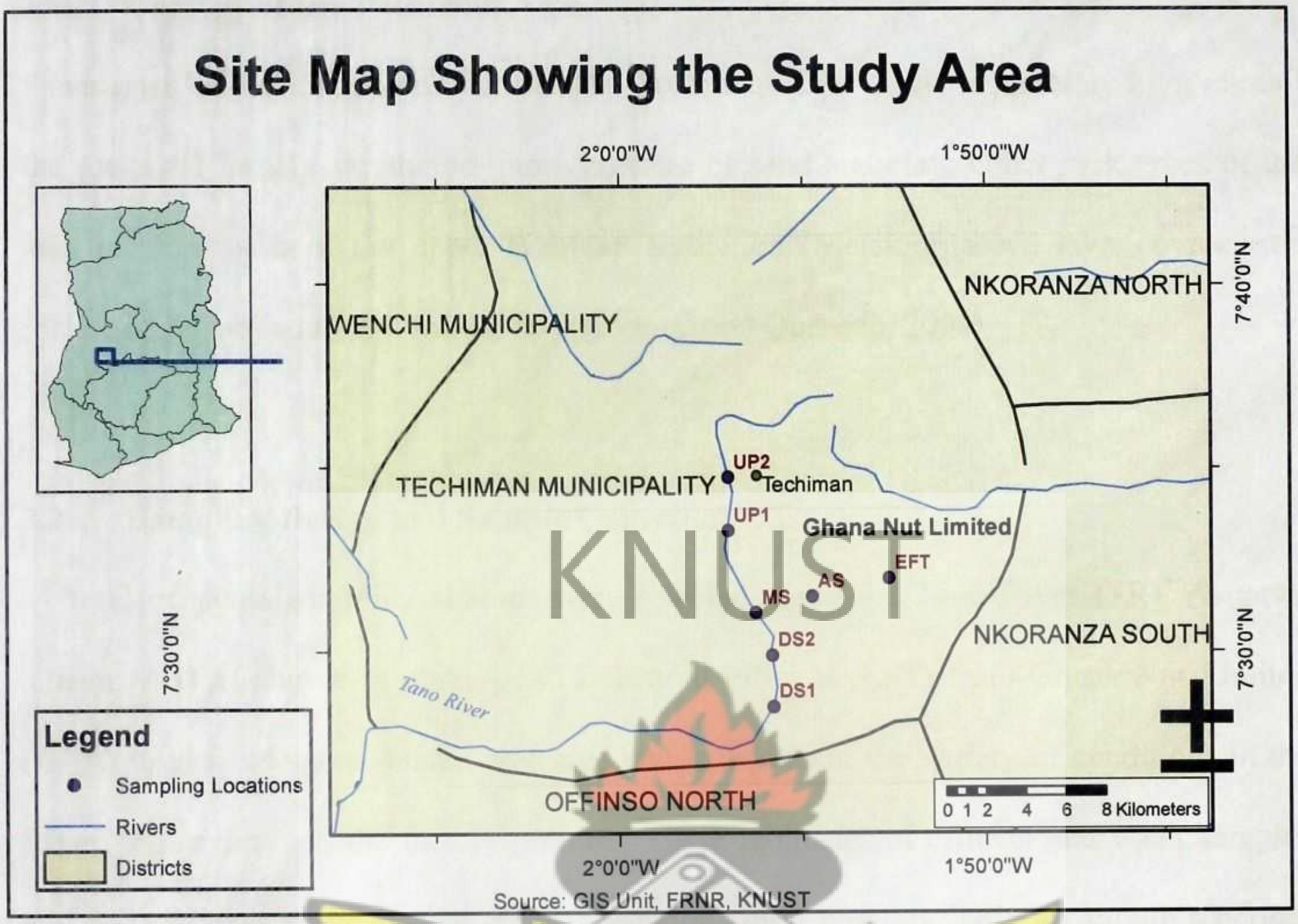

Fig. 3.1: The study area showing the sampling locations

3.1.1 Climate and vegetation

The municipality has two main seasons, that is, the rainy and dry seasons. The major rains start from April to July and the minor from November and lasts till March. The highest rainfall is 1650 mm recorded in the south west and declines northwards to about 1250 mm and the temperature ranges between 26°C and 30°C. The municipality has three main vegetation zones namely; the guinea savannah woodland located in the north-west, semi deciduous zone located in the south and the transitional zone which stretches from the south east and west up to the north of the municipality (Kortatsi and Quansah, 2004).

3.1.2 Geology of the Techiman Area

Sandstones of the Upper Voltain underlie Techiman. Due to the moderately high rainfall the rocks are largely weathered into a mixture of sand and clay. Other rock types of the area include rocks of the upper Birimian formation (Metamorphosed lavas, pyroclastic rocks and hypabyssal basic intrusives) (Kortatsi and Quansah, 2004).

3.2 Sampling Design and Sample Collection

A total of seven sampling stations were selected along the Tano River (TR), Asuotwe stream (AS) as shown in plate 4 and industrial effluent (EFT) from Ghana Nut Limited (GNL) to give adequate spatial coverage and to represent the variety of conditions in the River, the stream and the factory premise. Three replicates of effluent and water samples and *in-situ* data were collected from the stations on a monthly basis for month's period. The River was divided into five (5) sampling locations as illustrated in Figure 3.2; upstream (UP1 and UP2), midstream (MS) and downstream (DS1 and DS2). The upstream portion of the river (UP1) refers to the portion of the River entering the Techiman Township called Techiman Site which is situated away from the entry point of the industry effluent. The area is characterized by the inadequate provision of social infrastructure, unsanitary conditions at the famous Techiman market, unplanned buildings and overcrowded living conditions. The other sampling locations along the river are relatively unaffected by anthropogenic activities and is located away from the human settlements.

The effluent and stream samples were also collected from the premises of the Ghana Nuts Limited and the Asuotwe stream

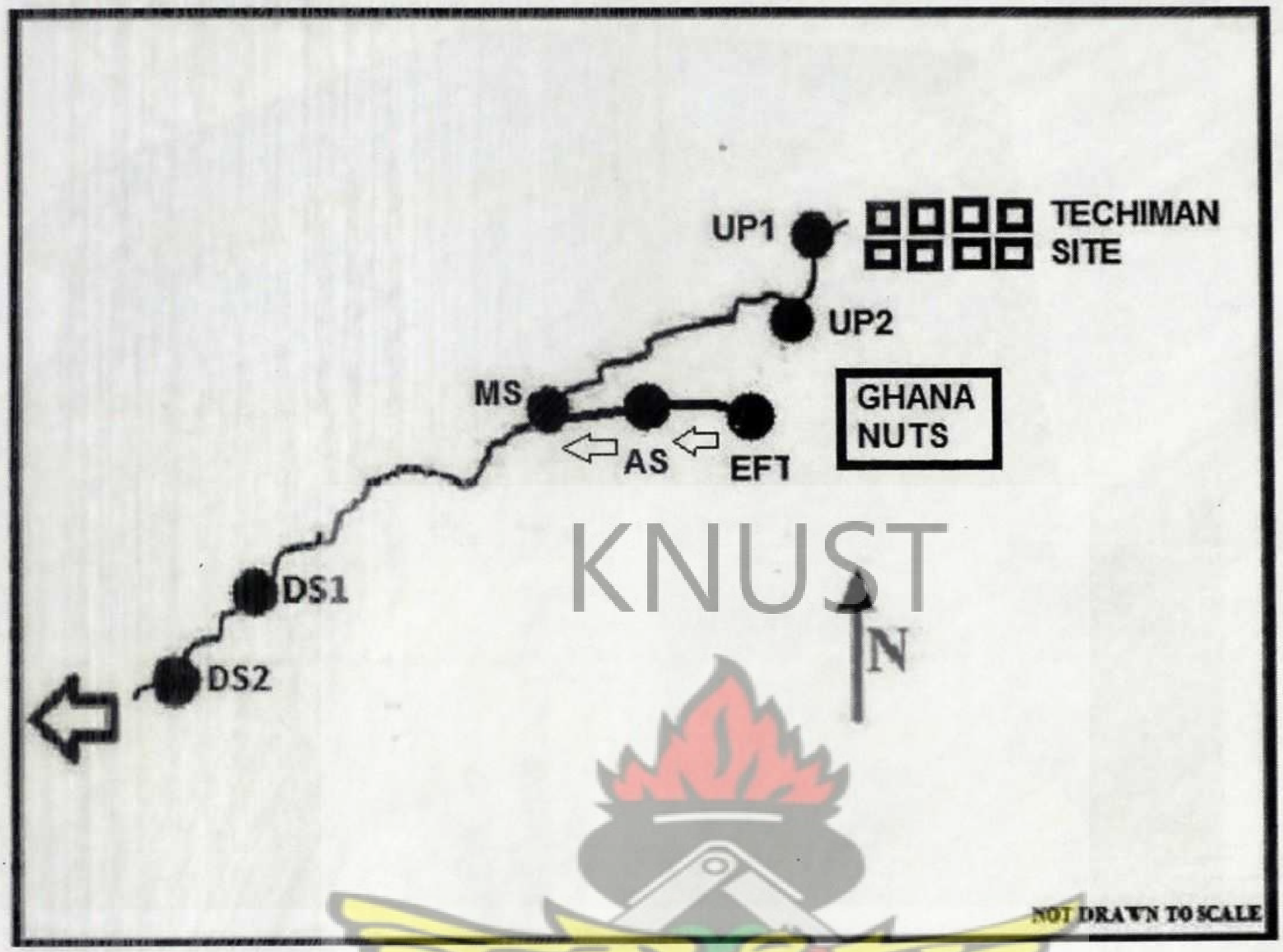

Fig. 3.2: Sketched map of the study area of the different sampling points during the study.

At each sampling location, three samples were collected into sterile 1.5L plastic bottles for analysis on monthly basis for a 4 months study period from February to May 2012. Samples were labeled and placed under ice in an ice chest and transported to laboratory for analysis within 24 hours.

Plate 1: The front view of Ghana Nuts Limited, Techiman

Plate 2: The researcher sampling water from the Discharge point of the Tano River

Plate 3:The researcher sampling effluent discharge linking the Asuotwe stream from GNL.

Plate 4: Asoutwe stream: receptacle for untreated effluent discharge at AS sampling location.

3.3 Physico-chemical and microbiological Analysis

The industrial effluents (EFT) from the industrial productions of Ghana Nuts Limited, Asuotwe stream (AS) and Tano river (TR) samples were analysed in terms of physico-chemical quality (temperature, pH, alkalinity, turbidity, total dissolved solids, total soluble solids, biological oxygen demand, oil and grease, COD, phosphorus and nitrate) and microbiological quality (total and faecal coliforms) using appropriate standard methods (APHA, 2005). The laboratory analyses were done at Water Supply and Sanitation laboratory at the Civil Engineering Department of the Kwame Nkrumah University of Science and Technology, (KNUST), the Faculty of Renewable and Natural Resources Laboratory (Plate 5) and the Microbiology Laboratory at the Department of Biological Science, KNUST

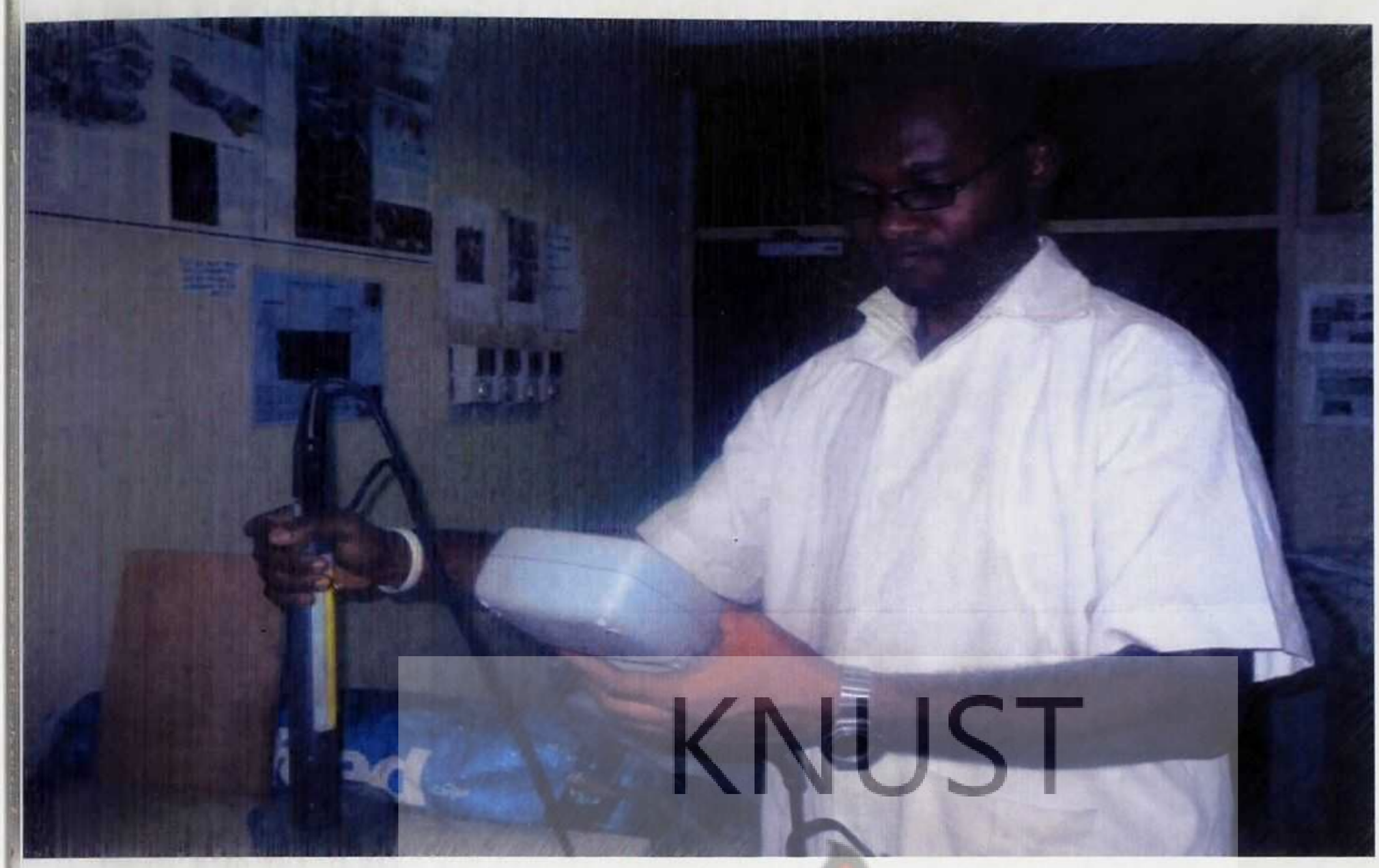

Plate 5:The researcher conducting laboratory Analyses of Physico-Chemical Parameters at Faculty of Renewable Natural Resources (FRNR) Laboratory of Kwame Nkrumah University of Science and Technology (KNUST)

3.4.1 Determination of Alkalinity

Titrimetric analysis was employed in the determination of alkalinity with reference to (APHA, 2005). A volume of 100 ml of the sample was measured into a volumetric flask. Three drops of phenolphthalein indicator were added. Sample was titrated with 0.1 N HCl until a red colour appeared indicating the endpoint, and the volume was recorded.

$$\text{Alkalinity as mg/ L } CaCO_3 = \frac{(V \times N) \times 1000}{\text{sample volume, mL} \times 2} x\ 100$$

V = titration volume in mL

N = normality of the HCl

100 = molecular mass of $CaCO_3$

3.4.1 Turbidity

Photometric method was employed to determine the turbidity of samples. A 25mL of the sample was measured with a measuring cylinder and poured into a clean cell; the cell was carefully cleaned with tissue paper before placed into the instrument light cabinet and covered with the light shield. The stable turbidity reading was recorded in f Nephelometric Turbidity Units (APHA, 2005).

3.4.3. pH

The pH was measured with a pH meter immediately after collecting the water sample into the plastic container. Enough samples were collected so that the tip of the probe could be submerged. The probe was rinsed with distilled water before placing it in the sample to take the readings (APHA, 2005).

3.4.4 BOD

Principle

The dilution method was employed in the determination of the BOD. An airtight BOD bottle of size 300ml was filled with the sample till it overflowed. The sample was corked and incubated at 20°C for five days. The dissolved oxygen concentration was measured before and after the incubation. BOD was calculated from the difference between the initial and final DO (APHA, 2005).

Procedure

Dilution water was prepared by adding 1ml each of phosphate buffer; $MgSO_4$, $CaCl_2$, $FeCl_3$ reagents into 1 L volumetric flask and topping it up to the mark. A10 ml of the sample was made up to 1 litre with the dilution water. The mixed dilution was siphoned into two BOD (300) bottles excluding air bubbles. One of the BOD (300ml) bottle was

corked and incubated for five days at 20°C. To the other BOD bottle, 2ml of Manganous sulphate ($MnSO_4$), followed by 2ml by 35 alkaline-iodide azide were added and bottle corked carefully to exclude air bubbles. The content was then mixed thoroughly by shaken and inverting several times and allowing the precipitate to settle at the bottom. After the precipitate has settled, 2ml concentrated sulphuric acid (H_2SO_4) was added, corked and inverted several times to dissolve the precipitate, an intense yellow colour was obtained. 100 ml of the solution was taken and titrated with Sodium thiosulphate to a pale yellow colour with 1ml starch as an indicator. The titration continued tilled the first disappearance of the colour. The above procedure was followed for the incubate samples at the end of the 5 days to determine the difference in DO for the computation of BOD as follows:

BOD_5, mg/l= (D1-D2)/P

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

D2= DO of diluted sample after 5 days incubation at 20°C, mg/l

P= decimal volumetric fraction of sample used (1/dilution factor)

3.4.5 COD (Open Reflux Method)

The sample, to be measured, was oxidized under reflux with a known amount of potassium dichromate in strong sulphuric acid with silver sulphate as a catalyst. Organic matter reduced part of the dichromate and the remainder was determined by titration with iron (II) ammonium sulphate (FAS) using ferroin as indicator. Interferences from chloride were suppressed by the addition of mercuric sulphate to the reaction mixture. The chemical oxygen demand (COD) was expressed as milligrams of oxygen absorbed from standard dichromate per litre of sample (APHA, 2005).

CALCULATION,

$$\text{COD (mg/ L)} = \frac{(A - B) \times M \times 8000}{\text{sample volume, mL}}$$

Where,

A = ml iron (II) ammonium sulphate (FAS) used for blank

B = ml FAS used for sample

M = molarity of FAS and

8000 = milli-equivalent of Oxygen x 1000 ml/ L

3.4.6 Nitrate

Photometric method was employed in the determination of the nitrate. The Nitratest Tube was filled with the sample to the 20 ml mark. One level spoonful of Nitratest Powder and one Nitratest tablet was added. The screw cap was replaced and the tube was shaken for one minute. The tube was allowed to stand for about one minute and gently inverted three times to aid flocculation. Tube was allowed to stand for 5 minutes to ensure complete settlement. The screw cap was removed and a clean tissue was used to wipe around the top of the tube. The clear solution was carefully decanted into a round test tube, filling to the 10 ml mark. One Nitricol tablet was crushed and added and mixed to dissolve. The mixture was allowed to stand for 10 minutes to allow full colour development. Wavelength of 570 nm on the Photometer was selected and the photometer reading was taken (APHA, 2005).

3.4.7 Colour

By visual comparison method

Apparatus BDH Lovibond Nesslerizer, colour disk, matched Nessler tubes 50 ml, tall form

Principle of Colour determination

Colour is determined by visual comparison of a sample with special glass colour disks, which have been calibrated.

Procedure

The Nessler tube was filled to the 50ml mark with the sample. The sample was placed in the right hand compartment of the Nesslerizer lighted cabinet. Nessler tube filled with distilled water was placed in the left hand compartment for reference. The colour disk was placed in the compartment. The Nesslerizer light was switched on. The disk rotated until a colour match was obtained and the colour was read from the disk. Since turbidity was not removed, it was recorded as apparent colour. When the colour exceeded 70 units, the sample was diluted and the colour was calculated as:

Colour (TCU) = (A x 50)/B

Where A = estimated colour of diluted

B = ml of sample taken for dilution

3.4.8 Conductivity

Method

Electrometric method with aid of Multi-parameter conductivity cell (probe) Type PCM/141 was employed in the determination of the conductivity.

Principle of Conductivity determination

At constant temperature, the electrical conductivity of a given water sample is a function of its concentration of ions. The probe was sensitive to the ionic charges in the solution. A factor that controls the current carrying of the water sample helps the meter provide a direct reading of the conductivity of the test sample.

Procedure

The conductivity cell was connected to the conductivity meter and the cell was rinsed thoroughly with a portion of the sample. The cell was inserted into the well shaken water samples Tano river that were collected from the locations of the and the conductivity value read on the display after the value has stabilized.

3.4.9 Phosphate (PO_4-P)

By stannous chloride method

Molybdophosphoric acid is formed and reduced by stannous chloride to intensely coloured molybdenum blue. The absorbance of the molybdenum blue at a wavelength of 690 nm was proportional to the concentration of the phosphate in sample.

Procedure

Standard phosphate solutions (KH_2PO_4) of known concentrations were prepared and absorbance read on the spectrophotometer for a calibration curve. 100 ml sample free of colour and turbidity was taken and 0.01 (1 drop) phenolphthalein indicators added. When the sample turned pink, strong acid solution (mixture of conc. and HNO_3) is added drop wise to discharge the colour. A smaller volume of the sample is taken if more than 0.25 ml (5 drops) is required, and the sample is then diluted to 100 ml with de-ionised water and then a drop of phenolphthalein indicator is add. The pink colour is discharged with strong acid. With thorough mixing 4.0 ml ammonia molybdate reagent 1[$(NH_4)6MO_7O_{24}.4H_2O$)] is added and 0.5 ml (10 drops) stannous chloride reagent 1 ($SnCl_2.H_2O$) is also added with thorough mixing. A blank solution is prepared using de-ionised water. After 10 minutes, but before 12 minutes, the absorbance at a wavelength of 690 nm is measured on the spectrophotometer using 1cm light path. The absorbance of the blank solution is determined by switching the spectrophotometer to zero. The calibration graph was used to determine the concentration of (PO_4-P) in the unknown sample.

3.4.10 Oil and Grease Determination (Partition- Gravimetric Method)

A 200 ml of sample was measured into a flask and acidified with Hydrochloric acid to pH 2 and transferred into a separatory funnel. The sampling bottle was carefully rinsed with 30 ml petroleum ether and solvent washings were added into a separatory funnel. The separatory funnel was shaken vigorously for 2 minutes and corked. The separating funnel was inverted and the pressure is released through the bottom. The shaking was

repeated and the pressure released until there was no more pressure built up in the separatory funnel. The separatory funnel was opened and hung upright to allow solvent to separate from the water sample.

The solvent layer was drained through a funnel containing solvent moistened filter paper into a clean-tarred evaporating dish when the layer separates. The extraction was repeated twice more with 30 ml solvent each. The extracts were combined in a tarred flask and the filter paper washed with additional 20 ml solvent. The solvent was distilled from a distilling flask on a water bath at 70°C till the flask was mainly due to oil and grease

CALCULATION

$$\text{Oil \& Grease (mg/ L)} = \frac{(A - B) \times 1000}{\text{sample volume, mL}}$$

Where A = total gain in the weight of the flask in grams

B = Solvent blank.

3.4.11 Total Suspended Solids (TSS)

Procedure

The gravimetric method was employed in the analysis of total suspended solids. A 50mL of a well-mixed sample was filtered through a weighed standard glass-fiber filter paper. The residue retained on the filter was then dried in an oven at 105°C for 1 hour.

It was then cooled in dessicator and weighed. The increase in weight of the filter represents the total suspended solids (APHA, 2005).

Calculation

The T.S.S was computed for using the formula below:

$$\text{mg total suspended solids/L} = \frac{(A - B) \times 1000}{\text{sample volume, mL}}$$

A = weight of filter + dried residue, mg, and

B = weight of filter, mg

3.4.12 Determination Iron and Calcium

Atomic Absorption Spectrophometer (AAS 220 Model) was used in determining the total concentrations of Iron and Zinc in the previously digested samples. The acetylene gas and compressor were fixed and compressor turned on and the liquid trap blown to rid off any liquid trapped. The Extractor was turned on and the AAS 220 power turned on (AOAC, 2006). The capillary tube and nebulizer block were cleaned with cleansing wire and opening of the burner cleaned with an alignment card.

The worksheet of the AAS software on the attached computer was opened and the hollow cathode lamp inserted in the lamp holder. The lamp was turned on ray from cathode aligned to hit target area of the alignment card for optimal light throughput, and then the machine was ignited. The capillary was placed in a 10 ml graduated cylinder containing deionized water and aspiration rate measured, and set to 6 ml per minute.

The analytical blank was prepared, and a series of calibration solutions of known amounts of analyte element (standards) were made. The blank and standards were

atomized in turn and their responses measured. A calibration graph was plotted for each of the solutions, after which the sample solutions were atomized and measured. Metal concentrations from the sample solutions were determined from the calibration, based on the absorbance obtained for the unknown (AOAC, 2006).

3.5 Microbiological parameters

3.5.1 Total and faecal coliforms

The Most Probable Number (MPN) method was used to determine total and faecal coliforms in the sample. Serial dilutions of 10^{-10} were prepared by picking 1 ml of the sample into 9 ml sterile distilled water. One milliliter aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth and incubated at 35°C for total coliforms and 44°C faecal coliforms for 18-24 hours. Tubes showing colour change from purple to yellow positive for both total and faecal coliforms. Counts per 100ml were from Most Probable Number (MPN) table (Obiri-Danso *et al.*, 2005).

3.5.2 E. coli (Thermotolerant Coliforms)

The most probable method was employed in the determination of *E. coli* in the water and effluent samples. From each of the position tubes identified a drop was transferred into a 5 ml test tube of trypton water and incubated at 44°C for 24 hours. A drop of Kovacs' reagent was then added to the tube of trypton water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and recorded as presumptive for thermotolerant coliforms (*E. coli*). Counts per 100ml were calculated from Most Probable Number (MPN) tables (Obiri-Danso *et al.*, 2005).

3.6 Statistical analysis

Data were presented in tables as means ± SD. All descriptive statistics were executed using the Graph Pad Prism 5 Software Version 5.00 (2007). In all cases, differences were considered significant at $p < 0.05\%$.

CHAPTER FOUR

4.0 RESULTS

4.1 Physico-chemical and microbiological parameters of the Tano River sampling locations.

The physico-chemical and microbiological parameters used to assess the quality of the Tano river (TR) samples were total soluble solids (TSS), turbidity, colour, temperature, alkalinity, pH, total dissolved solids (TDS), conductivity, hardness, calcium, iron, oil and grease, biological oxygen demand, (BOD) chemical oxygen demand (COD), sulphate, phosphate, nitrates, total coliform, feacal coliform, and *Escherichia Coli.* The mean values of three replicates at each sampling locations with standard deviations and their corresponding WHO drinking water guideline for the Tano River samples, and the percentage reductions of the contaminants levels of the Tano River from the upstream, midstream and downstream sampling locations are shown in Tables 4.1 and 4.2 respectively.

Table 4.1 Means and Standard Deviations of the physical-chemical and microbiological parameters from Tano river sampling locations and WHO drinking water quality standards from Feb. to May 2012.

	UP1	UP2	MS	DS1	DS2	WHO (2011)
TSS (mg/l)	37.00±3.00	20.17±1.77	24.58±1.30	16.25±2.62	11.67±0.58	200
Turbidity (NTU)	65.08±6.25	36.67±4.27	43.08±3.72	24.75±2.28	23.33±2.12	5
Colour (Pt/Co)	475.0±7.16	329.9±5.51	361.7±4.49	226.1±3.70	258.8±2.86	15
Temperature (°C)	27.21±4.52	25.03±3.64	26.19±1.43	24.68±3.32	24.98±2.86	40
Alkalinity (mg/l)	85.74±5.33	78.08±2.37	88.33±4.25	56.31±2.25	30.26±1.49	500
pH	6.65	7.21	6.44	6.46	6.62	6.5-8.5
TDS (mg/l)	96.92±4.91	77.00±2.85	87.42±3.94	71.83±2.53	44.17±2.97	1000
Conductivity (mg/l)	27.21±4.52	25.03±2.37	26.19±1.43	24.68±3.32	24.98±4.11	1500
Hardness (mg/l)	84.33±22.43	79.17±23.77	67.75±20.54	48.83±4.94	38.83±11.07	500
Calcium (mg/l)	9.23±4.02	7.22±3.03	9.13±3.67	10.06±3.46	4.00±0.86	
Iron (mg/l)	6.00±3.63	4.98±2.36	6.15±1.49	4.58±1.32	4.42±0.96	0.3
Oil & Grease (mg/l)	0.00±0.00	0.00±0.00	0.13±0.05	0.09±0.05	0.06±0.02	10
BOD (mg/l)	83.15±7.41	25.33±1.14	24.93±7.77	35.91±2.71	38.43±2.05	15
COD (mg/l)	129.50±5.90	65.75±3.84	75.83±3.28	107.90±8.17	120.30±8.40	10-20
Sulphate (mg/l	10.25±5.27	10.83±3.67	10.68±1.85	9.48±1.59	7.35±2.82	250
Phosphate (mg/l)	4.07±0.62	3.97±0.67	4.41±1.22	2.64±0.25	3.65±0.83	50
Nitrate (mg/l)	1.23±0.27	1.12±0.20	1.19±0.15	1.18±0.28	1.02±0.11	50
*Total Coliform	$12590\pm14.43\times10^{4}$	$14.00\pm1.83\times10^{2}$	$29.00\pm4.24\times10^{2}$	$311\pm4.13\times10^{3}$	$88\pm1.06\times10^{3}$	0
*Faecal Coliform	$110\pm2.08\times10^{3}$	$2.38\pm4.50\times10$	$4.70\pm5.20\times10^{1}$	$4.34\pm3.72\times10^{1}$	$3.86\pm3.90\times10^{1}$	0
*_Escherichia coli_	$6.20\pm1.93\times10^{1}$	$0.75\pm1.50\times10^{1}$	$0.30\pm4.24\times10^{1}$	$119\pm1.97\times10^{2}$	$0.51\pm4.62\times10^{0}$	0

*T.coliform $x10^5$ (TC/100CFUml) WHO Guidelines for Drinking-Water Quality
*F.coliform $x\ 10^5$ (FC/100mlCFU)
*E.coli $X10^5$ (EC/100mlCFU)

NB:The means of Total coliform, Feacal coliform, *E. coli* have their exponential figures below the table and the second figures attached to them are their standard deviations.

Table 4.2: Percentage reductions of the contaminants levels of the Tano River (TR) from upstream (UP1&UP2), midstream (MS) and the downstream (D1&D2) sampling locations from Feb. to May 2012

	UP1	%Reduction (UP1-UP2)	UP2	%Reduction (UP2-MS)	MS	%Reduction (MS-DS1)	DS1	%Reduction (DS1-DS2)	DS2
TSS (mg/l)	37.00	45.49	20.17	-21.86	24.58	33.89	16.25	28.18	11.67
Turbidity (NTU)	65.08	43.65	36.67	-17.48	43.08	42.55	24.75	5.74	23.33
Colour (Pt/Co)	475.0	30.55	329.9	-9.64	361.7	37.49	226.1	-14.46	258
Temperature (°C)	27.21	8.01	25.03	-4.63	26.19	5.77	24.68	-1.22	24.98
Alkalinity (mg/l)	85.74	8.93	78.08	-13.13	88.33	36.25	56.31	46.26	30.26
pH	6.65	-8.42	7.21	10.68	6.44	-2.80	6.46	2.42	6.62
TDS (mg/l)	96.92	20.55	77.00	-13.53	87.42	17.83	71.83	38.51	44.17
Conductivity (uS/cm)	27.21	8.01	25.03	-4.63	26.19	5.77	24.68	-1.22	24.98
Hardness (mg/l)	84.33	6.12	79.17	14.42	67.75	27.93	48.83	20.48	38.83
Calcium (mg/l)	9.23	21.78	7.22	-26.45	9.13	-10.19	10.06	60.24	4.00
Iron (mg/l)	6.00	17.00	4.98	-23.49	6.15	25.53	4.58	3.49	4.42
Oil & Grease (mg/l)	0.00	N/A	0.00	N/A	0.13	30.77	0.09	33.33	0.06
BOD (mg/l)	83.15	69.54	25.33	1.58	24.93	-44.04	35.91	-7.02	38.43
COD (mg/l)	129.50	49.32	65.75	-15.13	75.83	-42.29	107.90	-11.49	120.30
Sulphate (mg/l)	10.25	-5.66	10.83	1.39	10.68	11.24	9.48	22.47	7.35
Phosphate (mg/l)	4.07	2.66	3.97	-11.08	4.41	40.14	2.64	-38.26	3.65
Nitrate (mg/l)	1.23	8.94	1.12	-6.25	1.19	0.84	1.18	13.56	1.02
*Total Coliform	259099.6		14.00	-107.14	29.00	-972.41	311	71.70	88
*Faecal Coliform	110	97.84	2.38	-97.48	4.70	7.66	4.34	11.06	3.86
**Escherichia coli*	6.20	87.90	0.75	60.00	0.30	-39566.67	119	99.57	0.51

*T.coliform x10^5
*F.coliform x 10^5.
**E .coli* x 10^5

DISTANCE FROM A SOURCE TO A DESTINATION:
UP1-UP2=500m UP2-MS=460m MS-DS1=481m DS1-DS2=465m

Table 4.2 shows the percentage reductions, indicating the various attributes from a particular source to its destination. This indicates the dilution of the contaminants levels of the Tano River as it receives the GNL effluents and discharges from non-point sources of pollutants from the riparian settlements.

4.1.1 Total Soluble Solids (TSS)

The mean values of TSS of the Tano River samples ranged from 11.67 mg/l to 37.00 mg/l (Table 4.1). The highest mean value of 37.00 mg/l was recorded at UP1whereas the lowest value of 11.67 mg/l was recorded at DS1 location. The other mean values of 20.17 mg/l, 24.58 mg/l and 16.25 mg/l were recorded for UP1, MS, and DS2 respectively. All the mean values of the various sampling locations were below the WHO drinking water guideline of 200 mg/l. The highest percentage reduction of the TSS from UP1-UP2 was 45.49% whereas the lowest of 28.18% was recorded at DS1-DS2 indicating that the amount of total soluble solids (TSS) reduced as UP1 reaches UP2 and DS1 reaches DS2 were 45.49% and 28.18% respectively as shown in the Table 4.2.

4.1.2 Turbidity

The highest mean value was 65.08 NTU for UP1, whereas the lowest mean value recorded was 23.33NTU for DS1 (Table 4.1). The other mean values of 36.67NTU, 43.08 NTU and 24.75 NTU were recorded for UP2, MS, and DS2 sampling locations respectively. All the mean values recorded at the TR sampling locations exceeded the WHO drinking water quality guidelines of 5 NTU. The highest percentage reduction of turbidity recorded at UP1-UP2 was 43.65% whereas the lowest recorded at DS1-DS2 was 5.74 % (Table 4.2). Thus, percentage reductions recorded as UP1 reaches UP2 and DS1 reaches DS2 were 43.65% and 5.74% as depicted in Table 4.2.

4.1.3 Colour

The mean colour values ranged from 226.0 to 475.1 Pt/Co along the Tano River sampling locations (Table 4.1). The highest mean value of 475.1 Pt/Co was recorded at the UP1sampling locations whilst the lowest recorded mean was at the DS2 sampling locations. The other mean values were 329 Pt/Co, 361.7Pt/Co and 258.8 Pt/Co were recorded for UP2, MS and DS1 sampling locations (Table 4.1).The highest percentage reduction observed at MS-DS1 was 37.49% whilst the lowest percentage change was observed at UP1-UP2 was 30.55%. This shows that, the colour level reduced as the river flowed from MS to DS1 and from UP1 to UP2 as shown in Table 4.2

4.1.4 Temperature

The mean temperature values ranged from 27.21°C to 24.68°C along the TR sampling locations. The highest recorded mean value was 27.21°C at UP1 sampling location whereas the lowest mean of 24.68°C recorded at the DS1 sampling location. The other mean values were 25.03°C, 26.19°C and 24.98°C were recorded for UP2, MS, and DS2 respectively. All the mean values were below the WHO drinking water guideline of 40°C. The highest percentage reduction of 8.01% was observed at UP1-UP2 whereas the lowest of 5.77°C was recorded at MS-DSI (Table 4.2).

4.1.5 Alkalinity

The mean alkalinity values ranged from 88.33 mg/l to 30.26 mg/l along the TR sampling locations. The highest mean of 88.33 mg/l was recorded at the MS sampling location whereas the lowest of 30.26 mg/l was recorded at the DS2sampling location. The other mean values of 85.74 mg/l, 78.08mg/l and 56.31 mg/l were recorded for UP1, UP2, DS1 sampling locations respectively. All the mean values of the various sampling locations were below the WHO guideline of 500 mg/l(Table 4.1). The highest percentage reduction of alkalinity observed along the TR sampling location were at DS1-DS2 which was recorded as 46.26% whilst the lowest percentage reduction of 8.93% was observed at UP1-UP2 as shown in (table 4.2).

4.1.6 pH

The mean pH values sampling locations along the TR ranged from 7.21 to 6.44. The highest mean value of 7.21 was recorded at the UP1 and the lowest mean pH was recorded at MS sampling location. The other mean pH values of 6.65, 6.46 and 6.62 were recorded for UP1, DS1, and DS2 sampling locations. Apart from MS and DS1 mean pH values that were slightly below the WHO guideline range of 6.5-8.5. All the other mean pH of the UP1, UP2 and DS2 sampling locations were within the WHO guideline range of 6.5-8.5 as shown in table 4.1.The highest percentage reduction of 10.68% was recorded at the UP1-UP2 whilst the lowest percentage reduction of 2.42% was recorded at the DS1-DS2. This indicates that the pH level of the river reduced at 10.68% and 2.42% respectively (Table 4.2).

4.1.7 Total Dissolved Solids (TDS)

The mean TDS values ranged from 96.92 mg/l to 44.17 mg/l along TR sampling locations. The highest recorded mean was 96.92 mg/l at UP1 sampling location whilst the lowest recorded mean of 44.17 mg/l was at the DS2 sampling location. The other mean pH of 77.00 mg/l, 87.42 mg/l and 71.83 mg/l were recorded for UP2, MS and DS1 sampling locations (Table 4.1). All the mean values of the various sampling locations were below the WHO guideline values of 1000 mg/l(Table 4.1). The percentage reductions for TDS ranged from 17.83% to 38.51%. The lowest reduction of 17.83% was recorded as the TR flows from MS to DS1 with the highest recording of 38.51% as TR flows from DS1 to DS2 as shown in Table 4.2. This indicates that more dissolved solids were removed from the river as it flows downstream.

4.1.8 Conductivity

The mean conductivity ranged from 27.21 uS/cm to 24.68 uS/cm along the TR sampling locations. The highest value of 27.21uS/cm was recorded at the UP1 sampling location whereas the lowest value was recorded at DS2 sampling location. The other mean conductivity values of 25.03 mg/l, 26.19 mg/l and 24.98 mg/l were recorded for UP2, MS and DS1 sampling locations. All the mean values of the various sampling locations were below the WHO guideline values of 1500mg/l (Table 4.1). The highest percentage reduction recorded for conductivity was 8.01% at UP1-UP2 and the lowest reduction of 5.77% was recorded at MS-DS1 (Table 4.2).

4.1.9 Hardness

The water hardness revealed a decreasing trend throughout the study period. The mean values recorded ranged from 38.83 mg/l to 84.33 mg/l. The highest mean value of 84.33

mg/l was recorded at UP1 sampling location whereas DS2 sampling location recorded the lowest value of 38.83 mg/l. UP2, MS and DS1 recorded mean values of 79.17mg/l, 67.75mg/l and 48.83mg/l respectively. All the mean values of the various sampling locations were below the WHO drinking water quality guideline of 500 mg/l.

From Table 4.2 the highest percentage reduction of hardness was 27.93% at MS-DS1 whereas the lowest of 6.12% was recorded at UP1-UP2 indicating that the hardness reduced as UP1 reaches UP2 and MS reaches DS1.

4.1.10 Calcium

The mean values of calcium along TR sampling locations ranged from 10.00 mg/l to 4.06 mg/l. The highest mean value of 10.06mg/l was recorded at DS1 whereas the lowest mean value of 4.00 mg/l was recorded at DS2 location. The other mean values of 9.23 mg/l, 7.22 mg/l and 9.13 mg/l were recorded for UP1, UP2, and MS sampling locations respectively. The highest percentage reduction recorded for calcium was 60.24% at DS1-DS2 and the lowest reduction of 21.78% was recorded at MS-DS1 (Table 4.2).

4.1.11 Iron

The mean values of iron reduced from UP1 to UP2 but slightly showed an increase in MS and gently reduced again at DS1 and DS2. The mean values of iron ranged from 4.42 mg/l to 6.15mg/l. The MS sampling location recorded the highest mean value of 6.15mg/l whereas the lowest value of 4.42 mg/l was recorded at DS2 sampling location. The other mean values of 6.00 mg/l, 4.98 mg/l and 4.58 mg/l were recorded for UP1, UP2, and DS1 respectively. All the mean values recorded at the various sampling locations were above the WHO drinking water guideline of 0.3 mg/l as shown in Table 4.1. The iron level

along river Tano recorded the lowest value of 3.49% reduction at DS1-DS2 whilst the highest value of 25.53% reduction was recorded at MS-DS1 (Table 4.2).

4.1.12 Oil and Grease

Mean values of 0.00mg/l were recorded for both UP1 and UP2 sampling locations along the TR. However, the highest mean values of 0.13mg/l was recorded at MS sampling location whereas 0.09mg/l was recorded at DS1 sampling location with the lowest mean value of 0.06mg/l recorded at DS2 (Table 4.1). No values were recorded for oil and grease at UP1-UP2 and UP2-MS. However, the lowest percentage reduction of 30.77% was recorded at MS-DS1 while 33.33% reduction was recorded as the highest level at DS1-DS2 (Table 4.2).

4.1.13 BOD

The BOD levels along the TR at the various sampling locations generally decreased from UP1 to MS but increased slightly from DS1 to DS2. The mean values of BOD recorded ranged between 24.93mg/l and 83.15mg/l (Table 4.1). The highest mean value of 83.15mg/l was recorded at UP1 whilst the lowest mean value of 24.93mg/l was observed at MS. However, UP2, DS1, and DS2 recorded mean values of 25.33mg/l, 35.91mg/l, and 38.43mg/l respectively. BOD levels along the river revealed the lowest level in percentage reduction to be 1.58% at UP2-MS whiles UP1-UP2 recorded the highest level to be 69.58% reduction (Table 4.2).

4.1.14 COD

The mean values of COD of the Tano river samples ranged from 65.75 mg/l to 129.50 mg/l. The highest mean value of 129.50 mg/l was recorded at UP1 whereas the lowest

mean value of 65.75 mg/l was recorded at UP2 sampling location. However, mean COD values showed considerable increase of 75.83mg/l, 107.90mg/l, and 120.00 mg/l at MS, DS1, and DS2 respectively (Table 4.1). The COD level showed a percentage reduction of 49.32% only at UP1-UP2 (Table 4.2).

4.1.15 Sulphate

The mean sulphate values ranged from 7.35 mg/l to 10.83 mg/l along the TR sampling locations. The highest recorded mean value of 10.83 mg/l was observed at UP2 whereas the lowest mean value of 7.35 mg/l was recorded at DS2 sampling locations. The other mean values of 10.25 mg/l, 10.68 mg/l and 9.48 mg/l were recorded for UP1, MS, and DS1 respectively. All the mean values recorded were far below the WHO drinking water guideline value of 250 mg/l (Table 4.1). The highest percentage reduction of 22.47% was observed at DS1-DS2 whereas the lowest value of 1.39% was recorded at UP2-MS (Table 4.2).

4.1.16 Phosphate

The mean values recorded for phosphate ranged from 2.64mg/l to 4.41mg/l. The highest and lowest mean values of 4.41 mg/l and 2.64mg/l were recorded at MS and DS1 sampling locations respectively. Mean values of 4.07 mg/l, 3.97 mg/l, and 3.65 mg/l were recorded for UP1, UP2, and DS2 sampling locations respectively. The highest percentage reduction of 40.14% was recorded at MS-DS1 whereas the lowest value of 2.66% was recorded at UP1-UP2 (Table 4.2).

4.1.17 Nitrate

The mean nitrate values ranged from 1.02 mg/l to 1.23mg/l. The highest mean value of 1.23 mg/l was recorded at UP1 whereas sampling location DS2 recorded the lowest mean value of 1.02 mg/l. the sampling locations UP2, MS, and DS1 recorded mean nitrate values of 1.12mg/l, 1.19 mg/l, and 1.18mg/l respectively. All the mean values recorded for nitrate at the various sampling locations were below the WHO drinking water guideline value of 50 mg/l. The percentage reduction for nitrate ranged from 0.84% to 13.56%. The highest percentage reduction (13.56%) was observed at DS1-DS2 whiles the lowest (0.84%) reduction was observed at MS-DS1 (Table 4.2).

4.1.18 Total Coliforms (TC), Faecal Coliforms (FC) and Escherichia Coli (*E. coli*)

The mean TC was found to vary from 12590×10^4 to 14.0×10^2counts/100ml at the TR sampling locations. The highest recorded mean value was 12590×10^5counts/100ml UP1 sampling location whilst the lowest mean of 14.0×10^2counts/100ml at the UP2 sampling location.

A similar trend of result was observed for FC with mean values ranging from 110×10^5 to 2.38×10^5counts/100ml. The highest value of 110×10^5count/100 ml was recorded at theUP1 and the lowest mean of 2.38×10^5 count/100ml was recorded at the UP2 sampling locations. The other mean FC's of 4.70×10^5, 4.34×10^5 and 3.86×10^5count/100 ml were recorded for MS, DS1 and DS2 respectively(Table 4.1)

Escherichia coli (E. coli) determined along the TR was observed to vary from 119×10^5 to 0.30×10^5counts/100ml. The highest mean value of 119×10^5counts/100ml was recorded at

the DS1 sampling locations whilst the lowest mean value of 0.30×10^5counts/100 ml was recorded at MS sampling location. The other values of 6.20×10^5, 0.75×10^5 and 0.51×10^5counts/100mlwere recorded for UP1, UP2 and DS2 sampling locations respectively. The mean results obtained for TC, FC, and *E. coli* concentrations as indicated above were excessively higher compare to WHO water quality guideline of 0 counts/100ml. The total coliform in the TR recorded high percentage reduction of 99.6% at UP1-UP2 whereas a lower percentage reduction of 71.70% was recorded at DS1-DS2 (Table 4.2). The highest percentage reductions of 97.88% and 99.57% were recorded at UP1-UP2 and DS1-DS2 for faecal coliform and *E. coli* respectively while the lowest percentage reductions of 7.66% and 60.00% were recorded at MS-DS1 and UP2-MS for faecal coliform and *E. coli* respectively (Table 4.2).

4.2 Physico-chemical and microbiological parameters of the effluent from Ghana Nut Limited (GNL) and Asuotwe stream (AS) sampling locations

The physico-chemical and microbiological parameters used to assess the quality of the EFT from GNL and AS samples were total soluble solids (TSS), turbidity, colour, temperature, alkalinity, pH, total dissolved solids (TDS), conductivity, hardness, calcium, iron, oil and grease, biological oxygen demand (BOD),chemical oxygen demand (COD), sulphate, phosphate, nitrates, total coliform (TC), faecal coliform (FC), and *Escherichia coli*. The mean values with their standard deviations with the corresponding WHO drinking water guideline for the TR samples and the assimilative capacity of the TR from the upstream (UP1&UP2) midstream (MS) and downstream (DS1&DS2) sampling locations are shown in Tables 4.3 and 4.4 respectively.

Table 4.3 Comparison of the physico-chemical and microbiological quality of the AS and EFT with EPA effluent discharge standards and WHO drinking water quality standard

	AS	WHO (2011)	EFFLUENT	EPA Guideline value
TSS (mg/l)	**36.33±1.18**	200	**1242.00±12.1**	50
Turbidity (NTU)	**63.75±3.78**	5	**605.50**±42.50	75
Colour (Pt/Co)	**344.6±3.86**	15	**1367.0±21.12**	200
Temperature (^{0}C)	26.72±1.03		34.73±2.12	< 3(above ambient)
Alkalinity (mg/l)	80.61±3.22	500	**151.70±9.09**	150
pH	**6.18**	6.5-8.5	**5.68**	6-9
TDS (mg/l)	64.17±2.25	1000	145.4±5.15	1000
Conductivity (mg/l)	26.72±1.03	1500	34.73±9.09	1500
Hardness (mg/l)	101.20±2.66	500	90.92±7.62	
Calcium (mg/l)	11.60±2.12		5013.08±1.53	
Iron (mg/l)	**9.22±3.85**	**2**	**13.38**±9.09	2
Oil & Grease (mg/l)	0.15±0.31		**6.31±2.96**	5
BOD (mg/l)	**33.53±1.68**	**30**	**1292.00±10.80**	50
COD (mg/l)	95.42±4.88	10-20	**3156.00±24.56**	250
Sulphate (mg/l)	10.85±8.29	250	29.83±1.98	200
Phosphate (mg/l)	**3.47±0.46**		**5.97± 0.76**	2
Nitrate (mg/l)	1.85±0.8050		2.60± 0.3850	
Total Coliform/100CFUml	**112** x10^5=**2.08x10^3**	0	**3330** x10^5±4.34x10^5	400
Faecal Coliform/100mlCFU	**8.13** x10^5±1.10x10^2	0	**333** x10^5±4.35x10^3	
Escherichia coli/100mlCFU)	**0.79** x10^5±1.07x10^1	**0**	**81.3** x10^5±1.08x10^2	10

WHO Guidelines for Drinking-Water Quality
EPA-Ghana Effluent Quality Standard for Discharges into natural water bodies
The bolded figures are above the EPA guideline values.

Table 4.4: Percentage reduction of contaminant levels of the Asuotwe stream (AS) and Tano River discharge point (MS) sampling locations from Feb. to May 2012.

	EFT	EFT-AS	AS	AS-MS	MS
		% Reduction		% Reduction	
TSS (mg/l)	1242.00	**97.07**	36.33	**32.34**	24.58
Turbidity (NTU)	605.50	**89.49**	63.75	**32.42**	43.08
Colour (Pt/Co)	1367.0	**74.79**	344.6	**-4.96**	361.7
Temperature (^{0}C)	34.73	**23.06**	26.72	**1.98**	26.19
Alkalinity (mg/l)	151.70	**46.86**	80.61	**-9.58**	88.33
pH	5.68	**-8.80**	6.18	**-4.21**	6.44
TDS (mg/l)	145.4	**55.87**	64.17	**-36.23**	87.42
Conductivity (mg/l)	34.73	**23.06**	26.72	**1.98**	26.19
Hardness (mg/l)	90.92	**-11.31**	101.20	**33.05**	67.75
Calcium (mg/l)	13.08	**11.31**	11.60	**21.29**	9.13
Iron (mg/l)	13.38	**31.09**	9.22	**33.30**	6.15
Oil & Grease (mg/l)	6.31	**97.62**	0.15	**13.33**	0.13
BOD (mg/l)	1292.00	**97.40**	33.53	**25.65**	24.93
COD (mg/l)	3156.00	**96.98**	95.42	**20.53**	75.83
Sulphate (mg/l)	29.83	**63.63**	10.85	**1.57**	10.68
Phosphate (mg/l)	5.97	**41.88**	3.47	**-27.09**	4.41
Nitrate (mg/l)	2.60	**28.85**	1.85	**35.68**	1.19
Total Coliform (TC/100CFUml)	3330 x10^5	**99.66**	112 x10^5	**74.11**	29.00
Faecal Coliform (TC/100CFUml)	333 x10^5	**97.56**	8.13 x10^5	**42.19**	4.70
Escherichia coli (EC/100CFUml)	81.3 x10^5	**99.03**	0.79 x10^5	**62.03**	0.30

DISTANCE FROM A SOURCE TO A DESTINATION:
EFT-AS=500m AS-MS=204m

The measured parameters of the EFT were compared to EPA of Ghana standards for effluent discharge into surface waters as well as WHO drinking water quality standard to ascertain their wholesomeness (Tables 4.3 and 4.1). The extent of dilution of the Asuotwe stream (AS) was assessed as the Effluent (EFT) moves from its source to the discharge point (MS) along the Tano River (TR) (Table 4.4). Comparing the measured parameters of AS to the WHO (2011) standards for drinking water and the EFT discharge to the EPA (2007) standards the results illustrated below were obtained.

4.2.1 Total Suspended Solids (TSS)

The mean TSS levels of the AS and EFT sampling stations were found to be 36.33 mg/l and 1242.00 mg/l respectively compared to the WHO (2011) standards for drinking water and EPA (2007) effluent discharge guideline values of 200 mg/l and 50 mg/l respectively. The highest mean TSS level of the EFT sampling location was over 500 times higher than the effluent discharge guideline indicating high pollution levels of the effluents. The TSS mean level of the AS stream was, however, found to be lower than the WHO (2011) guideline for drinking water (Table 4.3). The highest percentage reduction of 97.07% was recorded at EFT-AS whereas the lowest value of 32.34% was recorded at AS-MS (Table 4.4).

4.2.2 Turbidity

The mean turbidity level recorded at AS sampling location was 63.75 NTU which was above the WHO (2011) drinking water quality guidelines value of 5 NTU. However, the mean turbidity value recorded for EFT was 605.50 NTU and higher than the EPA (2007) mean value of 5 NTU. The highest mean turbidity value of 605 NTU was over 120 times

higher than the regulatory guideline value of the EPA (2007). The highest percentage reduction of 89.49% was recorded at EFT-AS whereas the lowest value of 32.42% was recorded at AS-MS.

4.2.3 Colour

The mean colour levels recorded at both AS and EFT sampling locations were 80.61 mg/l and 151.71mg/l respectively. The mean value of the EFT was found to be above EPA standard of 200mg/l. The percentage reduction for EFT-AS was 74.79%. However, there was percentage increment at AS-MS.

4.2.4 Temperature

The temperature levels recorded at both AS and EFT sampling locations were 26.72^{0}C and 34.73^{0}C respectively. However, the mean value of the AS was below WHO (2011) drinking water guideline of 40^{0}C whereas the mean value of EFT was also within EPA of Ghana standard of less than 3^{0}C above ambient temperature.

4.2.5 Alkalinity

The alkalinity levels recorded at both the AS and EFT sampling locations were 80.61 mg/l and 151.70mg/l respectively. The mean value for AS was found to be below the WHO (2011) drinking water quality guidelines value of 500 mg/l whereas the mean value for EFT was observed to be a slightly above the EPA (2007) effluent discharge guideline value of 150 mg/l. A percentage reduction of 46.86% was observed at EFT-AS (Table 4.4).

4.2.6 pH

The mean pH value of 5.68 recorded at the EFT sampling location was generally acidic and fell below the 6.5-8.5 range of the EPA (2007). However, a mean value of 6.18 which was within the acceptable range of6-9 of the WHO (2011) drinking water quality guidelines was recorded for the AS sampling location.

4.2.7 TDS

The mean TDS levels of the AS and EFT sampling stations were found to be 64.17 mg/l and 145.40 mg/l respectively compared to the WHO (2011) and EPA (2007) guideline values of 1000 mg/l each (Table 4.3). A percentage reduction of 55.87% was observed at EFT-AS (Table 4.4).

4.2.8 Conductivity

The conductivity levels recorded at both the AS and EFT sampling locations were 26.72 uS/cm and 34.73 uS/cm respectively which were below the WHO (2011) drinking water quality guidelines and EPA (2007) effluent discharge guideline value of 1500 uS/cm respectively. There was however, a percentage reduction of 23.06% and 1.98% at the EFT-AS and AS-MS respectively (Table 4.4).

4.2.9 Hardness

The hardness levels recorded at both the AS and EFT sampling locations were 101.20 mg/l and 90.92 mg/l respectively (Table 4.3). The mean value of AS recorded was observed to be below the WHO (2011) drinking water quality guidelines value of 500 mg/l. A percentage reduction of 33.05% was observed at AS-MS (Table 4.4).

4.2.10 Calcium

The calcium levels recorded at both AS and EFT sampling locations were 11.60mg/l and 13.08mg/l respectively. The mean value of AS recorded was observed to be below the WHO drinking water guideline of 50 mg/l. Although the EPA of Ghana standard for Ca was not found, the 13.08mg/l recorded was still on the high side. The highest the percentage of reduction of 21.29% was recorded at AS-MS whereas the lowest percentage was recorded at EFT-AS (Table 4.4).

4.2.11 Iron

Iron concentrations at the EFT sampling location recorded a mean value 13.38 mg/l whereas that of the AS sampling location recorded mean value of 9.22 mg/l. The iron concentrations at both sampling locations were several times above the EPA (2007) of Ghana standards of 2mg/l for effluent discharge as well as the WHO (2011) drinking water quality guideline values of 0.3mg/l respectively (Table 4.3). The highest percentage reduction of 33.30% was recorded at AS-MS whereas the lowest value of 31.09% was recorded at EFT-AS (Table 4.4).

4.2.12 Oil & Grease

The oil and grease levels recorded at both the AS and EFT sampling locations were 0.15mg/l and 6.31 mg/l respectively. The mean level recorded at the EFT sampling location was found to be slightly above the EPA (2007) standards for effluent discharge of 5 mg/l. A percentage reduction of 97.62% and 13.33% were observed at EFT-AS and AS-MS respectively (Table 4.4).

4.2.13 BOD

The BOD levels recorded at the AS and EFT sampling locations were 33.53 mg/l and 1292.00 mg/l respectively. The mean level recorded at the EFT sampling location was found to be several folds above the EPA (2007) standards for effluent discharge of 50 mg/l(Table 4.3). A percentage reduction of 97.40% and 25.65% were observed at EFT-AS and AS-MS respectively (Table 4.4).

4.2.14 COD

The COD levels recorded at both the AS and EFT sampling locations were 95.42 mg/l and 3156.00 mg/l respectively. The mean level recorded at the EFT sampling location was found to be several folds above the EPA (2007) standards for effluent discharge of 250 mg/l (Table 4.3). However, a percentage reduction of 96.98% was recorded for EFT-AS whereas 20.53% was recorded for AS-MS (Table 4.4).

4.2.15 Sulphate

The sulphate levels recorded at both the AS and EFT sampling locations were 10.85mg/l and 29.83mg/l respectively which were below the WHO (2011) drinking water quality guidelines value of 250mg/l and the EPA (2007) standards for effluent discharge of 200 mg/l respectively (Table 4.3). A percentage reduction of 63.63% and 1.57% were observed at EFT-AS and AS-MS respectively (Table 4.4).

4.2.16 Phosphate

The phosphate levels recorded at both the AS and EFT sampling locations were 3.47 mg/l and 5.97 mg/l respectively. The mean value recorded at the EFT sampling location was however, found to be approximately three folds higher than the EPA (2007) standard for

effluent discharge guidelines value of 2 mg/l. There was however, a percentage reduction of 41.88% recorded at the EFT-AS (Table 4.4).

4.2.17 Nitrate

The nitrate levels recorded at both the AS and EFT sampling locations were 1.85 mg/l and 2.60 mg/l respectively which were below the WHO (2011) drinking water quality guidelines value and the EPA (2007) standards for effluent discharge of 50 mg/l. A percentage reduction of 28.85% and 35.68% were observed at EFT-AS and AS-MS respectively (Table 4.4).

4.2.18 Total Coliform, Faecal Coliform and *Escherichia coli* (*E. coli*)

The TC levels recorded at both the AS and EFT sampling locations were 112 $x10^5$ counts/100ml and 3330 $x10^5$ counts/100ml respectively which were above the WHO (2011) drinking water quality guidelines value of 0 counts/100ml and the EPA (2007) standards for effluent discharge of 400 count/100ml respectively (Table 4.3). A percentage reduction of 99.66% and 74.11% were observed at EFT-AS and AS-MS respectively (Table 4.4).

The FC and *E. coli* levels recorded at both the AS and EFT sampling locations were 8.13 $x10^5$ counts/100ml, 0.79 $x10^5$ counts/100ml: and 333 $x10^5$ counts/100ml,81.3 $x10^5$ counts/100ml respectively. The mean values recorded at AS sampling location for FC and *E. coli* were above the WHO (2011) drinking water quality guidelines value of 0 counts/100ml whereas the mean value of *E. coli* recorded for the EFT sampling location was higher than the EPA (2007) standards for effluent discharge value of 10 count/100ml respectively(Table 4.4). There was a percentage reduction of 97.56% and 42.19%

observed at EFT-ASFC respectively and 99.03% and62.03% observed at EFT-AS and AS-MS for *E.coli* respectively (Table 4.4).

4.3 Spatial Variations in the Physico-chemical and Microbial Parameters

The mean physico-chemical and microbiological parameters were generally similar among all the sampling stations with the EFT sampling station recording significantly different concentrations and levels from the other sampling locations. Although the EFT location recorded higher temperature and colour levels compared to the other sampling locations, there were no significant spatial variations ($p>0.05$) among all the sampling locations. There were however significant differences ($p<0.05$) between the total suspended solids and turbidity values recorded at the EFT sampling location and the other locations.

Alkalinity levels recorded over the sampling period exhibited significant spatial variations ($p<0.05$) between the EFT sampling location and the other sampling locations. The pH recorded at the various sampling locations exhibited a similar spatial trend as the alkalinity, however, the UP2 and TS recorded pH levels that were significantly different ($p<0.05$). The mean TDS and conductivity levels measured at the various sampling stations were fairly similar with significant variations recorded only between TS and EFT, and between DS2 and EFT. Calcium levels at the various sampling stations also exhibited a similar trend over the sampling period.

Hardness and Iron and levels recorded at the sampling locations did not vary over a wide range with no significant spatial variations ($p>0.05$) among them. There were significant

differences ($p<0.05$) in the mean oil and grease concentrations recorded at the EFT sampling location and the other locations, with only the EFT sampling location recording measurable oil and grease concentrations over the four-month period.

With the exception of the EFT sampling location which recorded relatively very high levels of BOD and COD, the levels recorded at the other sampling stations were fairly similar among the other sampling stations. There were highly significant variations ($p<0.05$) between the levels of COD and BOD recorded at the EFT location and the other sampling locations over the four-month period.

Although the EFT sampling location comparatively recorded higher sulphate and nitrate concentrations, there were no significant variations ($p>0.05$) among the sampling locations over the sampling period. Mean sulphate concentrations on the other hand exhibited significant spatial variation between the EFT sampling location and the other sampling stations.

Although there were observed differences in the studied microbiological loads of the different sampling locations over the study period, there were no statistical differences ($p>0.05$) in the mean counts recorded at the different stations. Spatially, however the EFT sampling location generally recorded the highest total coliform, faecal coliform and *E. coli*. loads over the sampling period.

Tables 4.5 and 4.6 show the summary of the statistical analysis showing the results of the Tukey's Multiple Comparison Tests to test for the spatial variations in the physico-chemical and microbiological parameters.

Table 4.5 The Results of the Tukey's Multiple Comparison Tests for the physico-chemical parameters of GNL's Effluent, Asuotwe stream and Tano river water samples from Feb. to May, 2012.

	UP1	UP2	MS	TS	DS1	DS2	EFT
Physico-chemical parameters							
TSS (mg/l)	37.00±3.00^{a}	20.17±1.77^{a}	24.58±1.30^{a}	36.33±1.18^{a}	16.25±2.62^{a}	11.67±0.58^{a}	1242.00±12.1^{b}
Turbidity	65.08±6.25^{a}	36.67±4.27^{a}	43.08±3.72^{a}	63.75±3.78^{a}	24.75±2.28^{a}	23.33±2.12^{a}	605.50±42.00^{b}
Colour	475.0±7.16^{a}	329.9±5.51^{a}	361.7±4.49^{a}	344.6±3.86^{a}	226.1±3.70^{a}	258.8±2.86^{a}	1367.0±21.12^{b}
Temperature	27.21±4.52^{a}	25.03±3.64^{a}	26.19±1.43^{a}	26.72±1.03^{a}	24.68±3.32^{a}	24.98±4.11^{a}	34.73±2.12^{a}
pH	6.65^{a}	7.21^{b}	6.44^{a}	6.18^{a}	6.62^{a}	6.46^{a}	5.68^{c}
Alkalinity	85.74±5.33^{a}	78.08±2.37^{a}	88.33±4.25^{a}	80.61±3.22^{a}	56.31±2.25^{a}	30.26±1.49^{a}	151.70±9.09^{b}
TDS	96.92±4.91^{a}	77.00±2.85^{a}	87.42±3.94^{a}	64.17±2.25^{ab}	71.83±2.53^{a}	44.17±2.97^{ab}	145.40±5.15^{ac}
Conductivity	27.21±4.52^{a}	25.03±2.73^{a}	26.19±1.43^{a}	26.72±1.03^{a}	24.68±3.32^{a}	24.98±4.11^{a}	34.73±9.09^{b}
Hardness	84.33±22.43^{a}	79.17±23.77^{a}	67.75±20.54^{a}	101.20±2.66^{a}	48.83±4.94^{a}	38.83±11.07^{a}	90.92±7.62^{a}
Calcium	9.23±4.02^{a}	7.22±3.03^{a}	9.13±3.67^{a}	11.60±2.12^{ab}	10.06±3.46^{a}	4.00±0.86^{ab}	13.08±1.53^{ac}
Iron	6.00±3.63^{a}	4.98±2.36^{a}	6.15±1.49^{a}	9.22±3.85^{a}	4.58±1.32^{a}	4.42±0.96^{a}	13.38±9.09^{a}
Oil & Grease	0.00±0.00^{a}	0.00±0.00^{a}	0.13±0.05^{a}	0.15±0.31^{a}	0.09±0.-5^{a}	0.06±0.02^{a}	6.31±2.96^{b}
BOD	83.15±7.41^{a}	25.33±1.14^{a}	24.93±7.77^{a}	33.53±1.68^{a}	35.91±2.71^{a}	38.43±2.05^{a}	1292.00±10.80^{b}
COD	129.50±5.90^{a}	65.75±3.84^{a}	75.83±3.28^{a}	95.42±4.88^{a}	107.90±8.17^{a}	120.30±8.40^{a}	3156.00±24.56^{b}
Sulphate	10.25±5.27^{a}	10.83±3.67^{a}	10.68±10.85^{a}	10.85±8.29^{a}	9.48±1.59^{a}	7.35±2.82^{a}	29.83±1.98^{b}
Phosphate	4.07±0.62^{a}	3.97±0.67^{a}	4.41±1.22^{a}	3.47±0.46^{a}	2.64±0.25^{a}	3.65±0.83^{a}	5.97±0.76^{b}
Nitrate	1.23±0.27^{a}	1.12±0.20^{a}	1.19±0.15^{a}	1.85±0.80^{a}	1.18±0.28^{a}	1.02±0.11^{a}	2.60±0.38^{b}

Mean ± SD (in the same row) with different letters in superscript differ significantly ($p<0.05$)

Table 4.6 The Results of the Tukey's Multiple Comparison Tests for the microbiological parameters of GNL's Effluent, Asuotwe Stream and Tano River water samples from Feb. to May, 2012.

	UP1	UP2	MS	AS	DS1	DS2	EFT
Microbiological Parameters							
Total Coliform	$2.59\times10^{8}\pm 14.43\times10^{4\,a}$	$1.43\times10^{6}\pm 1.83\times10^{2\,a}$	$2.92\times10^{6}\pm 4.24\times10^{2\,a}$	$1.12\times10^{7}\pm 2.08\times10^{3\,a}$	$3.11\times10^{5}\pm 4.13\times10^{3\,a}$	$8.81\times10^{5}\pm 1.06\times10^{3\,a}$	$3.33\times10^{9}\pm 4.34\times10^{4\,b}$
Faecal Coliform	$1.10\times10^{7}\pm 2.08\times10^{3\,a}$	$2.38\times10^{5}\pm 4.50\times10^{3\,a}$	$4.7\times10^{5}\pm 5.20\times10^{1\,a}$	$8.13\times10^{5}\pm 1.10\times10^{2\,a}$	$4.34\times10^{5}\pm 3.72\times10^{1\,a}$	$3.86\times10^{5}\pm 3.90\times10^{1\,a}$	$3.33\times10^{7}\pm 4.35\times10^{5\,b}$
Escherichia coli	$2.62\times10^{5}\pm 1.93\times10^{3\,a}$	$7.50\times10^{3}\pm 1.50\times10^{1\,a}$	$3.02\times10^{4}\pm 4.24\times10^{0\,a}$	$7.93\times10^{4}\pm 1.07\times10^{1\,a}$	$1.19\times10^{5}\pm 1.97\times10^{2\,a}$	$5.09\times10^{4}\pm 4.62\times10^{0\,a}$	$8.13\times10^{5}\pm 1.08\times10^{2\,a}$

Mean ± SD (in the same row) with different letters in superscript differ significantly ($p<0.05$)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Physico-chemical and microbiological parameters of Tano River

Over the last years, in many African countries a considerable population growth has taken place, accompanied by a steep increase in urbanization, industrial and agricultural land use. This has entailed a tremendous increase in discharge of a wide diversity of pollutants to receiving water bodies and has caused undesirable effects (such as stench, outgrowth of algae and colouration) on the different components of the aquatic environment (Saad *et al.*, 1984). The effects of the untreated effluents from the Ghana Nuts Limited (GNL) appear to have had an adverse effect on the water quality of the adjoining stream (AS) and downstream sampling locations (DS1&DS2). The physico-chemical and microbiological parameters used to assess the quality of the Tano river (TR) are discussed in this section:

5.1.1 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) is a common measure of water quality and refers to all suspended particulate matter in water column. Domestic wastewater usually contains large quantities of suspended solids that are organic and inorganic in nature. Total Suspended Solid (TSS) is a solid in water that can be trapped by a filter. TSS includes a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. The mean values of TSS of the TR samples ranged from 11.67 mg/l (lowest) to 37.00 mg/l (highest). High TSS is indicative of poor water quality (Shaw,

2000), thus, all factors being equal, low TSS can be said as an indication of good water quality. The TSS levels were higher than regulatory limits at the UP1 sampling locations due to the adverse impacts of the anthropogenic activities which introduce solid matter at this location. This in turn poses threat on human, animal and aquatic life.

According to LVEMP (2002), the discharge of industrial and domestic wastewater with a high TSS level could have adverse impact on aquatic life. This is because the high TSS can cause an increase in surface water temperature as well as reduction in dissolved oxygen levels (Mitchell and Stapp, 1992). This could reduce the aquatic animals' population. The highest percentage reduction of the TSS from UP1-UP2 was 45.49% whereas the lowest of 28.18% was recorded at DS1-DS2, which implies that, the highest clean up of TSS occurred from UP1 to UP2 which is attributed to differences in the level of anthropogenic activities along these sampling locations whereas the lowest clean up recorded from D1to D2 was due to the fact that there was not much difference in the anthropogenic activities along the D1 and D2 sampling locations.

5.1.2 Turbidity

Turbidity is caused by suspended and colloidal particulate matter such as clay, silts, finely divided organic and inorganic matter, plankton and other microscopic organisms. It is another factor use to indicate the water quality of natural waters with respect to colloidal and residual suspended matter (Lamb, 1985). The high value of turbidity recorded at the sampling locations, especially at the UP1 sampling location agrees to a work done by Lamb (1985) which was attributed to factors such as the presence of clay,

silt, organic matter, algae and other microorganisms as the causes of high turbidity recorded. All the mean values recorded at the TR sampling locations exceeded the WHO drinking water quality guidelines of 5 NTU. The highest percentage reduction of turbidity recorded at UP1-UP2 whereas the lowest recorded at DS1-DS2.This was attributed to the differences in the anthropogenic activities along the sampling locations which resulted in the efficient clean-up as the river flows from UP1 to UP2, and a poor clean-up as it flows from DS1 to DS2.

5.1.3 Colour

Colour in natural waters can originate from decomposition of organic matter and discharge of certain waste with contaminants of different materials and in varying concentrations. Colour interfere with penetration of light and affects photosynthesis. It may also hamper oxygen absorption from the atmosphere (Walakira, 2011). All the mean values were above WHO (2011) drinking water quality guideline of 200 Pt/Co. The higher mean values recorded might be due to the contaminants of both domestic and industrial waste which constitute decomposed organic matter. The highest percentage reduction of colour recorded at MS1-DS1 (37.49 Pt/Co) whereas the lowest percentage was recorded at UP1-UP2 (30.55 Pt/Co). The difference in colour reduction is as a result of varying rate of pollution at the various sampling location as more organic waste from many non-points sources are discharged into the river as it travels from UP1 to UP2 than as it travels from MS to DS1.

5.1.4 Temperature

The temperature of surface waters is influenced by latitude, altitude, and season, time of day, air circulation, cloud cover and the flow and depth of the water body. In turn,

temperature affects physical, chemical and biological processes in water bodies and, therefore, the concentration of many variables. As water temperature increases, the rate of chemical reactions generally increases together with the evaporation and volatilization of substances from the water (Chapman, 1996). All the mean values were below the WHO drinking water guideline of 40°C. This might be due to the loss of heat by convection to the atmosphere. The highest percentage reduction of 8.01% was observed at UP1-UP2 whereas the lowest of 5.77°C was recorded at MS-DSI. The differences in the reduction rate were due to the abundant cloud cover, shade and air circulation along the UP1-UP2 sampling locations as compared to MS-DS1.

5.1.5 Alkalinity

The alkalinity of natural water is the measurement of the capacity of the water to neutralize acids which reflects its buffer capacity (inherent resistance to pH change). It is also noted that alkalinity of water has direct relation to the presence of bicarbonates formed in reaction in the soils through which the water percolates (Chapman, 1996). According to Ireland EPA (2001), alkalinity is involved in the consequential effect of eutrophication of waters. Though the mean value range from 88.33mg/l to 30.26mg/l, all the recorded mean values were below the WHO drinking water guideline of 500mg/l which might be attributed to the effluent discharge and pH reduction by atmospheric and other acidic depositions (Chapman, 1996). A percentage reduction of 46.26% was recorded as the river flows from D1 to D2. Thus, it is attributed to the high dilution rate of the river as the water flows from a point of high acidic content to a point with low acidic content.

5.1.6 pH

The pH of an aquatic ecosystem is important because it is closely linked to biological productivity. Although the tolerance of individual species varies, pH values between 6.5 and 8.5 usually indicate good water quality and this range is typical of most major drainage basins of the world. The general pH levels recorded from TR sampling locations were, however, slightly acidic at most of the sampling stations, except for the UP2 sampling station which was relatively undisturbed by anthropogenic activities. The other sampling locations had relatively different levels of human influence with the UP1 sampling locations showing the most noticeable human impacts. According to Agedengbe (2003), the pH of food processing industries effluents shows that effluents from food usually tend to be acidic. The low pH levels at the point of discharge (MS) and the downstream (DS1 and DS1) sampling locations is probable due to effluent discharges from food processing industries of which the raw materials are made of acidic enzymes, lactic acid, benzoic acid and yeasts that are discharge into the stream close to the Tano river (Chennakrishnan, 2008). According to Matovu, (2010), the pH of surface water bodies receiving effluent discharged, can be decreased by the carbon dioxide released by the bacteria breaking down the organic wastes. Carbon dioxide dissolves in water to form carbonic acid. Although this is a weak acid, large amounts of it will lower the pH and when waters with low pH values come into contact with certain chemicals and metals, this often makes them more lethal than normal (Matovu, 2010).

5.1.7 Total Dissolved Solids (TDS)

All the mean values of the various sampling locations were below the WHO guideline values of 1000 mg/l. The low TDS levels at all the sampling stations recorded was similar to the work done by Igbinosa and Okoh (2009) and Walakira (2011) who studied the impacts of industrial effluents on receiving streams in South Africa and Uganda respectively. Walakiri (2011) attributed the low TDS levels at his sampling stations to the dilution effect and other natural processes along the stream.TDS cause toxicity through increases in salinity, changes in the ionic composition of the water, and Toxicity of individual ions. The lowest reduction of 17.83% was recorded as the TR flows from MS to DS1 with the highest recording of 38.51% as TR flows from DS1 to DS2 as shown in Table 4.2. This indicates that more dissolved solids were removed from the river as it flows downstream.

5.1.8 Conductivity

All the mean values of the various sampling locations were below the WHO guideline values of 1500mg/l. The low results recorded in all the sampling locations may be attributed to the river being a lotic system and for that matter; there is continuous recharge into the river either in the form of precipitation or from the adjoining Asuotwe stream. It could also be as a result of low concentrations of dissolved ions present in the water and the effluent. Municipal, agricultural, and industrial discharges can contribute ions to receiving waters or can contain substances that are poor conductors (organic compounds) changing the conductivity (Stoddard *et al.*, 1999) of the Tano river. The highest percentage reduction recorded for conductivity was at UP1-UP2 and the lowest

reduction was recorded at MS-DS1 (Table 4.2).The difference in conductivity reduction is as a result of varying rate of pollution at the various sampling location as more municipal, agricultural and domestic waste from many non-points sources are discharged into the river as it travels from at the UP1 to UP2 than as it travels from MS to DS1.

5.1.9 Hardness

Hardness of water is the measure of the soap-consuming power of the water. Very hard water can cause household pipes choking, scaling, and incrustations on cooking utensils (APHA, 2005).The hardness of the water revealed a decreasing trend throughout the sampling locations from 84.33mg/l to 38.83mg/l. Though all the mean values were below the WHO guideline of 500mg/l. The highest value of 85.33mg/l recorded at UP1 might be due to the fact that UP1 being the major recipient of domestic effluents whereas 38.83mg/l recorded as the DS2 was due to the low recipient of domestic effluent at the sampling location. The highest percentage reduction of 27.93% at MS–D1 is accounted for by the high dilution rate and the low discharge of domestic effluent at that point whereas the lower percentage reduction of 6.12% is due to the high and continuous discharge of domestic effluent at the point.

5.1.10 Calcium

Waters associated with granite or siliceous may contain less than 10mg/l of calcium whereas those with gypsiferious shale may contain 100mg (APHA, 2005). The mean values of calcium ranged from 10.0mg/l to 4.06mg/l, though the WHO drinking water

quality was not found. The value indicates that the water sample of TR at the Techiman portion is associated with granite and siliceous. High level of calcium can result in hardness of water leading to scales of cooking utensils (APHA, 2005).The highest percentage reduction of 60.24% at DS1-DS2 and the lowest reduction of 21.78% at MS-DS1 were recorded. This might be attributed to the high amount of calcium contained in the EFT that joins MS and the differences in the geochemical properties of the sediments beneath the water.

5.1.11 Iron

According to Ram *et al.,* (2011), the Indus basin aquifers have been evidenced to be iron contaminated, thus high amount of iron content on surface waters were linked to geochemical properties of the sediment beneath the surface waters. The mean value of iron ranged from 4.42mg/l to 6.15mg/l. The increase in the iron concentrations of the sampling locations along the Tano river are attributed to factors such as discharge of industrial and domestic waste and the geochemical properties of the sediments beneath the surface water. The highest percentage of reduction was recorded at AS-MS sampling locations might have been influenced by the constant flushing of the stream and the clear water samples

5.1.12 Oil and Grease

Oil and grease are general terms used to describe crude or refined petroleum products, as well as biological lipids and hydrocarbons (US EPA, 1999). No values for oil and grease were recorded at both upstream (UP1 and UP2) locations. This is obvious for the fact that these two locations are located far away from the point of discharge where effluent from the Nut industry enters the river. However, the values of the Tano River (TR) from the

midstream (MS) through downstream (DS) showed the following trend: MS > DS1 > DS2. The trend was as a result of the clean-up by the Tano River as it runs from the effluent discharge point (midstream) to the downstream of the river. Oil and grease have several effects on aquatic organisms in a number of ways. These include killing directly through coating and asphyxiation, contact poisoning, or through exposure to water-soluble components, destruction of more sensitive juvenile life-stages or through the reduction of prey species (Carr and Neary, 2008). Wake, (2005) reported that reductions in diversity and abundance of aquatic fauna have been associated with oil-laden refinery effluents.

5.1.13 BOD

The BOD levels along the TR at the various sampling locations generally decreased from UP1 to MS but increased slightly from DS1 to DS2. The mean values of BOD recorded ranged between 24.93mg/l and 83.15mg/l (Table 4.1).The high levels recorded at the UP1, DS2 sampling locations is indicative of a heavy load of organic and inorganic pollution that require more oxygen to oxidise under increased thermal conditions as was observed by Koushik and Saksena, (1999). The increased BOD levels could be attributed to domestic sewage and industrial effluent from the activities of GNL as well as organic contaminant entering the systems from the environment.BOD levels along the river revealed the lowest level in percentage reduction at UP2-MS whiles UP1-UP2 recorded the highest level(Table 4.2). The differences might be attributed to the fact that more organic and inorganic wastes are discharged at UP1 than UP2 to MS

5.1.14 COD

The high COD levels recorded at the UP1, DS2 sampling locations is indicative of a heavy load of organic and inorganic pollution that require more oxygen to oxidise under increased thermal conditions as was observed by Koushik and Saksena, (1999). The increased COD levels could be attributed to domestic sewage as well as the industrial effluent emanates from the activities of GNL as well as organic contaminant entering the systems from the environment. The COD recorded a percentage reduction of 49.32% only at UP1-UP2 which can be attributed to differences in anthropogenic activities along UP1 and UP2 sampling locations.

5.1.15 Sulphate

The sulphate level in the various sampling locations varied from upstream (UP1) through the midstream (MS) to downstream (DS). However, higher value recorded at the MS could be as a result of the direct entry of the Asuotwe stream which carries effluent from the Nut industry. This might imply higher dissolved sulphate solutes in the effluent than the stream samples. These high values of sulphate in MS did not influence the value of the downstream probably due to natural ability (22.47% reduction) of the river to recover from the impact of pollution.

5.1.16 Nitrate and Phosphate

The nitrate and phosphate levels in the water samples from the River is likely to be a direct consequence of agricultural activities, wastewater disposal and oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. The observed agricultural activities around the River are however, usually limited to small scale holdings and subsistence agriculture, with very little agrochemical use thus possibly

explaining the low nitrate and phosphate levels in the water. According to WHO (2011), surface water nitrate concentrations can also change rapidly owing to uptake by phytoplankton and denitrification by bacteria. The nitrate recorded highest reduction rate (8.94) at UP1-UP2 whereas the phosphate recorded the highest reduction at (40.14%) at MS-DS1. The reduction of nitrate pollutant might be as a result of differences in anthropogenic activities along UP1 and UP2 sampling locations as heavy load of domestic and sewage waste are released into the river at UP1 than UP2. The phosphate reduction from MS to DSI is as a result of the rivers natural ability to recover from the EFT which joins the river at MS.

5.1.17 Total Coliforms (TC), Faecal Coliforms (FC) and *Escherichia Coli* (*E. coli*)

Measurement of coliforms have been identified that they are easy to monitor and correlate with populations of pathogenic organisms. The coliform bacteria group is one of the most common indicator organisms. Coliforms are frequently monitored as total or faecal coliforms. Total coliform (TC) is defined as a large group of anaerobic, non-spore forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C (Chapra, 1997). *E. coli* is a common member of this group. Some pathogens enter the human body through the skin but more commonly they are ingested with drinking water. Faecal coliform (FC) is a subset of TC that comes from the intestines of warm-blooded animals (Chapra, 1997).

The extremely high levels of TC, FC and *E.coli* loads recorded at the UP1 sampling location which has the highest human population density lends credence to the fact that there are high numbers in human and animal faeces, sewage and water subject to recent faecal pollution. The lack of basic sanitary conditions of some of the riparian settlements and the absence of GNL's waste treatment plant, have led to sewage outfalls which are evidenced by the highly measurably microbiological loads in the TR. According to WHO (2011), most waterborne pathogens are introduced into drinking-water supplies in human or animal faeces. FC and *E. coli* are present in very high numbers in human and animal faeces and are rarely found in the absence of faecal pollution, although there is some evidence for growth in tropical soils (WHO, 2011). *E. coli* and FC are considered the most suitable indicators of faecal contamination in surface waters (WHO, 2011). The relatively higher loads in the effluent samples could be as a result of the EFT serving as a very suitable media for the growth of bacteria populations since the raw material for the manufacturing process are made of organic and inorganic substances such as enzymes and yeast which serves as a good substrate for microbial growth.

5.2 Physico-chemical and microbiological parameters of the Ghana Nut effluent and the Asuotwe stream.

5.2.1 TSS

Total Suspended Solids (TSS) are solids in water that can be trapped by a filter which include a wide variety of material, such as silt, decaying plant and animal matter,

industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life (Mitchell and Stapp, 1992).

The high level of TSS may be due to the adverse impacts of the domestic and industrial activities at the EFT and AS sampling locations. According to LVEMP (2002), the discharge of industrial and domestic wastewater with a high TSS level could have adverse impact on aquatic life. The lower level of TSS recorded at AS may be as result of the high assimilative capacity of the stream dissolving most of the solids. The industrial effluents entering the TR and its feeder stream, AS, were observed to be in both solid and liquid forms chiefly derived from the industrial activities of the GNL and agricultural activities. As a result, the TR which is a major receptacle of the untreated industrial wastes has become relatively polluted with respect to total soluble solids. The highest reduction of TSS pollutant was recorded at (EFT-AS) whereas the lowest was recorded at AS-MS (32.34%). The reduction in the level of the TSS might be due to the dilution by the fresh water stream that receives the effluent discharges as it travels from the GNL premises to join the Asuotwe Stream (AS).The lowest reduction could be attributed to high nutrients and/or soils debris from the nearby farmlands.

5.2.2 Turbidity

Turbidity indicates water quality of effluent and natural water with respect to colloidal and residual suspended matter. The high value of turbidity 605.50 mg/l at the EFT sampling locations is probably due to the presence organic particulate matter in the EFT from GNL. Turbidity affects aquatic life by interference with sunlight penetration. Water

plants need light for photosynthesis. If suspended particles block out light, photosynthesis and the production of oxygen, aquatic life will be reduced (Smith and Davies-Colley, 2001).

5.2.3 Colour

Colour in wastewater is an indication that it contains contaminants of different materials and in varying concentration. Colour interfere with penetration of light and affects photosynthesis. It may also hamper oxygen absorption from the atmosphere (Walakira, 2011). The mean value of the EFT colour was found to be above EPA standard of 200 Pt/Co whereas the mean value of the AS (344.6 Pt/Co) was higher than WHO (2011) guideline value of 15 Pt/Co. The higher mean values recorded for EFT and AS might be due to the contaminants of industrial waste emanating from Ghana Nuts Limited (GNL) which constitute decomposed organic matter. The percentage reduction for colour was recorded at EFT-AS was 74.79%. The reduction in the level of the colour might be due to the interference of light rays with colour of the effluent discharges and the dilution effect by the fresh water from the stream as the effluent travels from the GNL premises to join the Asuotwe Stream (AS).

5.2.4 Temperature

The temperature of the EFT was 34.73°C whilst the AS was recorded as 26.72°C. Although the temperature of effluent was higher than the River water temperature (24.68°C - 27.21°C), it does not appear to pose any threat to the homeostatic balance of the receiving water body in conformity with the reports of Jaji *et al.*,(2007) and Igbinosa and Okoh (2009). The high temperature of EFT is probably due to the heating process

associated with processing of nut and refining of edible oil by their solvent extraction facilities and refinery plants. The highest percentage reduction of temperature was recorded at EFT-AS (23.06%) which can also attributed to the high heating associated manufacturing process that releases the effluent.

5.2.5 Alkalinity

The alkalinity is the measurement of the capacity of the liquids to neutralize acids which reflects its buffer capacity (inherent resistance to pH change). According to Ireland EPA (2001), alkalinity is involved in the consequential effect of eutrophication of waters and wastewaters. The mean value for AS (80.61 mg/l) was found to be below the WHO (2011) drinking water quality guidelines value of 500 mg/l whereas the mean value for EFT (151.70 mg/l)was observed to be a slightly above the EPA (2007) effluent discharge guideline value of 150 mg/l. The low alkalinity levels recorded at AS was as a result of the stream been a receptacle of the GNL industrial discharges which serves as a acidic disposition whereas the slightly high alkalinity can be attributed to the presence of ions such as bicarbonate which might have been resulted from the reaction from organic and inorganic substances used in the manufacturing processes. A percentage reduction of 46.86% was observed at EFT-AS. This might be due to the interferences with the other acidic conditions with the effluent alkaline conditions as it travels from the GNL premises to join the Asuotwe Stream (AS).

5.2.6 pH

The pH of an aquatic ecosystem is important because it is closely linked to biological productivity. The mean pH value of the EFT of 5.68 in this study was fairly similar to the mean level recorded by Kayima and Kyakula, 2008 (5.07±0.14) in their study of the effects of oil mill effluent on the Nakivubo Channel in Uganda. According to Agedengbe *et al.,* (2003), the pH of food processing industries effluents shows that effluents from food usually tend to be acidic. The low pH levels in effluent from food processing industries could be due to the raw materials such acidic enzymes, lactic acid, benzoic acid and yeasts that are mainly used by food industry (Chennakrishnan *et al.*, 2008). The slightly acidic pH levels of 6.18 at AS sampling location observed in this study is probably due to the effluents from Ghana Nuts Limited containing organic waste which is discharged into the stream. Also the high pH of AS compared to the EFT may be as a result of dilution effect from the AS water.

According to Matovu, (2010), the pH of surface water bodies receiving effluent discharged, can be decreased by the carbon dioxide released by the bacteria breaking down the organic wastes. Carbon dioxide dissolves in water to form carbonic acid. Although this is a weak acid, large amounts of it will lower the pH and when waters with low pH values come into contact with certain chemicals and metals, this often makes them more lethal than normal.

5.2.7 TDS

The mean TDS levels of the AS and EFT sampling stations were found to be 64.17 mg/l and 145.40 mg/l respectively compared to the WHO (2011) and EPA (2007) guideline values of 1000 mg/l each. The total dissolved solids (TDS) levels at AS and EFT

sampling locations were generally within permissible limits, similar to the findings of Igbinosa and Okoh (2009) and Walakira (2011) who studied the impacts of industrial effluents on receiving streams in South Africa and Uganda respectively. Walakiri (2011) attributed the low TDS levels at his sampling stations to the dilution effect and other natural processes along the stream; hence the low TDS recorded can be attributed to his findings. A percentage reduction of 55.87% was observed at EFT-AS. This indicates that more dissolved solids were removed from the effluent as it flows from the GNL's premise to Asuotwe stream (AS).

5.2.8 Conductivity

Conductivity is a measure of the ability of water to conduct an electric current. It is sensitive to variation in dissolve solids mostly mineral salts. The degrees to which these dissociate into ion, the amount of electrical charge on each ion, ion mobility and the temperature of the system all have an influence on conductivity (Igbinosa and Okoh, 2009).Municipal, agricultural, and industrial discharges can contribute ions to receiving waters or can contain substances that are poor conductors (organic compounds) changing the conductivity (Stoddard *et al*., 1999) of water bodies. The low conductivity values of AS and EFT (compared to WHO and EPA limit of 1500mg/L each) could be attributed to low concentrations of dissolved ions present in the stream and the effluent. The highest percentage reduction of conductivity was recorded at EFT-AS (23.06 mg/l).This indicates that more dissolved solids were removed from the effluent as it flows from the GNL's premise to Asuotwe stream (AS).

5.2.9 Hardness

Hardness of water is the measure of the soap- consuming power of the water. Very hard water can cause household pipes choking, scaling, incrustations on cooking utensils (APHA, 2005).The hardness levels recorded at both the AS and EFT sampling locations were 101.20 mg/l and 90.92 mg/l respectively. The low levels of hardness recorded for both AS and EFT might be attributed to low levels of bicarbonates and carbonates of calcium and magnesium and probably boiling that is associated with the refinery facilities. A percentage reduction of 33.05% was observed at AS-MS is accounted for by the high dilution rate and the low discharge of domestic effluent at that point.

5.2.10 Calcium

Waters associated with granite or siliceous may contain less than 10mg/l of calcium whereas those with gypsiferious shale may contain 100mg/l. The mean value recorded at AS (11.60 mg/l) was observed to be below the WHO drinking water quality guideline of 50 mg/l. Although the EPA guidelines values for calcium were not found the mean value recorded at EFT (13.08 mg/l) can be said to be on low side. The low level of calcium in AS and EFT might be attributed to the low amount of calcium contained in the raw materials for the manufacturing processes and the difference in the geochemical properties (granite and siliceous materials) of the sediments beneath the water. The highest percentage reduction of calcium was recorded at AS-MS (AS-MS). This can be attributed to a dilution effect as the effluent joints the Tano River at the discharge point, MS.

5.2.11 Iron

According to Ram et al., (2011), the Indus basin aquifers have been evidenced to be iron contaminated, thus high amount of iron content on surface waters were linked to geochemical properties of the sediment beneath the surface waters. Iron concentrations at the EFT sampling location recorded a mean value 13.38 mg/l whereas that of the AS sampling location recorded mean value of 9.22 mg/l. The iron concentrations at EFT and AS sampling locations were several times above the EPA (2007) standards for effluent discharge as well as the WHO (2011) drinking water quality guideline values of 2 mg/l respectively. This might be attributed to the presence of a layout of cast iron tubes that carry the industrial discharges from the refinery tube to the drainage system that carries the effluents to the Asuotwe stream. The highest percentage reduction of 33.30% was recorded at AS-MS whereas the lowest value of 31.09% was recorded at AS. These differences in the reduction of iron pollutant level as the effluent travels to join the stream at AS are attributed to factors such as discharge of industrial and domestic wastes and the geochemical properties of the sediments beneath the water.

5.2.12 Oil and Grease

Oil and grease have several effects on aquatic organisms which include killing directly through coating and asphyxiation, contact poisoning, or through exposure to water-soluble components, destruction of more sensitive juvenile life-stages or through the reduction of prey species (Carr and Neary, 2008). Wake (2005) reported that reductions in diversity and abundance of aquatic fauna have been associated with oil-laden refinery effluents, but the effects on aquatic plants are less clear. Oil and grease are general terms used to describe crude or refined petroleum products, as well as biological lipids and

hydrocarbons (US EPA, 1999). The mean level recorded at the EFT sampling location was found to be slightly above the EPA (2007) standards for effluent discharge of 5 mg/l. The highest reduction of pollutants recorded at EFT-AS (97.62%) is as a result of degradation of the oily components of the effluents by sunlight and dilution of the effluent as the effluent joins the stream at AS. However the lowest reduction of pollutant recorded at AS-MS (13.33%) might be as a result of shaded cover surrounding AS and MS sampling locations.

5.2.13 BOD

Biological Oxygen Demand (BOD) is one of the most important parameters use to examine effluent quality since it reflect organic load in effluent. The BOD levels recorded at the AS and EFT sampling locations were 33.53 mg/l and 1292.00 mg/l respectively. The mean level recorded at the EFT sampling location was found to be several folds above the EPA (2007) standards for effluent discharge of 50 mg/l. A Biochemical oxygen demand was found to be excessively high at the EFT sampling station. The increased BOD level could be attributed to an increase in the addition of both organic and inorganic substance from the activities of Ghana Nuts Limited, as well as organic contaminant entering the systems from the environment. It therefore affects the quality of Tano River. A highest percentage reduction of BOD (97.40%) was observed at EFT-AS. This can be attributed to a dilution effect as the effluent joins the stream at AS which is influenced by constant flushing of the fresh water oozing out from a rock that serves as the source of the Asuotwe stream (AS).

5.2.14 COD

The chemical oxygen demand (COD) is a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant, such as dichromate. The COD is widely used as a measure of the susceptibility to oxidation of the organic and inorganic materials present in water bodies and in the effluents from sewage and industrial plants.

The study showed that the mean level of the EFT was 3156.00mg/l with AS recorded 95.42 mg/l. High values of COD of the effluent indicate the recalcitrance of chemicals that have escaped biodegradation. These chemicals may be persistent in nature and may cause severe environmental problems like bio-accumulation of aquatic organisms. The high COD levels recorded at the AS and EFTs sampling locations is indicative of a heavy load of organic and inorganic pollution that require more oxygen to oxidise under increased thermal conditions which agrees with a work done by Koushik and Saksena, (1999). Highest reduction of COD recorded at EFT-AS (96.98 %) was as a result of degradation of the organic and inorganic wastes of the effluents by sunlight and dilution of the effluent as it joins the stream at AS.

5.2.15 Phosphate and Nitrate

The nitrate ion (NO_3^-) is the common form of combined nitrogen found in natural waters. It may be biochemically reduced to nitrite (NO_2^-) by denitrification processes, usually under anaerobic conditions; the nitrite ion is rapidly oxidised to nitrate (Chapman, 1996). Why phosphate are not toxic and do not represent a direct health threat to human or other organisms, they do not represent a serious threat to water quality. The significance of

phosphate is principally in regard to the eutrophication of lakes and, to a lesser extent, rivers (Ireland EPA, 2001).

The nitrate levels at the AS and EFT sampling locations were significantly low compared to WHO (2011) and EPA (2007) limits. However, phosphate level in the samples from the EFT was above the regulatory limit of EPA of 2mg/l. Though, no WHO drinking water guideline of phosphate was found for the AS. The presence of nitrate and phosphate is likely to be a direct consequence of agricultural activities, from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. The observed agricultural activities around the Asuotwe stream are, however, usually limited to small scale holdings and subsistence agriculture, with very little agrochemical use thus possibly explaining the low nitrate and phosphate levels in the water. According to WHO (2011), surface water nitrate concentrations can also change rapidly owing to uptake by phytoplankton and denitrification by bacteria. The highest percentage reduction of phosphate was recorded at EFT-AS (41.88%).This was as a result of dilution of the industrial effluent as the effluent joins the stream at AS which was influenced by the constant oozing out of fresh water from a rock that serves as source of the Asuotwe stream (AS). However, that of the nitrate was recorded at AS-MS (35.68%) which could be attributed to dilution effect influenced by the fresh water that runs from UP2 to join the discharge point (MS) of the effluent and the Tano River.

5.2.16 Total Coliform, Faecal Coliform and *Escherichia coli (E. coli)*

Measurement of coliforms have been identified that they are easy to monitor and correlate with populations of pathogenic organisms. The coliform bacteria group is one of the most common indicator organisms. Coliforms are frequently monitored as total or

faecal coliforms. Total coliform (TC) is defined as a large group of anaerobic, non-spore forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C. *E. coli* is a common member of this group. Some pathogens enter the human body through the skin but more commonly they are ingested with drinking water. Faecal coliform (FC) is a subset of TC that comes from the intestines of warm-blooded animals (Chapra, 1997).

The lack of basic sanitary conditions of some of the riparian settlements and the breakdown off Industry's waste treatment plant, have led to sewage outfalls which are evidenced by the measurably microbiological loads in the AS and EFT. According to WHO (2011), most waterborne pathogens are introduced into drinking-water supplies in human or animal faeces. Faecal coliforms and *Escherichia coli* are present in very high numbers in human and animal faeces and are rarely found in the absence of faecal pollution, although there is some evidence for growth in tropical soils. *Escherichia coli* and faecal coliforms are considered the most suitable indicator of faecal contamination in surface waters (WHO, 2011). Their relatively higher loads in the effluent samples could be as a result of the effluents serving as a very suitable media for the growth of bacteria populations. Since the raw material for the manufacturing process are made of organic and inorganic substances such as enzymes and yeast which serves as a good substrate for microbial growth. The highest percentage reduction of the microbial loads (TC, FC and *E.coli.*) were all recorded at EFT-AS as 99.66%, 97.56% and 99.03% respectively. These reductions could be attributed to factors such as settlement of the bacteria which are

adsorbed on suspended solids, light intensity, temperature variations and dilution of the effluent as it travels from the GNL's premises to join the stream at AS.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the study conducted to assess the impact of Ghana Nut Limited (GNL) effluent (EFT) discharges on River Tano (TR) in Techiman Municipality, the following conclusions have been made:

- Comparing the assayed parameters of the EFT to the EPA of Ghana standards, most were found to be excessively higher than the guideline values. The activities of GNL appear to have impacted negatively on the receiving natural surface water (TR) in the study areas.
- The study revealed a clear relationship between anthropogenic activities at the sampling locations and the contaminant levels of the water bodies.
- Also, comparing the water samples from Tano River (TR) and Asuotwe (AS) to WHO drinking water quality guidelines, the result disqualifies the receiving water body for direct domestic use.

6.2 Recommendations

It is recommended that:

- Monitoring programs should be set up to track changes in the water quality of TR and to monitor the progress for remedial measures.
- The organization of educational programs to provide information to people of the riparian communities in and around the Techiman portion of the Tano watershed basin about the benefits of riparian waste management and waste disposal methods.
- A need for GNL to install a waste treatment plant with a view to treat wastes before being discharged into the receiving environments.
- Environmental Protection Agency (EPA) of Ghana should closely monitor the EFT emanating from the industries to make sure they are within the general effluent quality guidelines for discharge into natural water bodies.
- Further research can be conducted on the performance of the treatment stages done at the Tanoso water headwork's in relation to the downstream sampling location.
- Influence of seasonal variations on the impact of the Ghana Nut Limited effluent on the Tano River at the Techiman Municipality.

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APPENDICES

APPENDIX I: ANALYSIS OF VARIANCE

Appendix Ia: Analysis of variance for pH.

Table Analyzed	pH				
One-way analysis of variance					
P value	0.0020				
P value summary	**				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	5.228				
R squared	0.5990				
ANOVA Table	SS	df	MS		
Treatment (between columns)	5.223	6	0.8705		
Residual (within columns)	3.497	21	0.1665		
Total	8.720	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	-0.5633	2.761	No	ns	-1.502 to 0.3753
UP1 vs MS	0.2025	0.9925	No	ns	-0.7361 to 1.141
UP1 vs TS	0.4633	2.271	No	ns	-0.4753 to 1.402
UP1 vs DS1	0.03000	0.1470	No	ns	-0.9086 to 0.9686
UP1 vs DS2	0.1908	0.9353	No	ns	-0.7478 to 1.129
UP1 vs EFT	0.9658	4.734	Yes	*	0.02724 to 1.904
UP2 vs MS	0.7658	3.754	No	ns	-0.1728 to 1.704
UP2 vs TS	1.027	5.032	Yes	*	0.08808 to 1.965
UP2 vs DS1	0.5933	2.908	No	ns	-0.3453 to 1.532
UP2 vs DS2	0.7542	3.696	No	ns	-0.1844 to 1.693
UP2 vs EFT	1.529	7.495	Yes	***	0.5906 to 2.468
MS vs TS	0.2608	1.278	No	ns	-0.6778 to 1.199
MS vs DS1	-0.1725	0.8455	No	ns	-1.111 to 0.7661
MS vs DS2	-0.01167	0.05718	No	ns	-0.9503 to 0.9269
MS vs EFT	0.7633	3.741	No	ns	-0.1753 to 1.702
TS vs DS1	-0.4333	2.124	No	ns	-1.372 to 0.5053
TS vs DS2	-0.2725	1.336	No	ns	-1.211 to 0.6661
TS vs EFT	0.5025	2.463	No	ns	-0.4361 to 1.441
DS1 vs DS2	0.1608	0.7883	No	ns	-0.7778 to 1.099
DS1 vs EFT	0.9358	4.587	No	ns	-0.002757 to 1.874
DS2 vs EFT	0.7750	3.798	No	ns	-0.1636 to 1.714

Appendix Ib: Analysis of variance for TDS.

Table Analyzed	TDS				
One-way analysis of variance					
P value	0.0174				
P value summary	*				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	3.368				
R squared	0.4904				
ANOVA Table	SS	df	MS		
Treatment (between columns)	24510	6	4085		
Residual (within columns)	25470	21	1213		
Total	49980	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	19.92	1.144	No	ns	-60.19 to 100.0
UP1 vs MS	9.500	0.5456	No	ns	-70.60 to 89.60
UP1 vs TS	32.75	1.881	No	ns	-47.35 to 112.9
UP1 vs DS1	25.08	1.440	No	ns	-55.02 to 105.2
UP1 vs DS2	52.75	3.029	No	ns	-27.35 to 132.9
UP1 vs EFT	-48.50	2.785	No	ns	-128.6 to 31.60
UP2 vs MS	-10.42	0.5982	No	ns	-90.52 to 69.69
UP2 vs TS	12.83	0.7370	No	ns	-67.27 to 92.94
UP2 vs DS1	5.167	0.2967	No	ns	-74.94 to 85.27
UP2 vs DS2	32.83	1.886	No	ns	-47.27 to 112.9
UP2 vs EFT	-68.42	3.929	No	ns	-148.5 to 11.69
MS vs TS	23.25	1.335	No	ns	-56.85 to 103.4
MS vs DS1	15.58	0.8949	No	ns	-64.52 to 95.69
MS vs DS2	43.25	2.484	No	ns	-36.85 to 123.4
MS vs EFT	-58.00	3.331	No	ns	-138.1 to 22.10
TS vs DS1	-7.667	0.4403	No	ns	-87.77 to 72.44
TS vs DS2	20.00	1.149	No	ns	-60.10 to 100.1
TS vs EFT	-81.25	4.666	Yes	*	-161.4 to -1.146
DS1 vs DS2	27.67	1.589	No	ns	-52.44 to 107.8
DS1 vs EFT	-73.58	4.226	No	ns	-153.7 to 6.521
DS2 vs EFT	-101.3	5.815	Yes	**	-181.4 to -21.15

Appendix Ic: Analysis of variance for Temperature.

Table Analyzed	Temp				
One-way analysis of variance					
P value	0.0694				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	7				
F	2.335				
R squared	0.4002				
ANOVA Table	SS	df	MS		
Treatment (between columns)	295.1	6	49.19		
Residual (within columns)	442.3	21	21.06		
Total	737.5	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	2.183	0.9514	No	ns	-8.373 to 12.74
UP1 vs MS	1.017	0.4430	No	ns	-9.540 to 11.57
UP1 vs TS	0.4917	0.2143	No	ns	-10.06 to 11.05
UP1 vs DS1	2.525	1.100	No	ns	-8.032 to 13.08
UP1 vs DS2	2.233	0.9732	No	ns	-8.323 to 12.79
UP1 vs EFT	-7.517	3.276	No	ns	-18.07 to 3.040
UP2 vs MS	-1.167	0.5084	No	ns	-11.72 to 9.390
UP2 vs TS	-1.692	0.7372	No	ns	-12.25 to 8.865
UP2 vs DS1	0.3417	0.1489	No	ns	-10.21 to 10.90
UP2 vs DS2	0.05000	0.02179	No	ns	-10.51 to 10.61
UP2 vs EFT	-9.700	4.227	No	ns	-20.26 to 0.8566
MS vs TS	-0.5250	0.2288	No	ns	-11.08 to 10.03
MS vs DS1	1.508	0.6573	No	ns	-9.048 to 12.06
MS vs DS2	1.217	0.5302	No	ns	-9.340 to 11.77
MS vs EFT	-8.533	3.719	No	ns	-19.09 to 2.023
TS vs DS1	2.033	0.8861	No	ns	-8.523 to 12.59
TS vs DS2	1.742	0.7590	No	ns	-8.815 to 12.30
TS vs EFT	-8.008	3.490	No	ns	-18.56 to 2.548
DS1 vs DS2	-0.2917	0.1271	No	ns	-10.85 to 10.26
DS1 vs EFT	-10.04	4.376	No	ns	-20.60 to 0.5149
DS2 vs EFT	-9.750	4.249	No	ns	-20.31 to 0.8066

Appendix Id: Analysis of variance for Conductivity.

Table Analyzed	Conductivity				
One-way analysis of variance					
P value	0.0190				
P value summary	*				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	3.303				
R squared	0.4855				
ANOVA Table	SS	df	MS		
Treatment (between columns)	98950	6	16490		
Residual (within columns)	104900	21	4993		
Total	203800	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	39.67	1.123	No	ns	-122.9 to 202.2
UP1 vs MS	26.00	0.7359	No	ns	-136.5 to 188.5
UP1 vs TS	65.25	1.847	No	ns	-97.28 to 227.8
UP1 vs DS1	50.92	1.441	No	ns	-111.6 to 213.4
UP1 vs DS2	105.9	2.998	No	ns	-56.62 to 268.4
UP1 vs EFT	-97.83	2.769	No	ns	-260.4 to 64.70
UP2 vs MS	-13.67	0.3868	No	ns	-176.2 to 148.9
UP2 vs TS	25.58	0.7241	No	ns	-136.9 to 188.1
UP2 vs DS1	11.25	0.3184	No	ns	-151.3 to 173.8
UP2 vs DS2	66.25	1.875	No	ns	-96.28 to 228.8
UP2 vs EFT	-137.5	3.892	No	ns	-300.0 to 25.03
MS vs TS	39.25	1.111	No	ns	-123.3 to 201.8
MS vs DS1	24.92	0.7052	No	ns	-137.6 to 187.4
MS vs DS2	79.92	2.262	No	ns	-82.62 to 242.4
MS vs EFT	-123.8	3.505	No	ns	-286.4 to 38.70
TS vs DS1	-14.33	0.4057	No	ns	-176.9 to 148.2
TS vs DS2	40.67	1.151	No	ns	-121.9 to 203.2
TS vs EFT	-163.1	4.616	Yes	*	-325.6 to -0.5512
DS1 vs DS2	55.00	1.557	No	ns	-107.5 to 217.5
DS1 vs EFT	-148.8	4.210	No	ns	-311.3 to 13.78
DS2 vs EFT	-203.8	5.767	Yes	**	-366.3 to -41.22

Appendix Ie: Analysis of variance for Alkalinity.

Table Analyzed	Alkalinity				
One-way analysis of variance					
P value	0.0002				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	7.781				
R squared	0.6897				
ANOVA Table	SS	df	MS		
Treatment (between columns)	33060	6	5510		
Residual (within columns)	14870	21	708.2		
Total	47930	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	7.658	0.5756	No	ns	-53.55 to 68.87
UP1 vs MS	-2.583	0.1941	No	ns	-63.79 to 58.63
UP1 vs TS	5.133	0.3858	No	ns	-56.08 to 66.34
UP1 vs DS1	29.43	2.212	No	ns	-31.78 to 90.64
UP1 vs DS2	55.48	4.170	No	ns	-5.728 to 116.7
UP1 vs EFT	-65.96	4.957	Yes	*	-127.2 to -4.747
UP2 vs MS	-10.24	0.7697	No	ns	-71.45 to 50.97
UP2 vs TS	-2.525	0.1898	No	ns	-63.74 to 58.69
UP2 vs DS1	21.77	1.636	No	ns	-39.44 to 82.99
UP2 vs DS2	47.83	3.594	No	ns	-13.39 to 109.0
UP2 vs EFT	-73.62	5.533	Yes	*	-134.8 to -12.41
MS vs TS	7.717	0.5799	No	ns	-53.49 to 68.93
MS vs DS1	32.02	2.406	No	ns	-29.19 to 93.23
MS vs DS2	58.07	4.364	No	ns	-3.145 to 119.3
MS vs EFT	-63.38	4.763	Yes	*	-124.6 to -2.164
TS vs DS1	24.30	1.826	No	ns	-36.91 to 85.51
TS vs DS2	50.35	3.784	No	ns	-10.86 to 111.6
TS vs EFT	-71.09	5.343	Yes	*	-132.3 to -9.880
DS1 vs DS2	26.05	1.958	No	ns	-35.16 to 87.26
DS1 vs EFT	-95.39	7.169	Yes	***	-156.6 to -34.18
DS2 vs EFT	-121.4	9.127	Yes	***	-182.7 to -60.23

Appendix If: Analysis of variance for Turbidity.

Table Analyzed	Turbidity				
One-way analysis of variance					
P value	0.0004				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	6.703				
R squared	0.6570				
ANOVA Table	SS	df	MS		
Treatment (between columns)	1092000	6	182100		
Residual (within columns)	570400	21	27160		
Total	1663000	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	28.42	0.3448	No	ns	-350.7 to 407.5
UP1 vs MS	22.00	0.2670	No	ns	-357.1 to 401.1
UP1 vs TS	1.333	0.01618	No	ns	-377.7 to 380.4
UP1 vs DS1	40.33	0.4895	No	ns	-338.7 to 419.4
UP1 vs DS2	41.75	0.5066	No	ns	-337.3 to 420.8
UP1 vs EFT	-540.4	6.558	Yes	**	-919.5 to -161.3
UP2 vs MS	-6.417	0.07787	No	ns	-385.5 to 372.7
UP2 vs TS	-27.08	0.3287	No	ns	-406.2 to 352.0
UP2 vs DS1	11.92	0.1446	No	ns	-367.2 to 391.0
UP2 vs DS2	13.33	0.1618	No	ns	-365.7 to 392.4
UP2 vs EFT	-568.8	6.903	Yes	**	-947.9 to -189.8
MS vs TS	-20.67	0.2508	No	ns	-399.7 to 358.4
MS vs DS1	18.33	0.2225	No	ns	-360.7 to 397.4
MS vs DS2	19.75	0.2397	No	ns	-359.3 to 398.8
MS vs EFT	-562.4	6.825	Yes	**	-941.5 to -183.3
TS vs DS1	39.00	0.4733	No	ns	-340.1 to 418.1
TS vs DS2	40.42	0.4905	No	ns	-338.7 to 419.5
TS vs EFT	-541.8	6.574	Yes	**	-920.8 to -162.7
DS1 vs DS2	1.417	0.01719	No	ns	-377.7 to 380.5
DS1 vs EFT	-580.8	7.048	Yes	**	-959.8 to -201.7
DS2 vs EFT	-582.2	7.065	Yes	**	-961.2 to -203.1

Appendix Ig: Analysis of variance for Colour.

Table Analyzed	Colour				
One-way analysis of variance					
P value	0.6014				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	7				
F	0.7708				
R squared	0.1805				
ANOVA Table	SS	df	MS		
Treatment (between columns)	3823000	6	637200		
Residual (within columns)	17360000	21	826700		
Total	21180000	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	148.1	0.3257	No	ns	-1943 to 2239
UP1 vs MS	116.3	0.2559	No	ns	-1975 to 2208
UP1 vs TS	133.4	0.2935	No	ns	-1958 to 2225
UP1 vs DS1	251.9	0.5541	No	ns	-1839 to 2343
UP1 vs DS2	219.3	0.4823	No	ns	-1872 to 2311
UP1 vs EFT	-889.4	1.956	No	ns	-2981 to 1202
UP2 vs MS	-31.75	0.06984	No	ns	-2123 to 2060
UP2 vs TS	-14.67	0.03226	No	ns	-2106 to 2077
UP2 vs DS1	103.8	0.2284	No	ns	-1987 to 2195
UP2 vs DS2	71.17	0.1565	No	ns	-2020 to 2162
UP2 vs EFT	-1038	2.282	No	ns	-3129 to 1054
MS vs TS	17.08	0.03758	No	ns	-2074 to 2108
MS vs DS1	135.6	0.2982	No	ns	-1956 to 2227
MS vs DS2	102.9	0.2264	No	ns	-1988 to 2194
MS vs EFT	-1006	2.212	No	ns	-3097 to 1086
TS vs DS1	118.5	0.2607	No	ns	-1973 to 2210
TS vs DS2	85.83	0.1888	No	ns	-2005 to 2177
TS vs EFT	-1023	2.250	No	ns	-3114 to 1068
DS1 vs DS2	-32.67	0.07186	No	ns	-2124 to 2059
DS1 vs EFT	-1141	2.511	No	ns	-3233 to 950.0
DS2 vs EFT	-1109	2.439	No	ns	-3200 to 982.6

Appendix Ih: Analysis of variance for Sulphate.

Table Analyzed	Sulphate				
One-way analysis of variance					
P value	0.1009				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	7				
F	2.069				
R squared	0.3715				
ANOVA Table	SS	df	MS		
Treatment (between columns)	1398	6	233.0		
Residual (within columns)	2366	21	112.6		
Total	3764	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	-0.5858	0.1104	No	ns	-25.00 to 23.83
UP1 vs MS	-0.4275	0.08056	No	ns	-24.84 to 23.99
UP1 vs TS	-0.6025	0.1135	No	ns	-25.02 to 23.81
UP1 vs DS1	0.7642	0.1440	No	ns	-23.65 to 25.18
UP1 vs DS2	2.898	0.5460	No	ns	-21.52 to 27.31
UP1 vs EFT	-19.59	3.691	No	ns	-44.00 to 4.827
UP2 vs MS	0.1583	0.02984	No	ns	-24.25 to 24.57
UP2 vs TS	-0.01667	0.003141	No	ns	-24.43 to 24.40
UP2 vs DS1	1.350	0.2544	No	ns	-23.06 to 25.76
UP2 vs DS2	3.483	0.6564	No	ns	-20.93 to 27.90
UP2 vs EFT	-19.00	3.580	No	ns	-43.41 to 5.413
MS vs TS	-0.1750	0.03298	No	ns	-24.59 to 24.24
MS vs DS1	1.192	0.2246	No	ns	-23.22 to 25.60
MS vs DS2	3.325	0.6266	No	ns	-21.09 to 27.74
MS vs EFT	-19.16	3.610	No	ns	-43.57 to 5.254
TS vs DS1	1.367	0.2575	No	ns	-23.05 to 25.78
TS vs DS2	3.500	0.6595	No	ns	-20.91 to 27.91
TS vs EFT	-18.98	3.577	No	ns	-43.40 to 5.429
DS1 vs DS2	2.133	0.4020	No	ns	-22.28 to 26.55
DS1 vs EFT	-20.35	3.835	No	ns	-44.76 to 4.063
DS2 vs EFT	-22.48	4.237	No	ns	-46.90 to 1.929

Appendix Ii: Analysis of variance for Phosphate.

Table Analyzed	Phosphate				
One-way analysis of variance					
P value	0.0002				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	7.628				
R squared	0.6855				
ANOVA Table	SS	df	MS		
Treatment (between columns)	25.21	6	4.202		
Residual (within columns)	11.57	21	0.5509		
Total	36.78	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	0.1025	0.2762	No	ns	-1.605 to 1.810
UP1 vs MS	-0.3375	0.9094	No	ns	-2.045 to 1.370
UP1 vs TS	0.6017	1.621	No	ns	-1.106 to 2.309
UP1 vs DS1	1.431	3.856	No	ns	-0.2762 to 3.138
UP1 vs DS2	0.4181	1.127	No	ns	-1.289 to 2.125
UP1 vs EFT	-1.900	5.118	Yes	*	-3.607 to -0.1923
UP2 vs MS	-0.4400	1.186	No	ns	-2.147 to 1.267
UP2 vs TS	0.4992	1.345	No	ns	-1.208 to 2.206
UP2 vs DS1	1.329	3.580	No	ns	-0.3787 to 3.036
UP2 vs DS2	0.3156	0.8503	No	ns	-1.392 to 2.023
UP2 vs EFT	-2.002	5.395	Yes	*	-3.709 to -0.2948
MS vs TS	0.9392	2.531	No	ns	-0.7681 to 2.646
MS vs DS1	1.769	4.766	Yes	*	0.06133 to 3.476
MS vs DS2	0.7556	2.036	No	ns	-0.9517 to 2.463
MS vs EFT	-1.562	4.209	No	ns	-3.269 to 0.1452
TS vs DS1	0.8294	2.235	No	ns	-0.8778 to 2.537
TS vs DS2	-0.1836	0.4947	No	ns	-1.891 to 1.524
TS vs EFT	-2.501	6.740	Yes	**	-4.209 to -0.7940
DS1 vs DS2	-1.013	2.730	No	ns	-2.720 to 0.6943
DS1 vs EFT	-3.331	8.975	Yes	***	-5.038 to -1.623
DS2 vs EFT	-2.318	6.245	Yes	**	-4.025 to -0.6104

Appendix Ij: Analysis of variance for Nitrate.

Table Analyzed	Nitrate				
One-way analysis of variance					
P value	0.3728				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	7				
F	1.143				
R squared	0.2461				
ANOVA Table	SS	df	MS		
Treatment (between columns)	7.839	6	1.306		
Residual (within columns)	24.01	21	1.143		
Total	31.85	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	0.1142	0.2135	No	ns	-2.345 to 2.574
UP1 vs MS	0.04167	0.07794	No	ns	-2.418 to 2.501
UP1 vs TS	-0.6192	1.158	No	ns	-3.079 to 1.840
UP1 vs DS1	0.05500	0.1029	No	ns	-2.404 to 2.514
UP1 vs DS2	0.2192	0.4100	No	ns	-2.240 to 2.679
UP1 vs EFT	-1.362	2.547	No	ns	-3.821 to 1.098
UP2 vs MS	-0.07250	0.1356	No	ns	-2.532 to 2.387
UP2 vs TS	-0.7333	1.372	No	ns	-3.193 to 1.726
UP2 vs DS1	-0.05917	0.1107	No	ns	-2.519 to 2.400
UP2 vs DS2	0.1050	0.1964	No	ns	-2.354 to 2.564
UP2 vs EFT	-1.476	2.761	No	ns	-3.935 to 0.9835
MS vs TS	-0.6608	1.236	No	ns	-3.120 to 1.799
MS vs DS1	0.01333	0.02494	No	ns	-2.446 to 2.473
MS vs DS2	0.1775	0.3320	No	ns	-2.282 to 2.637
MS vs EFT	-1.403	2.625	No	ns	-3.863 to 1.056
TS vs DS1	0.6742	1.261	No	ns	-1.785 to 3.134
TS vs DS2	0.8383	1.568	No	ns	-1.621 to 3.298
TS vs EFT	-0.7425	1.389	No	ns	-3.202 to 1.717
DS1 vs DS2	0.1642	0.3071	No	ns	-2.295 to 2.624
DS1 vs EFT	-1.417	2.650	No	ns	-3.876 to 1.043
DS2 vs EFT	-1.581	2.957	No	ns	-4.040 to 0.8785

Appendix Ik: Analysis of variance for Hardness.

Table Analyzed	Hardness				
One-way analysis of variance					
P value	0.3261				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	7				
F	1.240				
R squared	0.2616				
ANOVA Table	SS	df	MS		
Treatment (between columns)	12240	6	2040		
Residual (within columns)	34540	21	1645		
Total	46780	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	5.167	0.2548	No	ns	-88.12 to 98.45
UP1 vs MS	16.58	0.8178	No	ns	-76.70 to 109.9
UP1 vs TS	-16.83	0.8301	No	ns	-110.1 to 76.45
UP1 vs DS1	35.50	1.751	No	ns	-57.78 to 128.8
UP1 vs DS2	45.50	2.244	No	ns	-47.78 to 138.8
UP1 vs EFT	-6.583	0.3247	No	ns	-99.87 to 86.70
UP2 vs MS	11.42	0.5630	No	ns	-81.87 to 104.7
UP2 vs TS	-22.00	1.085	No	ns	-115.3 to 71.28
UP2 vs DS1	30.33	1.496	No	ns	-62.95 to 123.6
UP2 vs DS2	40.33	1.989	No	ns	-52.95 to 133.6
UP2 vs EFT	-11.75	0.5795	No	ns	-105.0 to 81.53
MS vs TS	-33.42	1.648	No	ns	-126.7 to 59.87
MS vs DS1	18.92	0.9329	No	ns	-74.37 to 112.2
MS vs DS2	28.92	1.426	No	ns	-64.37 to 122.2
MS vs EFT	-23.17	1.142	No	ns	-116.4 to 70.12
TS vs DS1	52.33	2.581	No	ns	-40.95 to 145.6
TS vs DS2	62.33	3.074	No	ns	-30.95 to 155.6
TS vs EFT	10.25	0.5055	No	ns	-83.03 to 103.5
DS1 vs DS2	10.00	0.4931	No	ns	-83.28 to 103.3
DS1 vs EFT	-42.08	2.075	No	ns	-135.4 to 51.20
DS2 vs EFT	-52.08	2.568	No	ns	-145.4 to 41.20

Appendix II: Analysis of variance for Calcium.

Table Analyzed	Calcium				
One-way analysis of variance					
P value	0.0063				
P value summary	**				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	4.197				
R squared	0.5453				
ANOVA Table	SS	df	MS		
Treatment (between columns)	209.9	6	34.99		
Residual (within columns)	175.1	21	8.338		
Total	385.0	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	2.006	1.389	No	ns	-4.636 to 8.647
UP1 vs MS	0.09917	0.06869	No	ns	-6.542 to 6.741
UP1 vs TS	-2.371	1.642	No	ns	-9.012 to 4.271
UP1 vs DS1	-0.8325	0.5766	No	ns	-7.474 to 5.809
UP1 vs DS2	5.225	3.619	No	ns	-1.417 to 11.87
UP1 vs EFT	-3.853	2.669	No	ns	-10.49 to 2.788
UP2 vs MS	-1.907	1.321	No	ns	-8.548 to 4.735
UP2 vs TS	-4.377	3.031	No	ns	-11.02 to 2.265
UP2 vs DS1	-2.838	1.966	No	ns	-9.480 to 3.803
UP2 vs DS2	3.219	2.230	No	ns	-3.422 to 9.861
UP2 vs EFT	-5.859	4.058	No	ns	-12.50 to 0.7824
MS vs TS	-2.470	1.711	No	ns	-9.112 to 4.172
MS vs DS1	-0.9317	0.6453	No	ns	-7.573 to 5.710
MS vs DS2	5.126	3.550	No	ns	-1.516 to 11.77
MS vs EFT	-3.952	2.738	No	ns	-10.59 to 2.689
TS vs DS1	1.538	1.066	No	ns	-5.103 to 8.180
TS vs DS2	7.596	5.261	Yes	*	0.9542 to 14.24
TS vs EFT	-1.483	1.027	No	ns	-8.124 to 5.159
DS1 vs DS2	6.058	4.196	No	ns	-0.5841 to 12.70
DS1 vs EFT	-3.021	2.092	No	ns	-9.662 to 3.621
DS2 vs EFT	-9.078	6.288	Yes	**	-15.72 to -2.437

Appendix Im: Analysis of variance for Iron.

Table Analyzed	Iron				
One-way analysis of variance					
P value	0.0583				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	7				
F	2.461				
R squared	0.4129				
ANOVA Table	SS	df	MS		
Treatment (between columns)	255.5	6	42.58		
Residual (within columns)	363.3	21	17.30		
Total	618.8	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	1.023	0.4917	No	ns	-8.544 to 10.59
UP1 vs MS	-0.1458	0.07012	No	ns	-9.713 to 9.421
UP1 vs TS	-3.217	1.547	No	ns	-12.78 to 6.350
UP1 vs DS1	1.424	0.6848	No	ns	-8.143 to 10.99
UP1 vs DS2	1.579	0.7593	No	ns	-7.988 to 11.15
UP1 vs EFT	-7.373	3.545	No	ns	-16.94 to 2.194
UP2 vs MS	-1.168	0.5618	No	ns	-10.74 to 8.399
UP2 vs TS	-4.239	2.038	No	ns	-13.81 to 5.328
UP2 vs DS1	0.4017	0.1931	No	ns	-9.165 to 9.969
UP2 vs DS2	0.5567	0.2677	No	ns	-9.010 to 10.12
UP2 vs EFT	-8.396	4.037	No	ns	-17.96 to 1.171
MS vs TS	-3.071	1.477	No	ns	-12.64 to 6.496
MS vs DS1	1.570	0.7549	No	ns	-7.997 to 11.14
MS vs DS2	1.725	0.8295	No	ns	-7.842 to 11.29
MS vs EFT	-7.228	3.475	No	ns	-16.79 to 2.339
TS vs DS1	4.641	2.232	No	ns	-4.926 to 14.21
TS vs DS2	4.796	2.306	No	ns	-4.771 to 14.36
TS vs EFT	-4.157	1.999	No	ns	-13.72 to 5.410
DS1 vs DS2	0.1550	0.07453	No	ns	-9.412 to 9.722
DS1 vs EFT	-8.798	4.230	No	ns	-18.36 to 0.7694
DS2 vs EFT	-8.953	4.305	No	ns	-18.52 to 0.6144

Appendix In: Analysis of variance for TSS.

Table Analyzed	TSS				
One-way analysis of variance					
P value	0.0171				
P value summary	*				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	3.382				
R squared	0.4915				
ANOVA Table	SS	df	MS		
Treatment (between columns)	5086000	6	847600		
Residual (within columns)	5263000	21	250600		
Total	10350000	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	16.83	0.06725	No	ns	-1135 to 1168
UP1 vs MS	12.42	0.04961	No	ns	-1139 to 1164
UP1 vs TS	0.6667	0.002663	No	ns	-1151 to 1152
UP1 vs DS1	20.75	0.08290	No	ns	-1131 to 1172
UP1 vs DS2	25.33	0.1012	No	ns	-1126 to 1177
UP1 vs EFT	-1205	4.814	Yes	*	-2356 to -53.57
UP2 vs MS	-4.417	0.01765	No	ns	-1156 to 1147
UP2 vs TS	-16.17	0.06459	No	ns	-1168 to 1135
UP2 vs DS1	3.917	0.01565	No	ns	-1148 to 1155
UP2 vs DS2	8.500	0.03396	No	ns	-1143 to 1160
UP2 vs EFT	-1222	4.882	Yes	*	-2373 to -70.40
MS vs TS	-11.75	0.04694	No	ns	-1163 to 1140
MS vs DS1	8.333	0.03329	No	ns	-1143 to 1160
MS vs DS2	12.92	0.05161	No	ns	-1139 to 1164
MS vs EFT	-1217	4.864	Yes	*	-2369 to -65.98
TS vs DS1	20.08	0.08024	No	ns	-1131 to 1172
TS vs DS2	24.67	0.09855	No	ns	-1127 to 1176
TS vs EFT	-1206	4.817	Yes	*	-2357 to -54.23
DS1 vs DS2	4.583	0.01831	No	ns	-1147 to 1156
DS1 vs EFT	-1226	4.897	Yes	*	-2377 to -74.32
DS2 vs EFT	-1230	4.915	Yes	*	-2382 to -78.90

Appendix Io: Analysis of variance for O&G

Table Analyzed	O & G				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	17.31				
R squared	0.8318				
ANOVA Table	SS	df	MS		
Treatment (between columns)	133.4	6	22.24		
Residual (within columns)	26.97	21	1.284		
Total	160.4	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2 2	0.0000	0.0000	No	ns	-2.607 to 2.607
UP1 vs MS	-0.1250	0.2206	No	ns	-2.732 to 2.482
UP1 vs TS	-0.1583	0.2794	No	ns	-2.765 to 2.448
UP1 vs DS1 1	-0.09167	0.1618	No	ns	-2.698 to 2.515
UP1 vs DS2 2	-0.05833	0.1029	No	ns	-2.665 to 2.548
UP1 vs EFT T	-6.308	11.13	Yes	***	-8.915 to -3.702
UP2 vs MS	-0.1250	0.2206	No	ns	-2.732 to 2.482
UP2 vs TS	-0.1583	0.2794	No	ns	-2.765 to 2.448
UP2 vs DS1 1	-0.09167	0.1618	No	ns	-2.698 to 2.515
UP2 vs DS2 2	-0.05833	0.1029	No	ns	-2.665 to 2.548
UP2 vs EFT T	-6.308	11.13	Yes	***	-8.915 to -3.702
MS vs TS	-0.03333	0.05883	No	ns	-2.640 to 2.573
MS vs DS1 1	0.03333	0.05883	No	ns	-2.573 to 2.640
MS vs DS2 2	0.06667	0.1177	No	ns	-2.540 to 2.673
MS vs EFT T	-6.183	10.91	Yes	***	-8.790 to -3.577
TS vs DS1 1	0.06667	0.1177	No	ns	-2.540 to 2.673
TS vs DS2 2	0.1000	0.1765	No	ns	-2.507 to 2.707
TS vs EFT T	-6.150	10.85	Yes	***	-8.757 to -3.543
DS1 vs DS2 2	0.03333	0.05883	No	ns	-2.573 to 2.640
DS1 vs EFT T	-6.217	10.97	Yes	***	-8.823 to -3.610
DS2 vs EFT T	-6.250	11.03	Yes	***	-8.857 to -3.643

Appendix Ip: Analysis of variance for BOD.

Table Analyzed	BOD				
One-way analysis of variance					
P value	0.0017				
P value summary	**				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	5.347				
R squared	0.6044				
ANOVA Table	SS	df	MS		
Treatment (between columns)	5378000	6	896400		
Residual (within columns)	3521000	21	167600		
Total	8899000	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	57.82	0.2824	No	ns	-884.0 to 999.6
UP1 vs MS	58.23	0.2844	No	ns	-883.6 to 1000
UP1 vs TS	49.63	0.2424	No	ns	-892.2 to 991.4
UP1 vs DS1	47.24	0.2308	No	ns	-894.5 to 989.0
UP1 vs DS2	44.73	0.2185	No	ns	-897.1 to 986.5
UP1 vs EFT	-1208	5.903	Yes	**	-2150 to -266.7
UP2 vs MS	0.4083	0.001995	No	ns	-941.4 to 942.2
UP2 vs TS	-8.192	0.04001	No	ns	-950.0 to 933.6
UP2 vs DS1	-10.58	0.05165	No	ns	-952.4 to 931.2
UP2 vs DS2	-13.09	0.06395	No	ns	-954.9 to 928.7
UP2 vs EFT	-1266	6.185	Yes	**	-2208 to -324.5
MS vs TS	-8.600	0.04201	No	ns	-950.4 to 933.2
MS vs DS1	-10.98	0.05365	No	ns	-952.8 to 930.8
MS vs DS2	-13.50	0.06594	No	ns	-955.3 to 928.3
MS vs EFT	-1267	6.187	Yes	**	-2208 to -324.9
TS vs DS1	-2.383	0.01164	No	ns	-944.2 to 939.4
TS vs DS2	-4.900	0.02393	No	ns	-946.7 to 936.9
TS vs EFT	-1258	6.145	Yes	**	-2200 to -316.3
DS1 vs DS2	-2.517	0.01229	No	ns	-944.3 to 939.3
DS1 vs EFT	-1256	6.134	Yes	**	-2197 to -313.9
DS2 vs EFT	-1253	6.121	Yes	**	-2195 to -311.4

Appendix Iq: Analysis of variance for COD.

Table Analyzed	COD				
One-way analysis of variance					
P value	0.0007				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	7				
F	6.181				
R squared	0.6385				
ANOVA Table	SS	df	MS		
Treatment (between columns)	32060000	6	5343000		
Residual (within columns)	18150000	21	864400		
Total	50210000	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	63.75	0.1371	No	ns	-2075 to 2202
UP1 vs MS	53.67	0.1154	No	ns	-2085 to 2192
UP1 vs TS	34.08	0.07332	No	ns	-2104 to 2173
UP1 vs DS1	21.58	0.04643	No	ns	-2117 to 2160
UP1 vs DS2	9.250	0.01990	No	ns	-2129 to 2148
UP1 vs EFT	-3027	6.511	Yes	**	-5165 to -888.3
UP2 vs MS	-10.08	0.02169	No	ns	-2149 to 2128
UP2 vs TS	-29.67	0.06382	No	ns	-2168 to 2109
UP2 vs DS1	-42.17	0.09071	No	ns	-2181 to 2096
UP2 vs DS2	-54.50	0.1172	No	ns	-2193 to 2084
UP2 vs EFT	-3091	6.648	Yes	**	-5229 to -952.1
MS vs TS	-19.58	0.04213	No	ns	-2158 to 2119
MS vs DS1	-32.08	0.06902	No	ns	-2171 to 2106
MS vs DS2	-44.42	0.09555	No	ns	-2183 to 2094
MS vs EFT	-3081	6.627	Yes	**	-5219 to -942.0
TS vs DS1	-12.50	0.02689	No	ns	-2151 to 2126
TS vs DS2	-24.83	0.05342	No	ns	-2163 to 2114
TS vs EFT	-3061	6.585	Yes	**	-5199 to -922.4
DS1 vs DS2	-12.33	0.02653	No	ns	-2151 to 2126
DS1 vs EFT	-3048	6.558	Yes	**	-5187 to -909.9
DS2 vs EFT	-3036	6.531	Yes	**	-5175 to -897.6

Appendix Ir: Analysis of variance for Total Coliforms.

Table Analyzed	Total Coliforms				
One-way analysis of variance					
P value	0.0759				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	7				
F	2.272				
R squared	0.3936				
ANOVA Table	SS	df	MS		
Treatment (between columns)	37120000000000000000	6	6187000000000000000		
Residual (within columns)	57200000000000000000	21	2724000000000000000		
Total	94320000000000000000	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	257300000	0.3118	No	ns	-3539000000 to 4053000000
UP1 vs MS	255800000	0.3099	No	ns	-3540000000 to 4052000000
UP1 vs TS	247500000	0.2999	No	ns	-3549000000 to 4044000000
UP1 vs DS1	227600000	0.2758	No	ns	-3568000000 to 4024000000
UP1 vs DS2	249900000	0.3028	No	ns	-3546000000 to 4046000000
UP1 vs EFT	-3075000000	3.726	No	ns	-6871000000 to 721100000
UP2 vs MS	-1499000	0.001817	No	ns	-3798000000 to 3795000000
UP2 vs TS	-9764000	0.01183	No	ns	-3806000000 to 3786000000
UP2 vs DS1	-29650000	0.03593	No	ns	-3826000000 to 3766000000
UP2 vs DS2	-7384000	0.008948	No	ns	-3803000000 to 3789000000
UP2 vs EFT	-3332000000	4.038	No	ns	-7128000000 to 463800000
MS vs TS	-8265000	0.01002	No	ns	-3804000000 to 3788000000
MS vs DS1	-28150000	0.03411	No	ns	-3824000000 to 3768000000
MS vs DS2	-5885000	0.007132	No	ns	-3802000000 to 3790000000
MS vs EFT	-3331000000	4.036	No	ns	-7127000000 to 465300000
TS vs DS1	-19890000	0.02410	No	ns	-3816000000 to 3776000000
TS vs DS2	2380000	0.002884	No	ns	-3794000000 to 3798000000
TS vs EFT	-3322000000	4.026	No	ns	-7119000000 to 473600000
DS1 vs DS2	22270000	0.02698	No	ns	-3774000000 to 3818000000
DS1 vs EFT	-3303000000	4.002	No	ns	-7099000000 to 493500000
DS2 vs EFT	-3325000000	4.029	No	ns	-7121000000 to 471200000

Appendix Is: Analysis of variance for Faecal coliforms.

Table Analyzed	Faecal coliforms				
One-way analysis of variance					
P value	0.1385				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	7				
F	1.846				
R squared	0.3453				
ANOVA Table	SS	df	MS		
Treatment (between columns)	3676000000000000	6	612700000000000		
Residual (within columns)	6971000000000000	21	331900000000000		
Total	10650000000000000	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	10770000	1.183	No	ns	-31130000 to 52680000
UP1 vs MS	10540000	1.157	No	ns	-31360000 to 52450000
UP1 vs TS	10200000	1.120	No	ns	-31710000 to 52110000
UP1 vs DS1	10580000	1.161	No	ns	-31330000 to 52480000
UP1 vs DS2	10630000	1.167	No	ns	-31280000 to 52530000
UP1 vs EFT	-22260000	2.444	No	ns	-64170000 to 19650000
UP2 vs MS	-231700	0.02543	No	ns	-42140000 to 41670000
UP2 vs TS	-574100	0.06302	No	ns	-42480000 to 41330000
UP2 vs DS1	-195800	0.02149	No	ns	-42100000 to 41710000
UP2 vs DS2	-147400	0.01618	No	ns	-42050000 to 41760000
UP2 vs EFT	-33030000	3.626	No	ns	-74940000 to 8872000
MS vs TS	-342400	0.03759	No	ns	-42250000 to 41560000
MS vs DS1	35920	0.003943	No	ns	-41870000 to 41940000
MS vs DS2	84250	0.009249	No	ns	-41820000 to 41990000
MS vs EFT	-32800000	3.601	No	ns	-74710000 to 9104000
TS vs DS1	378300	0.04153	No	ns	-41530000 to 42280000
TS vs DS2	426700	0.04684	No	ns	-41480000 to 42330000
TS vs EFT	-32460000	3.563	No	ns	-74370000 to 9446000
DS1 vs DS2	48330	0.005306	No	ns	-41860000 to 41950000
DS1 vs EFT	-32840000	3.605	No	ns	-74740000 to 9068000
DS2 vs EFT	-32890000	3.610	No	ns	-74790000 to 9020000

Appendix It: Analysis of variance for *E coli*.

Table Analyzed	E coli				
One-way analysis of variance					
P value	0.1429				
P value summary	ns				
Are means signif. different? (P < 0.05)	No				
Number of groups	7				
F	1.824				
R squared	0.3426				
ANOVA Table	SS	df	MS		
Treatment (between columns)	1957000000000	6	326100000000		
Residual (within columns)	3755000000000	21	178800000000		
Total	5712000000000	27			
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
UP1 vs UP2	254200	1.202	No	ns	-718500 to 1227000
UP1 vs MS	231500	1.095	No	ns	-741200 to 1204000
UP1 vs TS	182400	0.8627	No	ns	-790200 to 1155000
UP1 vs DS1	143200	0.6771	No	ns	-829500 to 1116000
UP1 vs DS2	210800	0.9968	No	ns	-761900 to 1183000
UP1 vs EFT	-551800	2.610	No	ns	-1524000 to 420900
UP2 vs MS	-22670	0.1072	No	ns	-995300 to 950000
UP2 vs TS	-71750	0.3393	No	ns	-1044000 to 900900
UP2 vs DS1	-111000	0.5250	No	ns	-1084000 to 861700
UP2 vs DS2	-43420	0.2053	No	ns	-1016000 to 929200
UP2 vs EFT	-805900	3.812	No	ns	-1779000 to 166700
MS vs TS	-49080	0.2321	No	ns	-1022000 to 923600
MS vs DS1	-88330	0.4178	No	ns	-1061000 to 884300
MS vs DS2	-20750	0.09814	No	ns	-993400 to 951900
MS vs EFT	-783300	3.704	No	ns	-1756000 to 189400
TS vs DS1	-39250	0.1856	No	ns	-1012000 to 933400
TS vs DS2	28330	0.1340	No	ns	-944300 to 1001000
TS vs EFT	-734200	3.472	No	ns	-1707000 to 238500
DS1 vs DS2	67580	0.3196	No	ns	-905100 to 1040000
DS1 vs EFT	-694900	3.287	No	ns	-1668000 to 277700
DS2 vs EFT	-762500	3.606	No	ns	-1735000 to 210200